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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY,
GEORGE OTIS SMITH, DIRECTOR

PROFESSIONAL PAPER 71

INDEX TO THE STRATIGRAPHY OF NORTH AMERICA

BY

BAILEY WILLIS

ACCOMPANIED BY A

GEOLOGIC MAP OF NORTH AMERICA

COMPILED BY THE UNITED STATES GEOLOGICAL SURVEY IN COOPERATION WITH THE GEOLOGICAL SURVEY OF CANADA AND THE INSTITUTO GEOLÓGICO DE MÉXICO UNDER THE SUPERVISION OF BAILEY WILLIS AND GEORGE W. STOSE

13363
WASHINGTON
GOVERNMENT PRINTING OFFICE
1912

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INDEX TO THE STRATIGRAPHY OF NORTH AMERICA.

By Bailey Willis.

Chapter I.

INTRODUCTION.

CONTENTS.

The "Index to the stratigraphy of North America" is a compilation designed to explain the geologic map which accompanies it. The compiler has assembled the latest or most authoritative statements of fact and opinion, selected according to his best judgment. He has been most helpfully advised by many colleagues, to whom he is under more obligation than he can here express. In a subjoined list (pp. 30–61) scientific credit is given to each person who has taken part in the work or from whom contributions have been received.

The material selected comprises discussions of stratigraphy, some citations of fossils, and some views on correlation. The aim has been to state stratigraphic facts as fully as the data available or the scope of the work permit and to include as much as space allows relating to faunas and correlation. Quotation is preferred, but where it was not practicable an abstract of facts has been made and the reference given.

The sources from which quotations have been taken include publications of all kinds, official, serial, and occasional. They are listed in the bibliography on pages 840–865. Many more have been consulted. The entries in the bibliography are numbered consecutively and corresponding numbers, printed as "superiors," are used in the text to indicate references.

The method of procedure in selecting material was based on the map, which furnishes the information that strata of a given age occur in a certain locality. If no other clue was available the province or State was looked up in the indexes to the volumes of the "Bibliography of North American geology," [616, 617, 870, 871, 872, 874] where the latest writing, at least since 1892, may be traced to the authors. In case a specific formation was in question, its name was followed up in the same indices or lists and all references to it during the last 18 years considered. In the later works earlier ones are usually cited. Occasionally some one geologist is so identified with the investigation of a particular subject or region that immediate reference to his works was suggested, but not in any instance intentionally to the exclusion of other observers.

The Canadian Survey has issued two bibliographies,[289, 618] which were very useful. In them subjects may readily be traced by locality, geologic division, or geologist.

For North American geology prior to 1892, the bibliography by Darton [230] has been used.

In addition to published material, the compiler has been freely given a very large amount of unpublished information from the records of the United States Geological Survey. Some has been taken from official manuscripts and some from notes prepared for this paper. All this material is credited in the text and in the list on pages 30–61, which shows the names of the contributors and the localities which they have described.

ARRANGEMENT OF MATERIAL.

The material assembled has been arranged arbitrarily according to the index of the map, in order to facilitate reference between the map and the text. Natural divisions and systematic classification have thus been subordinated to convenience.

The map is divided by parallels at intervals of 4 degrees and by meridians at intervals of 6 degrees, according to the plan of sheets of the Standard International Map of the World. Any space thus inclosed is designated by a letter and a number. The letters run from A at the equator to V at the pole, and may be said to designate zones. For example, zone A is bounded by the equator on the south and by the parallel of 4° north latitude on the north; zone H includes northern Mexico and the Gulf coast of the United States; zones L and M are traversed by the boundary of the United States and Canada; zones P, Q, and R comprise Alaska, northern Canada, and southern Greenland.

The spaces between meridians are numbered from west to east, from longitude 180° to Greenwich. In accordance with the usage of European cartographers, these spaces may be called columns. Alaska falls in columns 3 to 7. The eastern United States, Quebec, and the Labrador Peninsula lie in columns 18, 19, and 20.

The letter and number which designate the zone and column in which any division of the map lies define the position of that division and may be employed to designate it. For example, division L 18 comprises the St. Lawrence from Lake Ontario nearly to Quebec; J–K 13 covers the Rocky Mountains of Wyoming and Colorado; and E 14 takes in the City of Mexico and vicinity. The index divisions are employed throughout this work to designate areas.

The division into chapters is based on geologic divisions and in general each chapter corresponds with a geologic system or period defined by the current usage of the United States Geological Survey and named in the legend of the map, but there are departures from a systematic classification which arise partly from the exigencies of cartography and partly from the inaptness of standards. These departures are stated below, in the legend of the map, and in connection with each chapter also.

The order of description follows the alphabetical and numerical sequence—that is, from B 17 to B 20, then from C 16 to C 20, etc., wherever the outcrops of strata or the system under consideration occur. Each zone is followed from west to east and those divisions in which the system under description is known are taken up in numerical order. The intervening map divisions are skipped. This arbitrary order traverses all natural and political boundaries. The scope of some publications covers more than one zone or one column, in such a way as to necessitate the discussion of two or more divisions under one heading.

It is assumed that the text and map will be used together. To refer from the map to the text, note the letter and number of the map index for the area under examination and look them up in the chapter which describes the geologic system studied. If the reader has simply a certain spot of color on the map in view, the corresponding color in the legend of the map will give the name of the system and chapter.

To refer from the text to the map, note the chapter heading and map index under which a citation occurs and by aid of the legend and index on the margin of the map identify the corresponding spot of color.

GEOLOGIC DIVISIONS MAPPED.

The geologic divisions represented on the map are adjusted to the requirements of cartography. They involve a compromise between the accepted standards of geologic science and the facts of history. The latter point can not be adequately discussed here, but it is true that the European standard (or that of New York in so far as it conforms to that of Europe) is a close approximation to the natural classification in the Atlantic and Gulf provinces only, and that it does not correspond satisfactorily with the natural order of events in the Pacific and interior provinces.

The limitations of cartographic representation are inherent in the scale of the map and the processes of printing. The scale of the map was selected with reference to its use as a wall map and the major features of the continent are intended to be apparent at a distance. They must therefore have at least a certain minimum size and color distinction. The employment of the map for local reference is, however, desirable, and to this end more refined drafting with slighter distinctions of color is desirable. These minor distinctions have been pushed to the limit of lithographic methods.

Whatever geologic systems, series, groups, or formations may be adopted, it will be found that they can not be carried uniformly and with constant value over so broad a territory as North America, for several reasons.

The major problems arise from one or another of several conditions—the scale of the map; differences of knowledge and ignorance; differences among classifications peculiar to the surveys of Canada, Mexico, and the United States; unlike development of the geologic series in diverse provinces.

The scale of the map sets a limit to refinement of possible classification. On a large-scale map may be drawn or printed legibly narrow strips of color, which may represent formations or even subdivisions (members) of formations. On a map of smaller scale a color strip of the same minimum width covers the space representing a thick formation or a group or a series. Thus the desirability of printing a map that shall be legible controls the width of a color band, and the latter in turn determines the least geologic division that can be recognized. The real limitation in this regard is the space occupied by a least geologic division and it is therefore dependent on structure as well as on classification. Where strata lie flat they present as a rule wide expanses, but where they dip steeply they exhibit narrow edges. The latter is apt to be the case in mountainous regions, where the mosaic is intricate and the difficulty is thus enhanced. Contrast for instance the geologic map of the Great Plains and that of the Rocky Mountains.

The scale of the geologic map of North America is limited by the great scope of the map. Being continental, the scope demands a scale represented by 1 divided by millions, and considerations of convenience led the compilers to fix on 1 : 5,000,000, or approximately 1 inch to 80 miles. One-twentieth of an inch being about as narrow a band of color as can be read distinctly, 4 miles is nearly the narrowest zone of rocks that can be represented without exaggeration. Many zones narrower than 4 miles are of such importance that they must be represented even though exaggerated, but not many adjacent bands can be so treated. The scale therefore imposes severe limitations on classification.

As the limitations are more severe in mountains than in plains a refined set of geologic divisions which can be delineated for plains will be impracticable in mountains, whereas that series of terranes which is practicable for the former is likely to be much too comprehensive for the latter. In maps of moderate scope these differences are usually adjusted in such a manner that a uniform classification may be employed over the entire map; but where the scope is continental the differences become so great that a uniform classification for the continent becomes unsatisfactory. Even though the natural geologic divisions are the same, they must be grouped or separated according to the requirement that the map shall show all possible detail and yet be legible. Cambrian, Ordovician, Silurian, Devonian, and Carboniferous must be distinctly mapped and to some extent individually subdivided in eastern North America; but on the scale adopted they must be grouped where they are upturned on the flanks of the Rocky Mountains. Thus a uniform classification is impracticable for the geologic map of North America, and an elastic or varied classification is required by the conditions of printing and legibility inherent in the scale.

Knowledge contrasted with ignorance imposes a similar condition. In reconnaissance surveys major divisions only are distinguished, and these often but vaguely or along a narrow line of route. There are large areas of North America regarding which present knowledge is no more precise. Within or adjoining these regions are districts of greater or less extent which have been surveyed in detail. The boundaries of these districts may be those of a State or Province, or those of an arbitrary quadrangle. They are sharply defined. Beyond them lies comparative ignorance; within them is displayed the key to an understanding of what the unknown probably is. In depicting the well-known and the little-known side by side on the same map, we can not use one classification for both, without great loss in the one or certainty of error in the other. The only alternative is to map each according to our knowledge of it, using for the well-known district a detailed classification up to the limit set by the scale of the map and for the little-known region a generalized classification adapted to our ignorance. This method has been adopted in the map of North America, wherever the differences of knowledge are of such a degree as to occasion material difficulties in applying a uniform classification. The instances are readily recognized by the arbitrary boundary which separates several formations or series from a comprehensive major class that comprises them all. Each such occurrence points to an opportunity for investigation.

The legend of the map in detail is as follows:

QUATERNARY.

Color, cream.
Symbol, 1.
Distribution: Shown only where the Quaternary completely conceals the underlying formations.
Content: Alluvial, lacustrine, and desert-basin deposits, glacial drift (in small part only), and beach, dune, and marine deposits of the Atlantic and Gulf coasts; all comprised in one category (Quaternary) and shown by the one color and pattern.

PLIOCENE.

Color, lemon-yellow.
Symbol, 2.
Distribution: The Pliocene is distinguished on the Atlantic and Gulf coasts, so far as surveys permit, in California, and in northern Nevada. Elsewhere on the map it is classed with the Quaternary (1), as in the valley deposits of the Great Basin; or with the Miocene under the heading "Later Tertiary" (4). The Lafayette formation of the Atlantic and Gulf slopes, including the Altamaha of Georgia, is shown only where it completely conceals the underlying formations.
Content: Marine Pliocene of the Coast Ranges of California; Humboldt formation (nonmarine) of Nevada; marine Pliocene and Lafayette of the Atlantic and Gulf slopes east of the Mississippi, including Altamaha of Georgia; also Yucatan.

MIOCENE.

Color, light yellow.
Symbol, 3.
Distribution: The Miocene is separately indicated on the Pacific coast and on the Atlantic and Gulf coasts, so far as surveys permit. Elsewhere on the map it is comprised with Pliocene under the term "Later Tertiary" (4).
Content: Monterey shale and equivalents of the Pacific coast; beds of Carrizo Creek, California; and marine Miocene of the Atlantic and Gulf coasts. Does not include so-called "Arctic Miocene" nor "Old Miocene," both of which are included in the "Marine Eocene."

LATER TERTIARY (MIOCENE AND PLIOCENE).

Color, yellow.
Symbol, 4.
Distribution: Mapped where Miocene or Pliocene are recognized but can not be separated or be individually identified in the present state of knowledge.
Content: Pacific coast marine deposits; Alaskan Arctic coastal plain deposits; fluviatile and lacustrine beds of the Interior; western Gulf coast marine formations; and late marine Tertiary of Mexico, Central America, and South America.

MARINE OLIGOCENE.

Color, light orange (ruling).
Symbol, 5d.
Distribution: Atlantic and Gulf coasts of the United States, where it is separated from the Eocene. Elsewhere combined with the Eocene as "Earlier Tertiary."
Content: Marine Oligocene of the Atlantic and Gulf slopes.

CONTINENTAL OLIGOCENE.

Color, light orange (dots).
Symbol, 5c.
Distribution: Great Plains of Wyoming, the Dakotas, and Colorado.
Content: White River group, including Chadron and Brule formations.

EARLIER TERTIARY (EOCENE AND OLIGOCENE).

Color, orange (horizontal ruling).
Symbol, 5.
Distribution: Central America, West Indies, and Pacific coast to Alaska. Mapped separately on the Atlantic and Gulf coasts, in Greenland, and in the Interior.
Content: Marine Eocene and Oligocene formations of Central America and West Indies; corresponding marine formations on the Pacific coast of California and Oregon; and coal-bearing formations of Puget Sound (Puget group) and Alaska (Kenai formation).

MARINE EOCENE.

Color, orange (vertical ruling).
Symbol, 5b.
Distribution: Atlantic and Gulf coasts, Mississippi embayment, Jamaica, and Greenland, where it is separated from Oligocene. Elsewhere mapped with Oligocene as "Earlier Tertiary."
Content: Marine Eocene of the Atlantic and Gulf coasts, Jamaica, and Greenland, and estuarine deposits of the Mississippi embayment.

CONTINENTAL EOCENE.

Color, orange (dots).
Symbol, 5b–1.
Distribution: Interior basins of the western United States and Canada.
Content: Puerco, Fort Union, Wasatch, Green River, Bridger, and Uinta formations.

EARLIEST TERTIARY OR LATEST CRETACEOUS.

Color, orange-brown.
Symbol, 5a.
Distribution: Colombia, middle western United States, and Canada.
Content: Shoshone group; Denver and Arapahoe and equivalents in Colorado; "Upper Laramie," Lance formation, "Ceratops beds," or "Somber beds" in Wyoming, Montana, and the Dakotas; and Edmonton of Alberta; also "Upper Laramie" of Canadian reports. In Colombia, the Guaduas or Cerro de Oro formation.

LATE UPPER CRETACEOUS; LARAMIE.

Color, yellowish green.
Symbol, 6.
Distribution: Rocky Mountains of the United States, southern Wyoming to New Mexico.
Content: Late Cretaceous coal-bearing formations; Laramie of the Denver Basin; "Lower Laramie" of southern Wyoming; and coal-bearing equivalents in Colorado and New Mexico.

UPPER CRETACEOUS.

Color, light green.
Symbol, 7.
Distribution: South America and West Indies; present but not generally distinguished in Mexico from Lower Cretaceous; Atlantic and Gulf coasts from Mexican boundary to New England; the Interior province, New Mexico to Mackenzie; Pacific coast, Lower California to Alaska; the Arctic coastal plain of Alaska; and the west coast of Greenland.

Content: Marine and coastal-plain deposits of the Atlantic and Gulf coasts and West Indies, comprising Raritan to Manasquan, New Jersey; Black Creek ("Bladen") and Peedee ("Burches Ferry"), North Carolina; Tuscaloosa to Ripley, Alabama; and the Gulf series (Woodbine to Navarro) of Texas and Louisiana. In Mexico, included on map with Lower Cretaceous (8). Marine and coastal-plain deposits of the Interior, Dakota to Fox Hills, inclusive, and equivalents. Marine deposits of the Pacific coast, Chico and its equivalents. Laramie and coal-bearing portion of the Montana of the Rocky Mountains and Great Plains mapped separately.

MONTANA, COAL-BEARING PORTION.

Color, olive-green.
Symbol, 7a.
Distribution: Rocky Mountains and northern Great Plains of the United States and Canada.
Content: Middle Montana, generally coal bearing; Mesaverde of New Mexico, Colorado, and southern Wyoming; Eagle, Claggett, and Judith River of northern Wyoming and Montana, and their equivalents in Canada.

LOWER CRETACEOUS.

Color, medium green.
Symbol, 8.
Distribution: Atlantic, Gulf, and Caribbean coasts, New Jersey to South America; Pacific coast, Alaska to South America. In Mexico, areas mapped include Upper Cretaceous.
Content: Potomac group of the Atlantic slope, Georgia, and eastern Alabama; Comanche series; (comprising Trinity, Fredericksburg, and Washita groups) of Texas, Oklahoma, and Mexico; Shasta series (Knoxville and Horsetown formations) of California and Oregon; Queen Charlotte group of British Columbia; Kootenai formation of the Rocky Mountains, Montana northward to fifty-second parallel and beyond; Lower Cretaceous, Alaska.

TRIASSIC AND JURASSIC.

Color, dark greenish blue.
Symbol, 9.
Distribution: Middle western United States, Rocky Mountains, and High Plateaus, Montana to Arizona; western United States and eastern Alaska, where Triassic and Jurassic can not be separated or can not be separately identified.
Content: Red beds and marine deposits of the Cordillera, comprising Jurassic, Triassic, and Permian, where more or less certainly known to be present but not distinguishable, or too small to map separately; marine Triassic and Jurassic of the Pacific where not separated.

JURASSIC.

Color, greenish blue (horizontal ruling).
Symbol, 9a.
Distribution: Central America, Mexico, California, Oregon, Alberta, and parts of Alaska.
Content: Jurassic limestone and shale of Nevada; Mariposa slate, Sierra Nevada; Franciscan formation, Coast Range, California; Jurassic of Mexico; Chinitna shale and Tuxedni sandstone ("Enochkin formation"), also the Naknek formation, of Alaska Peninsula. The Jurassic of the Humboldt Range, Nevada, and the marine Sundance formation of the Rocky Mountains are not distinguished on the map from Triassic, as the areas are too small to distinguish the system separately.

TRIASSIC.

Color, dark green (horizontal ruling).
Symbol, 10.
Distribution: Central America, Mexico, New Mexico, and Texas; Nevada and California; British Columbia and Alaska; Atlantic slope from North Carolina to Nova Scotia.

Content: Marine Triassic of western Nevada and California; marine Triassic of Zacatecas and red beds in Mexico; red beds of Texas and New Mexico; Newark group, North Carolina to Nova Scotia; marine Triassic of the Arctic. In the Canadian Rockies the marine Triassic is mapped with the "Paleozoic, undivided" (19, 20). In Oregon, Idaho, middle western United States, and part of Alaska the Triassic is combined on the map with Jurassic (9).

PERMIAN.

Color, light gray.
Symbol, 11.
Distribution: Southwestern United States; West Virginia, Ohio, and Pennsylvania; New Brunswick and Nova Scotia. Elsewhere mapped with "Carboniferous, undivided."
Content: Permian limestone and red beds, Kansas to Texas; Permian red beds, New Mexico; Opeche and Minnekahta formations, Black Hills; Dunkard group of the northern Appalachians; red and gray sandstones and subjacent New Glasgow conglomerate of New Brunswick, Nova Scotia, and Prince Edward Island. Includes some Triassic red beds in mapping.

PENNSYLVANIAN.

Color, dark gray.
Symbol, 12.
Distribution: Guatemala, central and eastern United States, New Brunswick, and Nova Scotia. Present, though not distinguished from Mississippian, throughout the Cordillera, the Arctic region, and Newfoundland.
Content: "Coal measures" (Pottsville to Monongahela, inclusive) of eastern North America and their equivalents where distinguished; Carboniferous limestone of Guatemala. Mapped elsewhere with "Carboniferous, undivided" (14).

MISSISSIPPIAN.

Color, light French blue.
Symbol, 13.
Distribution: Guatemala; eastern North America from Oklahoma to Nova Scotia; present but included in the "Carboniferous, undivided," in the Cordillera, Arctic region, and Newfoundland.
Content: "Lower Carboniferous" limestones and their equivalents where they are separated on the map from coal measures of the Pennsylvanian. In Guatemala the Santa Rosa formation.

CARBONIFEROUS, UNDIVIDED.

Color, light blue.
Symbol, 14.
Distribution: Western North America, Arctic region, Newfoundland, and Central America; subdivided into Mississippian, Pennsylvanian, and Permian in eastern North America.
Content: Mississippian and Pennsylvanian limestones of the Cordillera including Devonian where present; Mankomen formation and Nabesna limestone of Alaska; Lisburne formation, Alaska; Carboniferous of the Parry Archipelago, Arctic; Carboniferous of Newfoundland; doubtful Carboniferous or Devonian of Honduras.

DEVONIAN.

Color, dark blue.
Symbol, 15.
Distribution: Eastern central United States and eastern Canada; Cordillera of the United States, Canada, and Alaska; northwestern Canada.
Content: Devonian as commonly defined through the Appalachians, including Helderberg at the base and higher formations to Chemung and Catskill, inclusive; in the northeast, from Gaspe to New York, Helderberg is included with the Silurian in mapping; in the Appalachian zone south of latitude 38° the Devonian color on the map includes Silurian; throughout the Cordillera from Mexico to Alaska the Devonian where present is mapped with "Carboniferous, undivided" (14), except that it is distinguished in the Klamath Mountains, California.

SILURIAN.

Color, violet.
Symbol, 16.
Distribution: General throughout northern and eastern North America east of the Great Plains; represented by the Devonian color (15) in the Appalachian zone south of latitude 38°; known to be present in the Cordillera and Alaska but not generally distinguished by separate color, except in Mexico, Nevada, and British Columbia.
Content: In the Appalachians in general includes Medina to Cayuga; in the southern Appalachians is mapped with Devonian; in eastern Canada and New York Helderberg is included on the map; in the Interior strata of Niagara age; in the Arctic, the Silurian color covers areas of the limestone series, known to include Ordovician and Silurian.

MIDDLE AND UPPER ORDOVICIAN.

Color, light bluish purple.
Symbol, 17.
Distribution: General throughout the continent. In the Arctic mapped with the Silurian (16); in the Rocky Mountains of the United States included in narrow bands of Cambrian and lower Ordovician (18).
Content: Middle to uppermost Ordovician (Chazy to Richmond, inclusive).

CAMBRIAN AND LOWER ORDOVICIAN.

Color, purplish red.
Symbol, 18.
Distribution: General throughout the continent.
Content: In general comprises Lower Cambrian (Georgian) to Lower Ordovician (Beekmantown), inclusive, or so much as may be present. In Appalachian zone, Virginia to Alabama, includes conformable formations below the Olenellus zone; Ocoee ana Chilhowee groups of Safford and other terranes. In the Cordillera, includes Upper Ordovician and Silurian where they are present and bands of color are too narrow for distinct mapping.

PALEOZOIC, UNDIVIDED.

Color, light reddish purple.
Symbol, 19.
Distribution: Little-known regions of the northern Cordillera, Montana, and Canada.
Content: Paleozoic in general, where data do not suffice to map the divisions separately. Includes some known marine Triassic in the Canadian Rockies.

METAMORPHIC PALEOZOIC, UNDIVIDED.

Color, light reddish purple with light dashes.
Symbol, 20.
Distribution: Venezuela, Cuba, Santo Domingo, Porto Rico; northeastern Appalachian region; northern Cordillera, California to Alaska.
Content: Metamorphic sedimentary rocks of known or supposed Paleozoic age, together with possibly pre-Paleozoic schists and some igneous intrusive rocks, which have not been separated. Includes some known marine Triassic in the Canadian Rockies.

LATE (?) PRE-CAMBRIAN (UNCLASSIFIED, LITTLE ALTERED).

Color, light brown with blue hachures.
Symbol, 21.
Distribution: Northern Canada (Labrador to Northwest Territories excluding the Lake Superior region); Avalon Peninsula, Newfoundland; Nova Scotia; Uinta and Wasatch ranges, Utah; Needle Mountains, Colorado.

Content: In Canada, sandstones and lava flows that are little disturbed or altered but have no fossils, "Cambrian" of Canadian reports, sometimes tentatively correlated with the Keweenawan series or with the Animikie group (Upper Huronian); Athabasca-Nastopoka series of Adams; gold-bearing Meguma series of Nova Scotia; Random and older formations of the Avalon group of Newfoundland; quartzites of Uinta and Wasatch ranges of Utah (mapped under Belt series); Needle Mountains group of Colorado (mapped under Belt series).

BELT SERIES.

Color, light brown.
Symbol, 21a.
Distribution: Western Rocky Mountains of Idaho, Montana, British Columbia, and Alberta.
Content: The Belt series (late Algonkian) of Idaho, Montana, British Columbia, and Alberta. (The quartzites of the Uinta and Wasatch mountains of Utah and the Needle Mountains group of Colorado, which are regarded as possible equivalents of the Belt series, have also been included under this color on the map, as has the Cherry Creek group of Montana, which is probably of early Algonkian age.)

KEWEENAWAN.

Color, light brown with red dashes.
Symbol, 21b.
Distribution: Lake Superior region, Ontario, Minnesota, Wisconsin, and Michigan.
Content: Keweenawan lava flows and sediments, within the area known to be of Keweenawan age; also "Nipigon" series, but not including possible equivalents in other districts. Areas mapped include intrusive igneous rocks.

UPPER HURONIAN (OF THE LAKE SUPERIOR REGION).

Color, brown (vertical ruling).
Symbol, 21c.
Distribution: Lake Superior region; Ontario, Minnesota, Wisconsin, and Michigan.
Content: Animikie and equivalents in the Lake Superior region only. Areas mapped include intrusive igneous rocks.

EARLIER (?) PRE-CAMBRIAN (UNCLASSIFIED, MUCH ALTERED).

Color, brown with white dashes.
Symbol, 22.
Distribution: Canada in general outside of the districts specially classified; Nova Scotia and Newfoundland; Cherry Creek group of Montana (probably of early Algonkian age, mapped under Belt series, late Algonkian).
Content: Metamorphosed sediments and volcanics, in places richly iron bearing, widely distributed throughout the Canadian shield, and commonly classed as "Huronian;" in Montana the Cherry Creek group (probably early Algonkian), which is mapped under Belt series, late Algonkian.

HASTINGS AND GRENVILLE.

Color, dark reddish brown.
Symbol, 22a.
Distribution: Eastern Canada, Ontario, and Quebec; probably present but not distinguished on the map in Adirondack region, New York.
Content: Limestone and associated rocks of the Hastings and the Grenville series in the type areas.

MIDDLE AND LOWER HURONIAN.

Color, brown with red dashes.
Symbol, 22b.
Distribution: Lake Superior region; Ontario, Minnesota, South Dakota, Wisconsin, and Michigan.
Content: Sedimentary and intrusive rocks in the Lake Superior region only; Sioux quartzite of South Dakota and Baraboo quartzite of Wisconsin. Areas mapped include intrusive igneous rocks.

"LAURENTIAN" (CANADIAN USAGE).

Color, pink and red hachures.
Symbol, 23.
Distribution: Throughout Canada and the Arctic.
Content: Gneisses and associated plutonic rocks throughout Canada, the Laurentian of Canadian geologists; included in Archean of Dana. (Areas of undifferentiated pre-Cambrian in Michigan, Wisconsin, Minnesota, and North Dakota have also been mapped under this color.)

LAURENTIAN (OF THE LAKE SUPERIOR REGION).

Color, pink with red hachures.
Symbol, 23d.
Distribution: Wisconsin, Michigan, and Minnesota.
Content: Acidic plutonic rocks intrusive in Keewatin, separately indicated only within the United States.

KEEWATIN.

Color, dark red with white hachures.
Symbol, 23a.
Distribution: Lake Superior region; Ontario, Michigan, Minnesota, and Wisconsin.
Content: Oldest pre-Cambrian of the Lake Superior region. Largely basic lavas.

UNDIFFERENTIATED PRE-CAMBRIAN.

Color, pink with red dashes.
Symbol, 23b.
Distribution: Appalachian province, Vermont to Alabama; Missouri, Texas, Arizona, New Mexico, California, and the Rocky Mountains of the United States; in Michigan, Wisconsin, Minnesota, and North Dakota is mapped under " 'Laurentian' (Canadian usage)."
Content: Gneisses known to be of pre-Cambrian age, but not otherwise correlated; included in Archean of Dana. Includes plutonic igneous rocks where not separately mapped, and some sediments of Paleozoic age.

GNEISSES, SCHISTS, AND METAMORPHOSED SEDIMENTS (SUPPOSED PRE-CAMBRIAN; POSSIBLY IN PART PALEOZOIC AND MESOZOIC).

Color, pink with blue dashes.
Symbol, 23c.
Distribution: In the Cordillera from South America to Alaska.
Content: Highly metamorphosed schists and associated plutonic rocks, apparently of great antiquity but not known to be pre-Cambrian; possibly in part Paleozoic or Mesozoic.

PRE-CAMBRIAN INTRUSIVE ROCKS.

Color, dark violet.
Symbol, 24.
Distribution: Plutonic igneous rocks in eastern Canada, eastern United States, and Oklahoma. Includes some effusive rocks of same age. Elsewhere mapped with associated pre-Cambrian rocks.

POST-CAMBRIAN INTRUSIVE ROCKS.

Color, dark red.
Symbol, 24a.
Distribution: The Cordillera from South America to Alaska; Santo Domingo; eastern United States, New Brunswick, Nova Scotia, and Newfoundland.
Content: Plutonic rocks of all kinds, chiefly granites, occurring in masses of sufficient size to be mapped. Mostly of Paleozoic and Mesozoic age. Includes some effusive rocks of same age and some older intrusives. Tertiary intrusives mapped with "Tertiary and later effusive rocks."

TERTIARY AND LATER EFFUSIVE ROCKS.

Color, scarlet.
Symbol, 25.
Distribution: Volcanic rocks and lava flows, chiefly of Tertiary age, of the Cordillera from Central America to Aleutian Islands; Venezuela and Windward Islands; Greenland and Iceland. Includes some intrusive rocks of same age.

In applying the preceding legend to the map adjustments to scale and to knowledge have been made by the compilers, but adjustments of classifications adopted by different surveys could be made only by authority of the responsible officers, and to bring them about has necessitated correspondence or required special conferences. The classification of the pre-Cambrian was discussed at two formal conferences at which the Canadian and Federal surveys were represented, with results that are stated in Chapter II.

Some other difficult questions may be enumerated here.

In applying the distinction indicated by the categories 23b and 23c, the compilers have placed in the former all areas where Cambrian sediments rest unconformably upon the pre-Cambrian. In 23c are classed those areas which contain highly metamorphic rocks overlain by later Paleozoic or Mesozoic strata and which may include masses that were deposited and metamorphosed in some post-Cambrian epoch. This is the case throughout the Cordillera, except in the southwestern United States.

The "Archean" of the southern Appalachian Mountains has been separated by Keith into undifferentiated pre-Cambrian, pre-Cambrian intrusives, and post-Cambrian intrusives. The undifferentiated pre-Cambrian is carried northward through New Jersey, New York, and New England to the international boundary. In the Adirondacks this division presumably comprises the "Laurentian" of Canada and also the Hastings and Grenville representatives.

The pre-Cambrian rocks of Sutton Mountain, Quebec, are mapped as igneous and undifferentiated pre-Cambrian, after Dresser. The distinction can not yet be carried across the international boundary.

The Random formation of Newfoundland is placed in the late pre-Cambrian by Walcott, and the rest of the Avalon group is mapped with it.

The gold-bearing Meguma series of Nova Scotia is classed as pre-Cambrian on the recommendation of C. K. Leith and because of the resemblance which the rocks bear to the Avalon group of Newfoundland, as noted by Selwyn, Murray, Howley, and Faribault.

The Belt series, though regarded as Cambrian by R. A. Daly, is retained in the Algonkian in accordance with the observations of Willis, confirmed by the later work of Walcott.

Most of the Paleozoic in New England is represented as undivided, because the metamorphism which the rocks have suffered has so far prevented recognition of divisions. In northwestern Maine it is rather the drift covering and the monotony of the black slates of the several terranes distinguished in Canada that has interfered with mapping.

In the northern Cordillera from Idaho to Alaska the unknown or little-known strata are generally classed as Paleozoic, but the few areas that have been worked up in detail indicate that the region really is a fine mosaic of many formations.

In the West Indies and in Venezuela the pre-Mesozoic sediments are classed as Paleozoic.

The systems of the lower Paleozoic (Cambrian and Ordovician) can not be mapped on this scale as separate terranes divided by the boundary which paleontologists have generally recognized, for the line in many areas falls in a great thickness of limestone which is not readily divisible. It has been found practicable to distinguish Cambrian and lower Ordovician from middle and upper Ordovician, the former including all below the Chazy and its equivalents, whereas the latter takes in the Chazy and all later Ordovician terranes.

The Helderberg of the New York and eastern Canada sections is classed as Devonian in the text and in the legend but is included with Silurian on the map. The difference arises from the facts that the Geological Survey of Canada has not yet recognized the Devonian age of the Helderberg and that the United States Geological Survey has only recently done so. The map would in most places not be perceptibly changed, however, by shifting the lines to accord with the text.

In the eastern United States the Carboniferous is readily divisible and the divisions (Mississippian, Pennsylvanian, and Permian) are easily shown upon the map. In western North America the Carboniferous has a different development and the areas are, moreover, too small to be subdivided on the scale of this map. Thus, although the equivalents of the Mississippian and Pennsylvanian are known in western North America, they are not separated on the map.

The Permian is not yet clearly distinguished from the older Carboniferous in some areas or from the Triassic in others. The adjustment of uncertainties can best be followed by referring to the authors quoted in the chapters on the Carboniferous and Triassic.

The Triassic of the Arctic is mapped according to Schei and extended to the Cape Rawson beds, which lie in the strike.

The Jurassic occupies but very small areas. Although it is widely represented in the central Rocky Mountains and thence northward, it occurs in such narrow belts that it can not be mapped separately from the Triassic in that province. It was not possible to insert another band of color between those representing the Triassic and Cretaceous.

The line between Jurassic and Cretaceous in the Coast Range of California is drawn by different observers below the Franciscan, at the base of the Knoxville, or in the upper part of the Knoxville. The mapping expresses the line at the base of the Knoxville, the only one that can be readily traced.

48011°—12——2

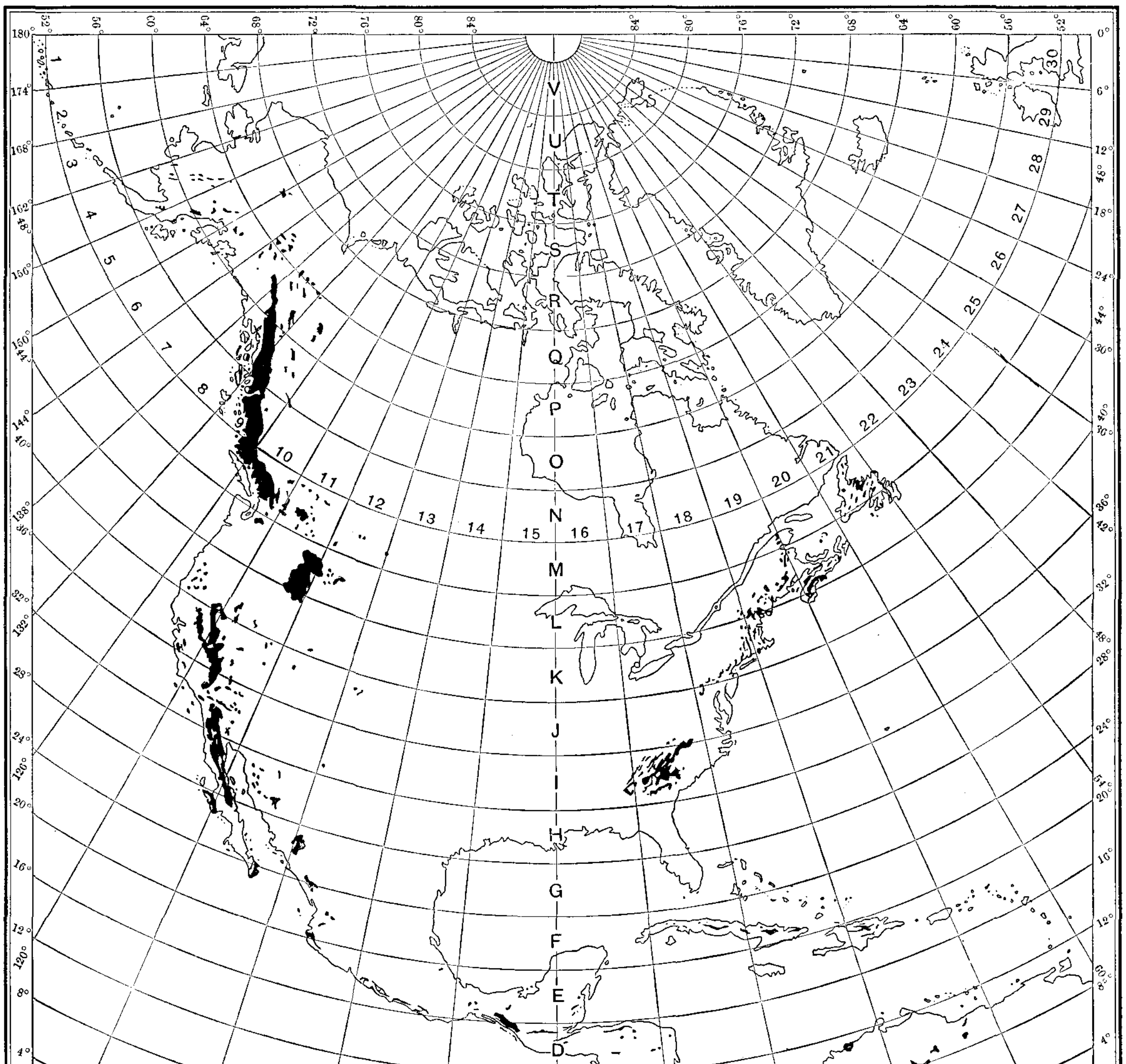

FIGURE 1.—Sketch map showing the distribution of post-Cambrian intrusive rocks represented on the geologic map of North America.

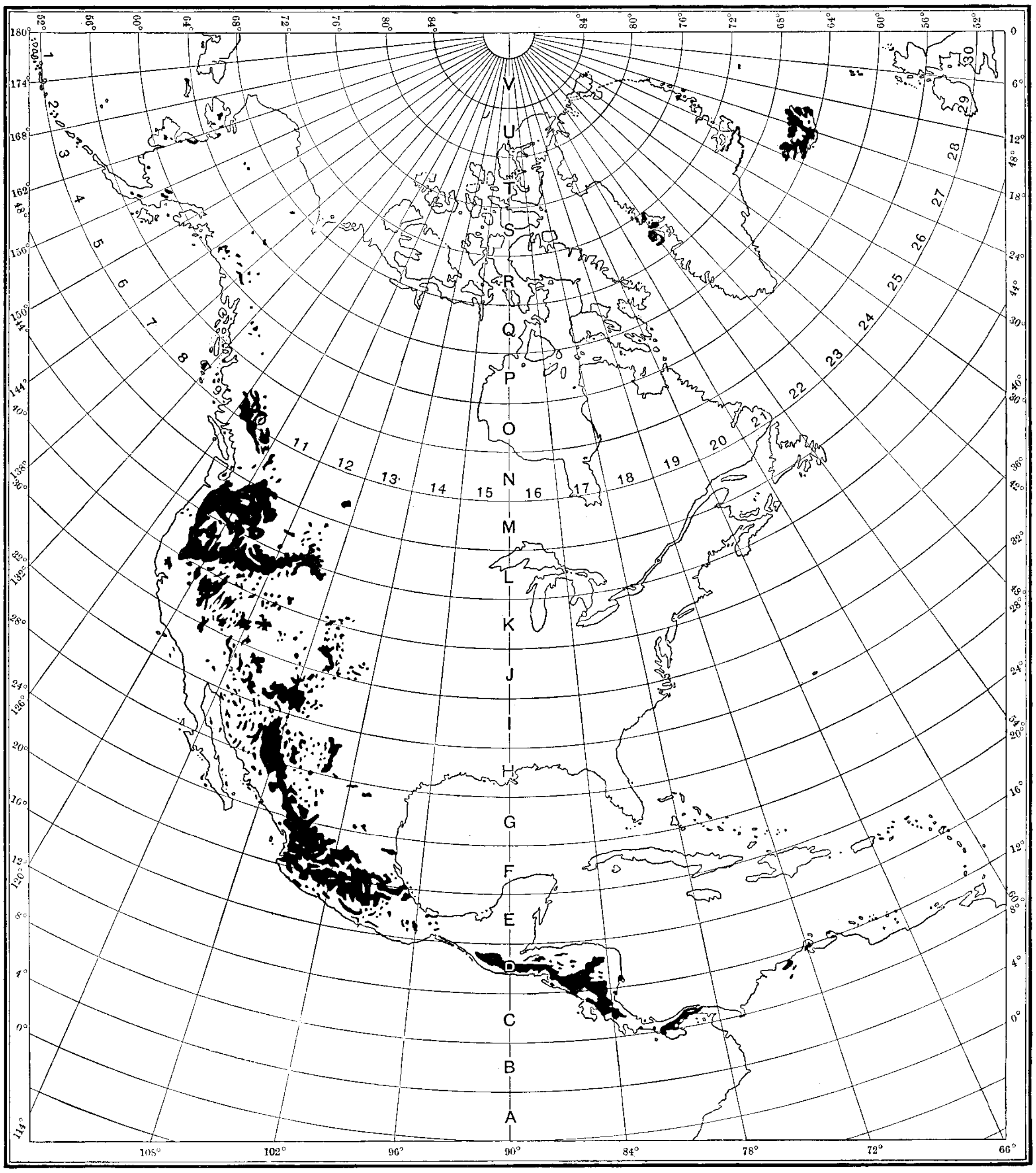

FIGURE 2.—Sketch map showing the distribution of Tertiary and later effusive rocks represented on the geologic map of North America.

The distinction between Upper and Lower Cretaceous in the United States is based on the natural divisions which are regarded as characteristic of North American Cretaceous. The Mexican Survey recognizes a threefold division, Eo-, Meso-, and Neo-Cretaceous, which is adjusted to European standards but which can not yet be carried out on the geologic map of Mexico, because not enough detailed work has been done in that country. The Lower Cretaceous is most widely distributed in Mexico, and the areas which are colored accordingly include also those of the Upper Cretaceous.

The line of division between the Cretaceous and Tertiary is everywhere in doubt from South America to Canada. The positions of the Laramie and its supposed equivalents and of those formations which have been placed in the Shoshone group of Cross have been controverted and are still matters of opinion. The data for the map assembled by the most recent work of the United States Geological Survey in Utah, Colorado, Wyoming, and Montana were compiled by Willis, who placed the Laramie in the Cretaceous, in accordance with the decision of the Survey, and assigned the Shoshone group to the "Paleocene," after Scott. "Paleocene" has not, however, been accepted by the Survey's committee on geologic names, and the group is here described as "earliest Tertiary or latest Cretaceous." The Canadian Survey stated that the corresponding line in western Canada should be drawn at the base of the Edmonton.

Many other questions will present themselves to the student, who is referred to the text for the data on which the map is constructed.

As this work includes no chapters describing the igneous rocks, figures 1 and 2, showing the distribution, as indicated on the geologic map, of the post-Cambrian intrusive rocks and the Tertiary and later effusive rocks, respectively, are inserted here. With the post-Cambrian intrusive rocks are included extrusive rocks of the same age, and with the Tertiary effusives are included associated intrusive rocks.

ACKNOWLEDGMENTS.

The chapters have been read by geologists of the United States Geological Survey and revised in accordance with their suggestions. The writer owes special acknowledgment to Messrs. C. D. Walcott, Charles Schuchert, E. O. Ulrich, and A. W. Grabau, who have read the citations on the lower Paleozoic; to Mr. E. M. Kindle, who read the Silurian and Devonian chapters in the original and also in the revised drafts; to Messrs. G. H. Girty, David White, and G. H. Ashley, for criticism of the Carboniferous chapters; to Mr. J. Perrin Smith, for revision of the Triassic chapter; to Mr. T. W. Stanton, for revision of the Jurassic and Cretaceous chapters; to Mr. F. H. Knowlton, for comments on Mesozoic paleobotany; to Mr. W. H. Dall, for consideration of the several chapters on the Tertiary; and to Mr. T. Wayland Vaughan, for contributions to the discussion of the Tertiary of the Atlantic, Gulf, and West Indian provinces.

The suggestions made by these able critics have been followed so far as the scope of the work permitted, but the responsibility for the substance and form of the text rests none the less with the compiler.

The preparation of the manuscript geologic map has been difficult and tedious. It is a task requiring peculiar skill and experience to prepare suitable copy of so

complex a map and to engrave and lithograph it according to the high standards of modern cartography. The writer has been fortunate in being associated with the Survey's editor of geologic maps, Mr. G. W. Stose, and aided by the chief engraver, Mr. S. J. Kübel. To them in particular and also to Mr. H. S. Selden, who drew the manuscript geologic map, and to the cartographic section of the Survey he would express his indebtedness.

The names of the contributors to the map are given in the list at the close of this introduction. There are, however, certain portions of the geologic map which are strikingly different from any previously published and which represent original contributions from geologists who are familiar with special districts. These contributions are especially acknowledged as follows:

Mr. Robert T. Hill prepared an original map of Sonora and Chihuahua, Mexico, and of portions of adjacent areas in the United States.

Messrs. T. W. Vaughan and A. C. Spencer furnished the map of Cuba according to published data and their own unpublished notes.

Mr. W. P. Blake supplied material for the little-known districts of Arizona and his map was adjusted to notes and maps supplied by other geologists.

Mr. Ralph Arnold prepared for the geologic map of North America issued by the International Geological Congress in 1906 the map of California south of San Francisco, and for the map accompanying this volume Mr. Robert Anderson reviewed this material and supplemented it from his own notes.

Mr. A. C. Lawson supplied a manuscript map of the northern Coast Ranges, which was adjusted to other data in hand.

Mr. T. Wayland Vaughan and Mr. L. W. Stephenson drew the map of the Atlantic and Gulf coastal plains according to cooperative work in progress in the several States.

Mr. Arthur Keith prepared the map of the Appalachian Mountains from Maryland to Georgia, east of the Appalachian Valley, after his own surveys, supplemented by the original work of other geologists.

Messrs. George Otis Smith and E. S. Bastin compiled the map of the New England region from surveys by several geologists, supplemented by their own original notes.

Mr. N. H. Darton, Mr. M. R. Campbell, and the geologists assisting Mr. Campbell supplied the data for the Mesozoic and Tertiary of Colorado, Wyoming, and Montana.

COLOR SCHEME.

PRINCIPLES.

Color is used on geologic maps to delineate the distribution of various rocks. Legibility is the first requirement, economy in printing the second, and good taste the third. Custom may prescribe certain associations of color with particular implications, which, being thus established, control other associations.

The requirement of legibility determines the first principle. Distinctions of color should be so marked as to be clearly recognized. As contrast depends on hue and tint or shade in flat colors, and also on pattern where devices are employed, distinctions of hue, tint, shade, or pattern may be used to produce it.

In order to discuss contrasts it is necessary to have in mind certain facts about colors. There are three primary colors—red, blue, and yellow, which may be more accurately spoken of in terms of pigments as crimson lake, cobalt blue, and cadmium yellow. If pairs of these colors are combined in equal volumes they yield the standard secondary colors purple, orange, and green. Again if the standard secondaries are mixed in equal volumes in pairs standard tertiary colors are obtained—russet from purple and orange; olive from purple and green; and citrine from orange and green. Red predominates in russet, blue in olive, and yellow in citrine; each primary forms one-half of the respective tertiary color, but the presence of the other two primaries modifies its brilliancy.

Although the above statements are true in a general way, they are not mathematically exact. A name does not define a color. There are various reds, blues, and yellows, and various secondaries and tertiaries result according to the choice of primaries with which to start. Given three primaries, however, corresponding standard secondaries and tertiaries may be produced in the manner above described.

If graduated proportions are mixed instead of equal parts a series of slightly differing tints are obtained. For instance, 9 volumes of red to 1 of blue, 8 of red to 2 of blue, 7 of red to 3 of blue, and so on to 1 of red to 9 of blue will yield a range of purples which are scarcely distinguishable one from the next, yet which run the gamut from red to blue. A similar range of greens from blue to yellow and one of oranges from yellow to red complete a circle of closely graded secondaries.

The tertiary mixtures may be graded in the same manner to produce a sequence of russets, olives, and citrines which range from purple through green and then through orange back to purple without a break.

If we call the primary, secondary, and tertiary colors thus mixed hues, we may distinguish tints and shades of any one of them. The normal *hue* has the full available strength of its constituent colors. A *tint* is lighter. It may be mixed by adding more of the medium, water or oil, or by adding white. On the other hand a *shade* is darker—that is, it reflects less light than the normal hue. It may be produced by adding black, but more artistically by mixing a complementary tertiary color with the normal hue. In color printing tints result where the white of the paper shines through the hue, which is thereby diluted, and shades are produced by overprinting grays, which are usually tints of olives or russets strong in blue.

Contrast depends on the juxtaposition of unlike hues. It is strongest between any two of the pure primaries. It is equally striking but less likely to be offensive between a primary and the secondary which is composed of the other two primaries. Contrast in general is less pronounced between secondary hues and is materially less between tertiaries. There is no stronger contrast than that of white and black; in relation to colors it enters in a subdued degree into the distinction between tints and shades. Hence where strong contrast is desired we may juxtapose primary hues, or a primary with its complementary secondary, or a light tint of a hue against a dark shade of the same or another hue. The requirement of distinctness may usually be met by lesser contrasts and in general the greater contrasts are reserved for small areas or for emphasis.

A second principle follows from the requirement of economy in printing: The color scheme should be devised to accomplish the required distinctions with the least practicable number of impressions or printings.

As the lithographic press prints but one color at a time, it might seem that there must be as many printings as colors; but printing one color over another has the effect of combining them as if they were mixed and therefore a small number of printings may yield many distinctions. In colored illustrations three colors—red, yellow, and blue or green—usually suffice, reinforced sometimes by black.

On assuming that we proceed with the three primaries, it is evident that by overprinting we may obtain the three secondaries and also one combination of all three primaries in the full strength of their several hues. This combination will be almost black. These seven effects are strong unmodified hues. To produce tints the lithographer substitutes fine lines or dots in place of flat colors. Many of the patterns employed are almost invisible, but they permit the white of the paper to shine through and lighten the hue. Several distinct tints of any one primary hue may be produced at one printing, and their various combinations constitute a wide range of secondaries and tertiaries. Only an experienced lithographer can know in advance what the effects of the combinations will be and how distinct they will be. They fall into groups and of each group some are too closely similar to one another for practical distinction and others are undesirable because they are distasteful. But a large number of good distinctions is possible with three printings, the number is very greatly increased by a fourth printing, and only very numerous and very refined differences require many printings. The geologic colors on the map of North America are produced by 12 printings, which yield 42 distinct effects. Two more printings are required for the black and blue of the base map.

Conspicuous patterns are more or less used in geologic maps and greatly increase the range of recognizable distinctions. They are, however, a concession to technical requirement and offend good taste unless they are very skillfully designed.

The third requirement, that of good taste, is commonly little considered, but if it is satisfied the prime requirement of proper distinctness will also have been met; for the essential of good taste is adaptation to purpose. In general it may be said that pleasing maps result from an association of light tints, particularly light tints of tertiary hues in large areas, with appropriate contrasts of bright primary or secondary hues which may be proportionately more brilliant as the areas covered by them are smaller.

USAGES.

If entire freedom of choice and arrangement in devising a color scheme is allowed, the principles stated above may easily be applied in most cases to produce a thoroughly satisfactory map; but usage has established certain associations of colors with definite meanings, and it is misleading to contravene those associations. Whether the difficulty thus occasioned in the mind of a reader is such as to overbalance the advantages that may be gained by using colors arbitrarily instead of according to custom is determinable only with reference to each particular case and is then often a matter of personal judgment.

Some familiar usages are those of red, the color of fire, for igneous rocks; pink for the ancient crystalline rocks; blue, the color of the rock, for limestone; yellow, by similar association, for sandstone; and many others in which the suggestion of the color has a mnemonic value.

Another class of usages comprises those established officially by the practice of a government survey or by agreement among such surveys. Among those which have been developed to meet a general application and which are therefore most comprehensive in character, there are two that have been considered for the map of North America—the color scheme adopted by the International Geological Congress for the general map of Europe, and that designed by the United States Geological Survey for the Geologic Atlas of the United States. The following table shows their resemblances and differences:

Colors and color schemes.

Natural order of tints, hues, and shades	International European color scheme	United States Geological Survey	
		Geologic Atlas of the United States	Geologic map of North America
Yellow orange-tinted (cream)	Quaternary		Quaternary
Yellow, light	Pliocene		Miocene
Yellow, medium	Miocene		Pliocene
Yellow, dark	Oligocene	Pliocene and Miocene	
Yellow, greenish			
Citrine, yellowish brown		Eocene and Oligocene	
Citrine, medium brown	Permian		
Citrine, greenish brown		Cretaceous, upper part	
Green, yellowish	Eocene		Cretaceous, late Upper
Green, light	Cretaceous, Upper		Cretaceous, Upper
Green, medium	Cretaceous, Lower	Cretaceous	Cretaceous, Lower
Green, dark	Wealden	Cretaceous, lower part	Triassic
Green, bluish	Volgian	Jurassic	
Olive, greenish	Cambrian (dark)		
Olive, medium	Devonian (dark)	Archean	
Olive, bluish			
Blue, greenish	Silurian (dark)	Triassic	Jurassic (light) Triassic and Jurassic (dark)
Blue, gray	Carboniferous (dark)	Carboniferous	Permian (light) Pennsylvanian (dark)
Blue, light	Jurassic, Upper	Carboniferous, upper part	Carboniferous
Blue, medium	Jurassic, Middle	Carboniferous, lower part	Mississippian
Blue, dark			Devonian
Blue, purplish	Jurassic, Lower		Ordovician, middle and upper
Purple, bluish	Triassic	Devonian	Silurian
Purple, light			Paleozoic
Purple, medium			
Purple, dark			Eruptives
Purple, reddish	Gneiss and protogine	Silurian	Cambrian and lower Ordovician.
Russet, purplish		Ordovician (reddish)	
Russet		Algonkian	Late pre-Cambrian
Russet, reddish	Eruptives		Earlier pre-Cambrian
Red, russet		Cambrian	
Red, light	Schists		Pre-Cambrian.
Red, medium			
Red, dark	Eruptives		Eruptives.
Red, yellowish	Effusives		
Orange, reddish	Effusives		Effusives.
Orange, medium	Effusives		Eocene
Orange, light			Oligocene.
Orange, yellowish			

The European international geologic color scheme embodies the results of prolonged consideration by the international committee who were charged by the Geological Congress with the duty of preparing the map of Europe. In it can be recognized some elements of the French usage, particularly in the colors employed for the Mesozoic and Tertiary terranes. German influence appears in the selection of tones for Paleozoic terranes, and the familiar association of gray with Carboniferous and of pink with the ancient crystalline schists is an obvious result of general practice. So also is the use of strong, brilliant colors for the igneous rocks. The writer is not definitely informed regarding the discussion of principles through which the result was reached, but by a study of the color schemes in the light of what is published concerning the controlling principles, it would seem that the committee recognized (1) established usage, (2) the order of prismatic colors from purple through blue and green to yellow for that portion of the scheme relating to the Triassic and post-Triassic terranes, and (3) the arbitrary principle that Mesozoic terranes should be distinguished from Paleozoic by a very decided contrast of light and shade, the Paleozoic terranes being indicated by dark colors.

The European color scheme is exceedingly well adapted to delineate the geology of Europe and would apply well to that portion of western North America in which the Mesozoic and Tertiary formations occupy large areas in contrast to the Paleozoic terranes, as they do in Europe also. The map of Europe is very clear and legible, the base map having been kept free from confusing details and the colors having been selected and printed with great skill. The color scheme thus commends itself through the beautiful appearance of the map. It must not be forgotten, however, that Europe presents a special form of geologic structure. The continent is made up of extensive areas of Mesozoic and Tertiary strata surrounding relatively small exposures of Paleozoic terranes. This arrangement of younger strata about older nuclei is, from the point of view of the cartographer, the most important feature which the continent presents. The committee with good reason sought to emphasize the fact, and through that emphasis the map of Europe gains in expression and educational value. The greater part of the map is easily legible, being covered only by the light colors which are used for the Mesozoic and Tertiary, and the difficulties which arise in attempting to read the geology of the minor Paleozoic areas are not forced upon the attention.

But the international color scheme is unfitted to lands in which the Paleozoic terranes predominate and are minutely subdivided, for the density of the colors selected for the Paleozoic would produce a map that would offend good taste and be illegible. Moreover, inasmuch as the range of prismatic colors from purple, blue, and green to yellow is preempted in the European color scheme for Mesozoic and Tertiary terranes and the reds are assigned to the ancient crystalline and eruptive rocks, the choice of colors remaining available for the Paleozoic is much too limited for satisfactory discriminations. This is at once evident on an examination of the Paleozoic areas as represented on the international map—such, for instance, as the coal fields of Belgium and France, or the peninsula of Brittany, or Wales and Scotland. Although the distinctions are limited to a few great systems they are recognizable only on close inspection and the areas are indistinguishable from one another at a little distance. A geologic map of eastern North America printed in these dark colors with so little difference of hue or shade would fail to present adequately the great Appalachian zone as distinguished from the broad plateaus of the coal measures and the domelike uplifts of the Cincinnati axis. In the pre-Cambrian also the number of formations recognized in North America is greatly in excess of those distinguished in Europe, and the simplicity of the European scheme renders it insufficient to delineate the geology of the Lake Superior region and the Canadian shield.

For these reasons, after very careful consideration, the compilers of the geologic map of North America found it necessary to abandon the European international scheme not only for the map issued by the International Geological Congress in 1906 but also for the map accompanying the present volume.

The color scheme adopted by the United States Geological Survey for the Geologic Atlas of the United States is based on three essential principles—(1) that the order of the colors shall be that of their natural association, (2) that there shall be a standard color for each of the great geologic periods, and (3) that subordinate distinctions under each color shall be obtained by the use of obvious patterns. To these may be added the practice of using dull, subdued tones for the sedimentary and brilliant colors for the igneous rocks, as well as the mnemonic association of patterns which assigns parallel lines to the sedimentary rocks, angular patterns to igneous rocks, hachure patterns to metamorphic rocks, and dotted patterns to the surficial deposits. This color scheme has been developed and applied in the office and engraving division of the United States Geological Survey, where special facilities and skill in technical processes have been available. In attempting to apply the scheme to geologic maps printed under contract with private firms, difficulties have been encountered both in technical execution and in cost. Experience shows that the applicability of any color scheme which requires a precise use of patterns is affected by the necessity of developing a different use of patterns to secure economy in printing. For this reason primarily the color scheme of the United States Geological Survey is unavailable in general practice.

As color schemes that employ definite associations of colors and time divisions are limited in application to provinces that have had a certain historic development, and as patterns that may occasion excessive cost are unpractical, it follows that neither of these usages can be adopted for a universal color scheme except to a qualified degree. Nevertheless, a color scheme which shall serve as the universal language of geologic cartography is extremely desirable. The writer has sought, therefore, to devise certain principles which would occasion as little departure from current usage as might be practicable and which should yet be of general application in all continents. The adoption of such general principles would not find favor in England, France, or Germany, as may readily be foreseen if we consider how long established the several usages of those countries are; nor can it hope to supersede the international color scheme already applied to a large part of the geologic map of Europe and to be extended to the incomplete portions of the map. But Europe represents only a small part of the earth's surface and the Americas, Africa, and Asia need not be governed by its practice. It may be hoped that in making local geologic maps of other continents than Europe, even European cartographers will strive toward uniformity of expression, especially in color schemes, and that the American nations which are not yet committed by established practice to diverse usages will unite upon common principles.

In order to promote this desirable end, the following principles, suggested by the writer, have been proposed by the United States Geological Survey for discussion with a view to the development of a common usage among the official surveys of the Americas and for application to the geologic maps of the world published on the standard 1:1,000,000 base. These principles have already been indorsed in a general way by the Geological Survey of Canada and the Instituto Geológico de México.

PRINCIPLES FOR COLORING GEOLOGIC MAPS.

The first principle shall be that the relations of color and relative age shall be invariable—that is, when applied to distinguish divisions of a sequence of strata, colors shall always be used in a definite succession which shall express relative age.

Let it be agreed that the sequence red, purple, violet, blue, green, and yellow shall be adopted to represent succession of formations, groups, or series of sedimentary rocks from older to younger and let the order of colors be invariable according to the principle stated above, no matter what part or how much of the geologic column is represented. Then red will always represent something older than that which is shown in purple, or violet, or blue, etc. Blue will always stand for something older than that shown in green or yellow. In looking at any geologic map thus colored the student would at once know which were the older and which the younger sedimentary rocks. The essential features of sequence and structure would be immediately obvious.

The second principle is that color and geologic time divisions shall be measurably independent; in other words, no color shall be regarded as precisely indicative of any particular time division.

This principle is a radical departure from general usage in any one of the several countries which have well-established color schemes, but it is simply a recognition of general practice if we take account of the differences of these established schemes. For instance, in Europe blue means Jurassic, but in the United States it stands for Carboniferous. Thus blue in each country represents something different, and to a student of one country examining the maps of the other it suggests something other than it should. Let us agree that blue shall not necessarily mean Jurassic or Carboniferous, but that it may represent either Jurassic or Carboniferous, or in general some Mesozoic or Paleozoic time division. Such an agreement will give that elasticity of usage which is essential to a general color scheme designed for application to different provinces. If applied with appropriate recognition of the first principle the elasticity thus introduced will not occasion confusion, because we will always know the relative age of those formations represented by blue as compared to those represented by green on the one side and violet on the other. Indeed, a certain orderliness will take the place of the disorder that is forced by arbitrary usages upon any student of the maps of several countries. This principle is not intended, however, to give license to use any color whatever for any period, nor to contravene the principle of utility, which requires that a color scheme for a given province shall be as nearly uniform as practicable.

To illustrate the application of the first and second principles that have been proposed, we may consider certain examples. A general geologic map of North America requires few distinctions in the Mesozoic but many in the Proterozoic, Paleozoic, and Cenozoic. We may therefore allot the colors as follows:

Cenozoic	Yellow.
	Green.
Mesozoic	Blue.
Paleozoic	Violet.
	Purple.
Proterozoic	Red.

A general geologic map of Europe makes different requirements—very few distinctions in the Proterozoic, few in the Paleozoic, but very many in the Mesozoic and Cenozoic. Hence for such a map we may allot the colors as follows:

Cenozoic	Yellow.
	Green.
Mesozoic	Blue.
Paleozoic	Violet.
	Purple.
Proterozoic	Red.

The braces are overlapped to avoid too precise an assignment—for it is the purpose of the second principle to preserve that elasticity which alone can make the scheme available everywhere. Yet through the first principle we secure an orderly sequence, which will always convey the idea of relative age.

The preceding considerations apply to general maps on a small scale, for instance, the accompanying geologic map of North America, or maps on the scale of 1:1,000,000, the standard international base. A cartographer having such a map to construct should consider the geologic development of the province which the map is to represent in whole or in part and should devise the application of his color scheme in such a way that it accords with the two principles suggested and yet gives the greatest range of colors where there is the greatest development of the geologic column.

Detailed maps, on larger scales than 1:1,000,000, present special conditions; they may be simple or comprehensive.

If they are simple, it is desirable that the colors used should correspond with those that represent the same general time divisions on the general map. Where one or two effects suffice for the latter, there may be two or three times as many on the simple detailed map, but the range of colors may not need to be greatly increased.

If the detailed map shows terranes that are greatly subdivided, the range of colors must be increased; but in that case the dominant effects may be and should be selected to correspond with colors indicating the general time divisions on the general map and only so many of the colors above and below as may be needed should be used. The reader will then know that (*a*) if warm ruddy tones predominate, the earlier periods are represented; (*b*) if cold blue tones are most evident, the rocks of middle geologic periods are shown; and (*c*) if bright greenish or yellowish tones prevail, the map indicates rocks of later geologic periods. If the greens are wanting, so that the yellow tones are in contact with blues, he will recognize a hiatus; and similarly if any other color in the sequence is omitted.

The first and second principles discussed above embody the essential suggestions for a general color scheme, but there are other considerations which may be stated as supplementary rules that are at least desirable. Thus, in regard to contrasts, if we recognize pure hues, tints, shades, and tertiary hues, as explained on a previous page, we may provide that the invariable sequence of colors shall apply equally to pure hues, tints, shades, and tertiary hues; that pure, brilliant hues shall as a rule be reserved for igneous rocks; and that shades and tints belonging to a single minor division of the color sequence shall preferably be so used that darker effects represent the lower and lighter effects the upper terranes, in such manner that gradations from dark to light correspond with conformable sequences and contrasts indicate systemic distinctions, so far as practicable.

These provisions establish certain usages which have become common—the use of strong, bright effects for igneous rocks as contrasted with subdued effects for sedimentary rocks, and the employment of darker tones for the older and lighter tones for the younger divisions of a group or series. They support the first principle but emphasize contrast.

Contrast is as necessary to good geologic coloring as harmony. The eye catches a line between contrasted values and identifies the horizon in the various associations that may be occasioned by complex structures. Among the contrasts available for mapping sedimentary rocks, those which occur between light tints of one hue and dark shades of the next hue in the natural order of colors are the most useful and most consistent with harmony.

With regard to patterns we may recognize that they are desirable in many cases, for they afford distinctions that otherwise may not be clearly made, and if used consistently they serve to suggest at once the igneous, sedimentary, metamorphic, or surficial character of the rocks. But as patterns may be costly and unless skillfully employed fail in desirable effects, we may agree that the use of patterns shall not be obligatory, yet that if visible patterns are used, it shall be according to an established classification. The experience of the United States Geological Survey indicates that this classification should be patterns in circular figures for surficial rocks, patterns in parallel lines for sedimentary rocks, patterns in hachures for metamorphic rocks, and patterns in angular figures for igneous rocks. Patterns so used must be such as are obvious to the eye at the usual reading distance for which the map is designed. The use of patterns that are not obvious but may be seen on close inspection is a method of combining colors to economize in printing and may modify the mnemonic suggestion of the origin of the rock. For instance, by close examination of many of the patterns employed for sedimentary rocks on the accompanying map of North America, it will be seen that they are made up of crossed lines which would suggest igneous rocks, but these patterns are so fine that they will not be seen at the distance at which the map will ordinarily be read if hung upon the wall. Where conspicuous patterns are employed, either in parallel lines or in hachures, they signify the character of the rock.

Although for some maps these visible patterns may be costly there may also be economy in their use, as stated below. A consideration which rises to the importance of a principle in devising any general color scheme relates to economy. Economy in reproduction is usually secured by limiting the number of printings. There are two ways in which this may be done—(*a*) by using patterns of one color which produce distinctions of tint; (*b*) by overprinting two or more colors. In applying the former method the preparation of a lithographic stone so that it shall print many devices in one color, yet shall give different effects, may occasion greater cost than would be involved in printing from two or more simpler stones. In applying the second method, the combinations secured by overprinting two or more colors are numerous and may be less monotonous than those obtained by patterns of one color. The lithographer has always to balance the cost of preparing stones and that of printing, and the calculation of least expense involves not only the number of effects required but also the size of the edition and other factors. The conditions vary with individual maps, and an economical color scheme for general use must permit the employment of either or both methods.

By coloring geologic maps according to the proposed principles, we may secure (*a*) legibility, because the invariable order of colors will indicate the order of age; (*b*) common usage of colors within limits, which may be wide, for freedom is imperative, but which are nevertheless significant; (*c*) recognition of customary usages that now exist but are often disregarded; and, consequently, (*d*) the equivalent of a universal language in the coloring of all maps that follow the accepted principles.

The accompanying geologic map of North America represents an application of the proposed principles to a general case of great complexity. It is hoped that it may serve to encourage consideration and adoption of a universal color language on geologic maps.

CONTRIBUTORS.

The list of contributors to the geologic map of North America and of the sources from which it has been compiled follows.[a]

In this list are included the names of authors of geologic maps, published and in manuscript, used in compiling the map of North America, and those who furnished data, published and unpublished, for the correction of previously existing maps, or contributing to the knowledge of little-known regions. The sources of information from which published maps were originally derived are not given except where specifically credited on the maps. The term "folio" in the citations refers to the Geologic Atlas of the United States, published by the United States Geological Survey.

Adams, F. D.

Member of the committee on pre-Cambrian nomenclature.

Data on Victoria, Peterborough, and Hastings counties: Ann. Rept. Geol. Survey Canada for 1892–93, vol. 6, Rept. J.

Montreal sheet: Ann. Rept. Geol. Survey Canada for 1894, vol. 7, Rept. J.

Geologic map of Laurentian area north of the Island of Montreal: Ann. Rept. Geol. Survey Canada for 1895, vol. 8, Rept. J.

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[a] This list has been prepared by G. W. Stose and (for the Canadian contributors) J. M. Nickles, from notes and lists by Bailey Willis and the Canadian Geological Survey and from other sources.

Adams, F. D.—Continued.

Data on Haliburton district, Ontario: Summ. Rept. Geol. Survey Canada for 1899, pp. 122–131 (with A. E. Barlow).

Data on Haliburton and Bancroft areas, Ontario: Summ. Rept. Geol. Survey Canada for 1901, pp. 145–148.

Geologic map of Island of Montreal and vicinity: Ann. Rept. Geol. Survey Canada for 1901, vol. 14, pt. O (with O. E. LeRoy).

Geologic map of central Ontario: Proc. Roy. Soc. Canada, 3d ser., vol. 2, sec. 4, p. 3, 1908 (with A. E. Barlow).

Geologic map of Haliburton and Bancroft areas, Ontario: Mem. Geol. Survey Canada No. 6, 1910 (with A. E. Barlow).

Adams, G. I.

Geologic map of the Ozark region of Missouri and Arkansas: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, pp. 69–94.

Geologic map of Louisiana and eastern Texas: Bull. U. S. Geol. Survey No. 184, 1901.

Geologic map of part of the eastern Choctaw coal field, Oklahoma: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, pp. 257–311 (with J. A. Taff).

Fayetteville folio, Missouri-Arkansas (with E. O. Ulrich).

Adán de Yarza, Ramón.

Geologic map of Cuba: Bol. Com. del Mapa Geol. de España, vol. 20, 1895, pp. 71–88.

Aguilera, J. G.

Furnished geologic map of Mexico compiled for the map of North America published by the International Geological Congress, 1906, and later compiled manuscript maps of parts of Mexico for the present map.

Alden, W. C.

Chicago folio, Illinois-Indiana; Milwaukee folio, Wisconsin (with T. C. Chamberlin).

Corrections to southeastern portion of geologic map of Wisconsin published in 1881, from unpublished notes on this area.

Ami, H. M.

Manuscript contributions; Paleozoic formations of St. Lawrence Valley.

Anderson, F. M.

Notes on the Cretaceous of California, used by Ralph Arnold and Robert Anderson in compilation of map of California: Proc. California Acad. Sci., 3d ser., Geology, vol. 2, 1902, pp. 1–154.

Anderson, Robert.

Compiled manuscript geologic map of Coast Ranges of California south of San Francisco, for this map.

Geologic maps of Santa Maria and Coalinga districts, Cal.: Bull. U. S. Geol. Survey Nos. 322, 1907, and 398, 1910 (with Ralph Arnold).

Manuscript geologic maps of parts of Diablo Range and Salinas Valley region, California.

Arnold, Ralph.

Compiled manuscript geologic map of Coast Ranges of California south of San Francisco for map of North America published by International Geological Congress, 1906; used in part in this map.

Geologic map of part of Olympic Peninsula, Washington: Bull. Geol. Soc. America, vol. 17, 1906, pp. 451–468.

Santa Cruz folio, California (with J. C. Branner and J. F. Newsom).

Geologic maps of Santa Clara Valley, Puente Hills, and Los Angeles oil districts (with G. H. Eldridge); of Summerland district; of Santa Maria and Coalinga districts (with Robert Anderson), and McKittrick-Sunset region (with H. R. Johnson): Bull. U. S. Geol. Survey Nos. 309, 321, 322, 398, and 406.

Manuscript geologic maps of San Luis Obispo County, Santa Monica and Pasadena quadrangles, and part of San Diego County, Cal.

Ashley, G. H.

Compiled detailed map of the Pennsylvanian and Permian series in the Appalachian region, from northern Pennsylvania to Alabama.

Notes on the distribution of the Pennsylvanian series in the Appalachian and central coal fields.

Ditney folio, Indiana (with M. L. Fuller).

Atwood, W. W.

Data on Alaska Peninsula, used in compiling manuscript map of Alaska.

Bailey, L. W.

Data on Queens, Sunbury, and York counties, New Brunswick: Rept. Prog. Geol. Survey Canada for 1872–73, pp. 180–230 (with G. F. Matthew).

Data on New Brunswick: Rept. Prog. Geol. Survey Canada for 1874–75, pp. 84–89 (with G. F. Matthew).

Data on southern New Brunswick: Rept. Prog. Geol. Survey Canada for 1870–71, pp. 13–240; idem for 1875–76, pp. 348–368 (with G. F. Matthew); idem for 1878–79, Rept. D (with G. F. Matthew and R. W. Ells).

Data on Albert and Westmoreland counties, New Brunswick: Rept. Prog. Geol. Survey Canada for 1876–77, pp. 351–395, with geologic map of lower Carboniferous rocks (with R. W. Ells).

Data on and geologic map of Carleton, Victoria, York, and Northumberland counties, New Brunswick: Ann. Rept. Geol. Survey Canada for 1885, vol. 1, Rept. G.

Geologic map of southwestern Nova Scotia: Ann. Rept. Geol. Survey Canada for 1892–93, vol. 6, Rept. Q; idem for 1896, vol. 9, Rept. M.

Data on the pre-Silurian of southern New Brunswick: Rept. Prog. Geol. Survey Canada for 1877–78, Rept. DD.

Bailey, L. W.—Continued.

Data on York and Carleton counties, New Brunswick: Rept. Prog. Geol. Survey Canada for 1882–84, Rept. G; Summ. Rept. idem for 1900, pp. 146–150.

Geologic map of Victoria, Northumberland, and Restigouche counties, New Brunswick: Ann. Rept. Geol. Survey Canada for 1886, vol. 2, Rept. N (with W. McInnes).

Data on northern New Brunswick and adjacent areas in Quebec and in Maine: Ann. Rept. Geol. Survey Canada for 1887–88, vol. 3, Rept. M (with W. McInnes).

Bain, H. F.

Geologic map of Illinois, compiled by Stuart Weller: Bull. State Geol. Survey Illinois No. 6, 1907.

Geologic map of the zinc and lead region of the upper Mississippi Valley: Bull. U. S. Geol. Survey No. 294, 1906.

Ball, M. W.

Data on Little Snake River coal field, Wyoming, used in compiling map of the Cretaceous and Tertiary.

Geologic map of eastern part of Little Snake River coal field, Wyoming: Bull. U. S. Geol. Survey No. 381, 1910, pp. 186–213 (with E. Stebinger).

Geologic map of western part of Little Snake River coal field, Wyoming: Bull. U. S. Geol. Survey No. 341, 1909, pp. 243–255.

Ball, S. H.

Geologic map of southwestern Nevada and adjacent parts of California; Bull. U. S. Geol. Survey No. 308, 1907.

Manuscript geologic map of part of Silver City quadrangle, New Mexico.

Bancroft, Howland.

Geologic map of part of Yuma County, western Arizona: Bull. U. S. Geol. Survey No. 451, 1911.

Bancroft, J. A.

Data on coast of British Columbia from Powell River to Kingcome Inlet: Summ. Rept. Geol. Survey Canada for 1907, pp. 16–18.

Barbour, E. H.

Notes on details of geology in Nebraska.

Bard, D. C.

Unpublished notes on details of lava of Snake River Plains, Elko County, Nev.

Barlow, A. E.

Data on Haliburton district, Ontario: Summ. Rept. Geol. Survey Canada for 1896, pp. 43–53; idem for 1899, pp. 122–131 (with F. D. Adams).

Data on Hastings and Renfrew counties, Ontario: Summ. Rept. Geol. Survey Canada for 1897, pp. 44–56.

Geologic map of Nipissing district, Ontario, and Pontiac County, Quebec: Ann. Rept. Geol. Survey Canada for 1897, vol. 10, Rept. I.

Data on Temagami district, Ontario and Quebec: Summ. Rept. Geol. Survey Canada for 1903, pp. 120–133; idem for 1904, pp. 190–194; idem for 1906, pp. 113–118.

Geologic map of Sudbury mining region, district of Algoma, Ontario: Ann. Rept. Geol. Survey Canada for 1901, Rept. H.

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Geologic map of central Ontario: Proc. Roy. Soc. Canada, 3d ser., vol. 2, sec. 4, 1908, p. 3 (with F. D. Adams).

Geologic map of Haliburton and Bancroft areas, Ontario: Mem. Geol. Survey Canada No. 6, 1910 (with F. D. Adams).

Barlow, Scott.

Data on Springhill coal field, Cumberland County, Nova Scotia: Rept. Prog. Geol. Survey Canada for 1873–74, pp. 147–160; idem for 1875–76, pp. 343–347.

Barnett, V. H.

Data on Smith River coal field, Montana, and on Cheyenne River and Standing Rock Indian reservations, South and North Dakota, used in compiling map of the coal-bearing Cretaceous and Tertiary.

Bascom, Florence.

Philadelphia and Trenton folios, Pennsylvania and New Jersey, and manuscript maps of neighboring regions.

Bastin, E. S.

Geologic map of New England, compiled by G. O. Smith and E. S. Bastin for geologic map of North America, Intern. Geol. Congress, 1906.

Geologic map of the granites of Maine: Bull. U. S. Geol. Survey No. 313, 1906 (with G. O. Smith and C. W. Brown).

Geologic map of part of southern Maine: Bull. U. S. Geol. Survey No. 420, 1910.

Penobscot Bay and Rockland folios, southeastern Maine, and manuscript maps of adjacent areas in Maine.

Manuscript geologic map of the Eastport quadrangle, Maine.

Bauerman, Hilary.

Data on country near forty-ninth parallel of north latitude west of the Rocky Mountains: Rept. Prog. Geol. Survey Canada for 1882–84, Rept. B.

Bayley, W. S.

Passaic folio, New Jersey, and manuscript for Raritan folio.

Becker, G. F.

Data on Kodiak Island used in compiling manuscript map of Alaska.

Geologic maps of the quicksilver districts of the Pacific slope: Mon. U. S. Geol. Survey, vol. 13, 1888.

Beede, J. W.

Cottonwood Falls folio, Kansas (with C. S. Prosser).

Beekly, A. L.

Data on Glenwood Springs coal field, Colorado, and on Cheyenne River and Standing Rock Indian reservations, South and North Dakota, used in compiling map of the coal-bearing Cretaceous and Tertiary.

Bell, J. M.

Data on country from Great Bear Lake to Great Slave Lake: Ann. Rept. Geol. Survey Canada for 1899, vol. 12, Rept. C.

Bell, Robert.

Data on Manitoulin Islands: Rept. Prog. Geol. Survey Canada for 1863–1866, pp. 165–169; idem for 1866–1869, pp. 109–116.

Data on country northwest of Lakes Superior and Nipigon: Rept. Prog. Geol. Survey Canada for 1866–1869, pp. 313–364.

Data on region north of Lake Superior between Nipigon and Michipicoten rivers: Rept. Prog. Geol. Survey Canada for 1870–71, pp. 322–351.

Data on country between Lake Superior and Albany River, Ontario: Rept. Prog. Geol. Survey Canada for 1871–72, pp. 101–114.

Data on country between Lake Superior and Lake Winnipeg: Rept. Prog. Geol. Survey Canada for 1872–73, pp. 87–111.

Data on country between Red River and south Saskatchewan, and region between Lake Superior and Red River: Rept. Prog. Geol. Survey Canada for 1873–74, pp. 66–90.

Data on country west of Lake Manitoba and Winnipegosis, and vicinity of Lake Winnipeg: Rept. Prog. Geol. Survey Canada for 1874–75, pp. 24–56.

Data on country between James Bay and Lakes Superior and Huron: Rept. Prog. Geol. Survey Canada for 1875–76, pp. 294–342.

Data on region north of Lake Huron and east of Lake Superior: Rept. Prog. Geol. Survey Canada for 1876–77, pp. 193–220.

Data on east coast of Hudson Bay: Rept. Prog. Geol. Survey Canada for 1877–78, Rept. C.

Data on country between Lake Winnipeg and Hudson Bay: Rept. Prog. Geol. Survey Canada for 1877–78, Rept. CC (with geologic map).

Geologic map of the Lake of the Woods region, Ontario: Rept. Prog. Geol. Survey Canada for 1880–1882, Rept. C.

Data on basin of Athabasca River, Alberta: Rept. Prog. Geol. Survey Canada for 1882–1884, Rept. CC.

Data on Labrador coast, Hudson Strait, and Hudson Bay: Rept. Prog. Geol. Survey Canada for 1882–1884, Rept. DD.

Data on Hudson Strait and Hudson Bay: Ann. Rept. Geol. Survey Canada for 1885, vol. 1, Rept. DD.

Data on Attawapishkat and Albany rivers, Lonely Lake to James Bay: Ann. Rept. Geol. Survey Canada for 1886, new ser., vol. 2, Rept. G.

Geologic map of Algoma and Nipissing districts, Ontario: Ann. Rept. Geol. Survey Canada for 1890–91, vol. 5, Rept. F.

French River sheet, Ontario: Ann. Rept. Geol. Survey Canada for 1896, vol. 9, Rept. I.

Geologic map of northern side of Hudson Strait: Ann. Rept. Geol. Survey Canada for 1898, vol. 11, Rept. M.

Data on Michipicoten district, Ontario: Summ. Rept. Geol. Survey Canada for 1898, pp. 99–106; idem for 1900, pp. 109–121.

Data on Churchill and Nelson rivers and around God's and Island lakes: Rept. Prog. Geol. Survey Canada for 1878–79, Rept. C.

Data on region west of Hudson Bay: Rept. Prog. Geol. Survey Canada for 1879–80, Rept. C.

Geologic map of Moose River basin: Rept. Prog. Geol. Survey Canada for 1880–82, Rept. C.

Data on Great Slave Lake region, Northwest Territory: Summ. Rept. Geol. Survey Canada for 1899, pp. 103–110.

Geologic map of basin of Nottaway River: Ann. Rept. Geol. Survey Canada for 1900, vol. 13, Rept. K.

Cobalt mining district, Ontario: Summ. Rept. Geol. Survey Canada for 1905, pp. 94–104; idem for 1906, pp. 110–112.

Manuscript geologic map of Newfoundland, furnished by Geological Survey of Canada for the map of North America published for the International Geological Congress, Mexico, 1906.

Berry, E. W.

Data on the Cretaceous of Maryland, Delaware, New Jersey, Pennsylvania, Virginia, North Carolina, South Carolina, Georgia, and Alabama and the Tertiary of Alabama and Mississippi, used in the compilation of the map of the Atlantic and Gulf Coastal Plain.

Bibbins, A. B.

Data on the Cretaceous of Maryland, Delaware, New Jersey, Pennsylvania, Virginia, and North Carolina, used in compilation of the map of the Atlantic Coastal Plain.

Blackwelder, Eliot.

Data on Yakutat Bay and Alsek River region, used in compiling manuscript map of Alaska, making use of earlier work of I. C. Russell.

Laramie-Sherman folio, Wyoming (with N. H. Darton and C. E. Siebenthal).

Blake, W. P.

Manuscript map of southern Arizona, used in part.

Böse, E.

Geologic map of Chiapas and Tabasco: Bol. Inst. geol. México No. 20, 1905.

Boutwell, J. M.

Geologic map of the Bingham district, Utah: Prof. Paper U. S. Geol. Survey No. 38, 1905 (with Arthur Keith).

Manuscript map of Park City district, Utah, on file in office of U. S. Geol. Survey.

Bowman, Amos.

Geologic map of Cariboo mining district, British Columbia: Ann. Rept. Geol. Survey Canada for 1887–88, vol. 3, pt. 1, Rept. C.

Bownocker, J. A.

Geologic map of Ohio, based on maps by Newberry and Orton, Ohio Geol. Survey, 1909.

Branner, J. C.

Geologic map of Arkansas: Am. Jour. Sci., 4th ser., vol. 2, 1896, pp. 229–236.

Map of novaculite area, central Arkansas: Third Ann. Rept. Geol. Survey Arkansas, 1890 (with L. S. Griswold).

Santa Cruz folio, California, and manuscript maps of San Jose and Mount Hamilton quadrangles, used in compilation by Ralph Arnold and Robert Anderson.

Brock, R. W.

Member (part of the time) of committee on classification of the pre-Cambrian. Furnished geologic map of Canada compiled for the map of North America published by the International Geological Congress, 1906, and later notes and sketch maps for the present map. Adjusted several points which arose between the Canadian and United States surveys.

Data on West Kootenay district, British Columbia: Summ. Rept. Geol. Survey Canada for 1898, pp. 62–71; idem for 1899, pp. 75–86; idem for 1900, pp. 62–84.

Data on the Boundary Creek district, British Columbia: Summ. Rept. Geol. Survey Canada for 1901, pp. 49–67; idem for 1902, pp. 92–138.

Data on the Lardeau mining district, British Columbia: Summ. Rept. Geol. Survey Canada for 1903, pp. 42–81; idem for 1904, pp. 80–91; idem for 1907, pp. 84–90.

Data on Rossland mining district, British Columbia (preliminary report): Geol. Survey Canada, 1906.

West Kootenay sheet, British Columbia: Ann. Rept. Geol. Survey Canada for 1901, vol. 14 (portfolio) (with R. G. McConnell).

Geologic map of Canada, including Labrador and Newfoundland, scale 100 miles to 1 inch (accompanies a descriptive sketch of the geology and economic minerals of Canada, by G. A. Young): Geol. Survey Canada, 1909.

Brooks, A. H.

Furnished geologic map of Alaska compiled from published maps and manuscript data.

Data on southeastern Alaska, upper Tanana and White River basins, Susitna basin, Alaska Range, Seward Peninsula, and Yukon-Tanana region (the last based on earlier work of Spurr), used in compiling manuscript map of Alaska.

Buckhannon folio, West Virginia (with J. A. Taff).

Brown, C. W.

Penobscot Bay folio, Maine (with G. O. Smith and E. S. Bastin).

Manuscript geologic map of Frenchmans Bay quadrangle, Maine.

Unpublished notes on the geology of Rhode Island.

Geologic map of the granites of Maine: Bull. U. S. Geol. Survey No. 313, 1906 (with E. S. Bastin and G. O. Smith).

Buckley, E. R.

Geologic map of Missouri: Rept. Missouri Bureau of Geol. and Mines for 1903–4.

Sketch manuscript map showing corrections to map of Missouri, 1904 (1907).

Buehler, H. A.

Notes on details of geology of Missouri.

Burchard, E. F.

Lancaster-Mineral Point folio, Wisconsin-Iowa-Illinois (with U. S. Grant).

Butler, B. S.

Unpublished notes on certain Devonian areas in Utah.

Manuscript geologic map of Frisco and adjacent region of western Utah.

Butts, Charles.

Rural Valley, Ebensburg, and Warren folios, Pennsylvania, and Birmingham folio, Alabama.

Cairnes, D. D.

Data on the foothills of Rocky Mountains south of main line of Canadian Pacific Railway: Summ. Rept. Geol. Survey Canada for 1905, pp. 62–67.

Whitehorse and Tantalus regions, Yukon: Summ. Rept. Geol. Survey Canada for 1906, pp. 22–30; idem for 1907, pp. 10–15; idem for 1908, pp. 26–32.

Geologic map of Moose Mountain district of southern Alberta: Geol. Survey Canada, 1907.

Geologic map of lower Lake Laberge and vicinity, Yukon Territory, scale 1 mile to 1 inch: Geol. Survey Canada, 1908.

Geologic map of Conrad and Whitehorse districts, Yukon: Geol. Survey Canada, 1908.

Calkins, F. C.

Geologic map of part of northern Washington: Bull. U. S. Geol. Survey No. 235, 1904 (with G. O. Smith).

Geologic map of the Cœur d'Alene district, Idaho: Prof. Paper U. S. Geol. Survey No. 62, 1908 (with F. L. Ransome).

Geologic map of part of east-central Washington: Water-Supply Paper U. S. Geol. Survey No. 118, 1905.

Geologic map of part of northern Idaho: Bull. U. S. Geol. Survey No. 384, 1909.

Manuscript map of Philipsburg quadrangle, Montana.

Snoqualmie folio, Washington (with G. O. Smith).

Calvert, W. R.

Geologic map of the vicinity of Judith Mountains, Montana: Bull. U. S. Geol. Survey No. 390, 1909.

Data on Lewistown and Livingston coal fields, Montana, used in compiling map of the coal-bearing Cretaceous and Tertiary.

Campbell, H. D.

Manuscript maps of Lexington and Natural Bridge quadrangles, Virginia.

Campbell, M. R.

Data on Black Mesa coal field, Arizona, used in compiling map of the coal-bearing Cretaceous and Tertiary.

Geologic map of the coal-bearing Cretaceous and Tertiary of the central Western States, compiled by Bailey Willis and M. R. Campbell.

Estillville, Pocahontas, Tazewell, London, Richmond, Standingstone, Bristol, Huntington, Charleston, and Raleigh folios, southern Appalachians, and manuscript maps of adjacent areas; Danville folio, Illinois; and Masontown-Uniontown, Brownsville-Connellsville, and Latrobe folios, Pennsylvania.

Geologic map of Deer Creek coal field, Arizona: Bull. U. S. Geol. Survey No. 225, 1904, pp. 240–258.

Camsell, Charles.

Data on the region southwest of Fort Smith, Slave River, Northwest Territory: Summ. Rept. Geol. Survey Canada for 1902, pp. 151–169.

Data on the headwater region of Severn River, Northwest Territory: Summ. Rept. Geol. Survey Canada for 1904, pp. 143–152.

Data on Peel and Wind rivers: Ann. Rept. Geol. Survey Canada for 1904, vol. 16, Rept. CC.

Data on Peel River, in the Yukon and Mackenzie districts: Summ. Rept. Geol. Survey Canada for 1905, pp. 36–46.

Data on Osoyoos and Similkameen mining divisions, British Columbia: Summ. Rept. Geol. Survey Canada for 1907, pp. 24–31; idem for 1908, pp. 61–64.

Geologic map of Similkameen district, British Columbia: Geol. Survey Canada, 1907.

Chamberlin, T. C.

Member of committee on pre-Cambrian nomenclature.

Geologic map of Wisconsin: Wisconsin Geol. Survey, 1881.

Milwaukee folio, Wisconsin (with W. C. Alden).

Clapp, C. H.

Data on southeastern part of Vancouver Island: Summ. Rept. Geol. Survey Canada for 1908, pp. 52–60.

Clapp, F. G.

Amity and Rogersville folios, Pennsylvania; Patoka folio, Indiana-Illinois (with M. L. Fuller).

Geologic map of Florida: Ann. Rept. Geol. Survey Florida, 1909 (with G. C. Matson and Samuel Sanford).

Clark, W. B.

Geologic map of Maryland: Maryland Geol. Survey, vol. 6, 1906.

Furnished geologic map of the Atlantic Coastal Plain north of North Carolina, from cooperative surveys with States.

Trenton and Philadelphia folios, New Jersey and Pennsylvania (with Florence Bascom and others).

Clarke, J. M.

Corrections to geologic map of New York published in 1901.

Geologic map of eastern part of Gaspe Peninsula, Quebec: Mem. New York State Mus. No. 9, 1908.

Manuscript map of other parts of Gaspe Peninsula, Quebec.

Collier, A. J.

Data on Miles City coal field, Montana, used in compiling map of the coal-bearing Cretaceous and Tertiary.

Geologic map of Arkansas coal field: Bull. U. S. Geol. Survey No. 326, 1907.

Data on Yukon Valley, St. Lawrence Island, Cape Lisburne region, and Seward Peninsula, used in compiling manuscript map of Alaska.

Collins, W. H.

Data on Montreal River district, Ontario: Summ. Rept. Geol. Survey Canada for 1908, pp. 115–120.

Geologic map of northwestern Ontario traversed by the Transcontinental Railway between Lake Nipigon and Sturgeon Lake: Geol. Survey Canada, 1908.

Geologic map of northwestern Ontario traversed by National Transcontinental Railway between Lake Nipigon and Clay Lake, Ontario: Geol. Survey Canada, 1909.

Geologic map of Gowganda mining division, district of Nipissing, Ontario: Geol. Survey Canada, 1909.

Geologic map of the region north of Lake Superior between Pic and Nipigon rivers, Ontario: Geol. Survey Canada, 1909.

Cook, G. H.

Geologic map of New Jersey: Geol. Survey New Jersey, 1890.

Crandall, Roderic.

Unpublished data on geology of Mount Hamilton region, California.

Crider, A. F.

Data on the Tertiary and Cretaceous of Mississippi and on the Tertiary of Arkansas, used in compilation of the map of the Atlantic and Gulf Coastal Plain.

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Crosby, W. O.

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Cross, Whitman.

Telluride, La Plata, Silverton, Rico, Needle Mountains, Ouray, and Engineer Mountain folios, southwestern Colorado, and manuscript maps of the adjacent Lake City and Durango quadrangles.

Notes for correction of the Hayden map of Colorado.

Geologic map of the Denver Basin, Colo.: Mon. U. S. Geol. Survey, vol. 27, 1896 (with S. F. Emmons and G. H. Eldridge).

Pikes Peak and Anthracite-Crested Butte folios, central Colorado.

Geologic map of Silver Cliff and Rosita Hills, Colorado: Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, pp. 269–403.

Cummins, W. F.

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Sterrett, D. B.
Manuscript geologic map of Kings Mountain and Gaffney quadrangles, North Carolina-South Carolina.

Stone, R. W.
Elders Ridge and Waynesburg folios, Pennsylvania.
Data on Musselshell River (Montana) and Powder River (Wyoming) coal field, used in compiling map of the coal-bearing Cretaceous and Tertiary.
Data on Kachemak Bay region, used in compiling manuscript map of Alaska.

Stose, G. W.
Assisted largely in compiling the map of North America and directing its drafting and publication.
Mercersburg-Chambersburg and Pawpaw-Hancock folios and manuscript maps of Carlisle, Fairfield, and Gettysburg quadrangles, southern Pennsylvania, Maryland, and West Virginia.
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Taff, J. A.

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Torrance, J. F.

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Turner, H. W.

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Manuscript maps of Silver Peak quadrangle, Nevada, and Yosemite quadrangle, California.

Tyrrell, J. B.

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Umpleby, J. B.

Manuscript geologic map of Lemhi County, Idaho.

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Van Hise, C. R.

Member of committee on pre-Cambrian nomenclature.

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White, James.

Member (part of the time) of committee on pre-Cambrian nomenclature.

Wilder, F. A.

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Willard, D. E.

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Williams, H. S.

Watkins Glen-Catatonk folio, New York (with E. M. Kindle and R. S. Tarr).

Willis, Bailey.

Compiler of map of North America; contributed local details in many districts.

Geologic map of part of Rocky Mountains, northern Montana: Bull. Geol. Soc. America, vol. 13, 1902, pp. 305–352.

Chairman of committee on pre-Cambrian nomenclature.

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Woodworth, J. B.

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Geologic map of Richmond area, Virginia: Nineteenth Ann. Rept. U. S. Geol. Survey, 1899, pp. 385-520 (with N. S. Shaler).

Woolsey, L. H.

Data on Bull Mountains coal field, Montana, used in compiling map of the coal-bearing Cretaceous and Tertiary.

Beaver folio, Pennsylvania.

Wright, C. W.

Data on southeastern Alaska, used in compiling manuscript map of Alaska.

Wright, F. E.

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Yeates, W. S.

Geologic map of Georgia: Rept. Geol. Survey Georgia for 1906.

Young, G. A.

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Data on Temagami and Rabbit lakes, district of Nipissing, Ontario: Summ. Rept. Geol. Survey Canada for 1904, pp. 195-198.

Data on Bathurst district and the Tobique country, Victoria County, New Brunswick: Summ. Rept. Geol. Survey Canada for 1908, pp. 129-131.

In the subjoined list, arranged by localities, only the names of the authors of data used in compiling the map are given. The sources of the data are given in the preceding list.

SOUTH AMERICA.

Hettner, Alfred.
Howe, Ernest.
Karsten, Hermann.
Sawkins, J. G.
Sievers, Wilhelm.
Wall, G. P.

CENTRAL AMERICA (INCLUDING PANAMA) AND WEST INDIES.

Adán de Yarza, Ramón.
Fernández de Castro, Manuel.
Hayes, C. W.
Hill, R. T.
Howe, Ernest.
Salterain y Legarra, Pedro.
Sapper, Karl.
Spencer, A. C.
Tippenhauer, L. G.
Torre, Carlos de la.
Vaughan, T. W.

MEXICO.

Aguilera, J. G.
Böse, E.
Hayes, C. W.
Hill, R. T.
Ordóñez, Ezequiel.
Sapper, Karl.
Willis, Bailey.

UNITED STATES EXCEPT ALASKA.

ALABAMA (H-I 16).

Ashley, G. H.
Berry, E. W.
Butts, Charles.
Hayes, C. W.
Matson, G. C.
Smith, E. A.
Stephenson, L. W.
Vaughan, T. W.

ARIZONA (H-J 11-12).

Bancroft, Howland.
Blake, W. P.
Campbell, M. R.
Darton, N. H.
Dutton, C. E.
Gregory, H. E.
Hayden, F. V.

ARIZONA (H-J 11-12)—Continued.

Hill, J. M.
Hill, R. T.
Jaggar, T. A., jr.
Lee, W. T.
Lindgren, Waldemar.
Palache, Charles.
Powell, J. W.
Ransome, F. L.
Richardson, G. B.
Schrader, F. C.
Walcott, C. D.
Wheeler, G. M.

ARKANSAS (I-J 15).

Adams, G. I.
Branner, J. C.
Collier, A. J.

ARKANSAS (I-J 15)—Continued.

Crider, A. F.
Fuller, M. L.
Griswold, L. S.
Purdue, A. H.
Taff, J. A.
Ulrich, E. O.
Vaughan, T. W.
Veatch, A. C.

CALIFORNIA (I-K 10-11).

Anderson, F. M.
Anderson, Robert.
Arnold, Ralph.
Ball, S. H.
Becker, G. F.
Branner, J. C.
Crandall, Roderic.

UNITED STATES EXCEPT ALASKA—continued.

CALIFORNIA (I-K 10-11)—Continued.

Darton, N. H.
Diller, J. S.
Eldridge, G. H.
Fairbanks, H. W.
Fisher, C. A.
Hamlin, Homer.
Harder, E. C.
Hayden, F. V.
Hershey, O. H.
Hess, F. L.
Hill, R. T.
Ireland, William.
Johnson, H. R.
Lawson, A. C.
Lindgren, Waldemar.
Mendenhall, W. C.
Merriam, J. C.
Newsom, J. F.
Pack, R. W.
Ransome, F. L.
Russell, I. C.
Smith, W. S. T.
Turner, H. W.
Weaver, C. E.
Willis, Bailey.
Winchester, D. E.
Woodruff, E. G.

COLORADO (J-K 12-13).

Beekly, A. L.
Campbell, M. R.
Cross, Whitman.
Darton, N. H.
Eldridge, G. H.
Emmons, S. F.
Fenneman, N. M.
Gale, H. S.
George, R. D.
Gilbert, G. K.
Goldman, M. I.
Hills, R. C.
Howe, Ernest.
King, Clarence.
Lee, W. T.
Powell, J. W.
Schrader, F. C.
Shaler, M. K.
Siebenthal, C. E.
Spencer, A. C.
Spurr, J. E.
Stose, G. W.
Washburne, C. W.
Wheeler, G. M.
Willis, Bailey.

CONNECTICUT (K 18).

Bastin, E. S.
Davis, W. M.
Emerson, B. K.
Gregory, H. E.
Keith, Arthur.
Robinson, H. H.

CONNECTICUT (K 18)—Continued.

Russell, I. C.
Smith, G. O.

DELAWARE (J 18).

Berry, E. W.
Bibbins, A. B.
Clark, W. B.
Darton, N. H.
Miller, B. L.

DISTRICT OF COLUMBIA (J 18).

Darton, N. H.
Keith, Arthur.
Miller, B. L.
Shattuck, G. B.

FLORIDA (G-H 16-17).

Clapp, F. G.
Matson, G. C.
Sanford, Samuel.
Sellards, E. H.
Vaughan, T. W.

GEORGIA (H-I 16-17).

Berry, E. W.
Hayes, C. W.
Keith, Arthur.
La Forge, Laurence.
McCallie, S. W.
Phalen, W. C.
Stephenson, L. W.
Vaughan, T. W.
Veatch, Otto.
Yeates, W. S.

IDAHO (K-M 11-12).

Calkins, F. C.
Drake, N. F.
Gale, H. S.
Gilbert, G. K.
Hayden, F. V.
Heikes, V. C.
Lindgren, Waldemar.
Ransome, F. L.
Russell, I. C.
Weeks, F. B.

ILLINOIS (J-K 15-16).

Alden, W. C.
Ashley, G. H.
Bain, H. F.
Burchard, E. F.
Campbell, M. R.
Clapp, F. G.
Fuller, M. L.
Glenn, L. C.
Grant, U. S.
Weller, Stuart.

INDIANA (J-K 16).

Alden, W. C.
Ashley, G. H.

INDIANA (J-K 16)—Continued.

Clapp, F. G.
Fuller, M. L.
Gorby, S. S.

IOWA (K 14-15).

Ashley, G. H.
Bain, H. F.
Burchard, E. F.
Grant, U. S.
Savage, T. E.
Todd, J. E.
Wilder, F. A.

KANSAS (J 14-15).

Beede, J. W.
Darton, N. H.
Haworth, Erasmus.
Prosser, C. S.
Schrader, F. C.

KENTUCKY (J 16-17).

Ashley, G. H.
Campbell, M. R.
Glenn, L. C.
Hoeing, J. B.
Norwood, C. J.
Phalen, W. C.
Willis, Bailey.

LOUISIANA (H 15-16).

Adams, G. I.
Harris, G. D.
Vaughan, T. W.
Veatch, A. C.

MAINE (K-L 19).

Bastin, E. S.
Brown, C. W.
Smith, G. O.
White, David.

MARYLAND (J 17-18).

Ashley, G. H.
Berry, E. W.
Bibbins, A. B.
Clark, W. B.
Darton, N. H.
Keith, Arthur.
Martin, G. C.
Matthews, E. B.
Miller, B. L.
Russell, I. C.
Shattuck, G. B.
Stose, G. W.
Swartz, C. K.
Taff, J. A.
Willis, Bailey.

MASSACHUSETTS (K 18-19).

Bastin, E. S.
Crosby, W. O.

UNITED STATES EXCEPT ALASKA—continued.

UNITED STATES EXCEPT ALASKA—continued.

OREGON (K–L 10–11).

Diller, J. S.
Drake, N. F.
Lindgren, Waldemar.
Russell, I. C.

PENNSYLVANIA (J–K 17–18).

Ashley, G. H.
Bascom, Florence.
Berry, E. W.
Butts, Charles.
Campbell, M. R.
Clapp, F. G.
Clark, W. B.
Darton, N. H.
Fuller, M. L.
Kümmel, H. B.
Lesley, J. P.
Lines, E. F.
Martin, G. C.
Matthews, E. B.
Miller, B. L.
Munn, M. J.
Phalen, W. C.
Richardson, G. B.
Russell, I. C.
Shaw, E. W.
Smith, A. D. W.
Stone, R. W.
Stose, G. W.
Swartz, C. K.
Woolsey, L. H.

RHODE ISLAND (K 19).

Bastin, E. S.
Brown, C. W.
Emerson, B. K.
Foerste, A. F.
Shaler, N. S.
Smith, G. O.
Woodworth, J. B.

SOUTH CAROLINA (I 17).

Berry, E. W.
Keith, Arthur.
Sloan, Earle.
Stephenson, L. W.
Sterrett, D. B.

SOUTH DAKOTA (K–L 13–14).

Barnett, V. H.
Beekly, A. L.
Darton, N. H.
Hall, C. M.
Hayden, F. V.
Jaggar, T. A., jr.
O'Harra, C. C.
Pishel, M. A.
Powell, J. W.
Smith, W. S. T.
Todd, J. E.
Vaughan, T. W.

TENNESSEE (I–J 15–17).

Campbell, M. R.
Glenn, L. C.
Hayes, C. W.
Keith, Arthur.
Safford, J. M.
Ulrich, E. O.
Vaughan, T. W.
Willis, Bailey.

TEXAS (G–I 13–15).

Adams, G. I.
Cummins, W. F.
Dumble, E. T.
Deussen, Alexander.
Gordon, C. H.
Gould, C. N.
Hill, B. F.
Hill, R. T.
Kay, F. H.
Paige, Sidney.
Richardson, G. B.
Spencer, A. C.
Udden, J. A.
Vaughan, T. W.

UTAH (J–K 12).

Boutwell, J. M.
Butler, B. S.
Campbell, M. R.
Dutton, C. E.
Eldridge, G. H.
Emmons, S. F.
Gale, H. S.
Gilbert, G. K.
Goldthwait, J. W.
Harder, E. C.
Hayden, F. V.
Huntington, Ellsworth.
Keith, Arthur.
King, Clarence.
Leith, C. K.
Powell, J. W.
Richards, R. W.
Richardson, G. B.
Smith, G. O.
Spurr, J. E.
Taff, J. A.
Tower, G. W.
Weeks, F. B.
Wheeler, G. M.
Willis, Bailey.

VERMONT (K–L 18–19).

Bastin, E. S.
Dale, T. N.
Hitchcock, C. H.
Keith, Arthur.
Smith, G. O.

VIRGINIA (J 17–18).

Berry, E. W.
Bibbins, A. B.
Campbell, H. D.

VIRGINIA (J 17–18)—Continued.

Campbell, M. R.
Clark, W. B.
Darton, N. H.
Gardner, J. A.
Geiger, H. R.
Keith, Arthur.
Miller, B. L.
Rogers, W. B.
Russell, I. C.
Shaler, N. S.
Shattuck, G. B.
Watson, T. L.
Woodworth, J. B.

WASHINGTON (L–M 10–11).

Arnold, Ralph.
Becker, G. F.
Calkins, F. C.
Merriam, J. C.
Reagan, A. B.
Russell, I. C.
Smith, G. O.
Willis, Bailey.

WEST VIRGINIA (J 17).

Ashley, G. H.
Brooks, A. H.
Campbell, M. R.
Darton, N. H.
Keith, Arthur.
Martin, G. C.
Phalen, W. C.
Rogers, W. B.
Stose, G. W.
Swartz, C. K.
Taff, J. A.
White, I. C.
Willis, Bailey.

WISCONSIN (K–L 15–16).

Alden, W. C.
Bain, H. F.
Burchard, E. F.
Chamberlin, T. C.
Grant, U. S.
Leith, C. K.
Van Hise, C. R.

WYOMING (K–L 12–13).

Ball, M. W.
Blackwelder, Eliot.
Campbell, M. R.
Darton, N. H.
Eldridge, G. H.
Fisher, C. A.
Gale, H. S.
Hague, Arnold.
Hayden, F. V.
Iddings, J. P.
King, Clarence.
Lupton, C. T.
O'Harra, C. C.

UNITED STATES EXCEPT ALASKA—continued.

DOMINION OF CANADA, LABRADOR, AND NEWFOUNDLAND.

DOMINION OF CANADA, LABRADOR, AND NEWFOUNDLAND—continued.

QUEBEC (L-N 17-21)—Continued.

Low, A. P.
McInnes, William.
McOuat, Walter.
Murray, Alexander.
Osann, A.
O'Sullivan, Owen.
Richardson, James.
Selwyn, A. R. C.
Torrance, J. F.
Vennor, H. G.

QUEBEC (L-N 17-21)—Continued.

Wilson, M. E.
Wilson, W. J.
Young, G. A.

SASKATCHEWAN (M-O 12-13).

Bell, Robert.
Dawson, G. M.
Dowling, D. B.
McConnell, R. G.
McInnes, William.

SASKATCHEWAN (M-O 12-13)—Contd.

Selwyn, A. R. C.
Tyrrell, J. B.

YUKON (O-R 7-10).

Camsell, Charles.
Dawson, G. M.
Keele, Joseph.
McConnell, R. G.
Tyrrell, J. B.

ALASKA.

[In terms of coordinate letters and numbers, arranged from south to north and west.]

N-O 8-9, SOUTHEASTERN ALASKA.

Brooks, A. H.
Knopf, Adolph.
Spencer, A. C.
Wright, C. W.
Wright, F. E.

O 7, YAKUTAT BAY AND ALSEK RIVER REGION.

Blackwelder, Eliot.
Russell, I. C.
Tarr, R. S.

P 6, CONTROLLER BAY REGION.

Maddren, A. G.
Martin, G. C.

P 6, LOWER COPPER RIVER.

Schrader, A. C.
Spencer, A. C.

P 6, PRINCE WILLIAM SOUND.

Grant, U. S.
Higgins, D. F.
Schrader, F. C.
Spencer, A. C.

P 6-7, CHITINA VALLEY.

Maddren, A. G.
Mendenhall, W. C.
Moffit, F. H.
Schrader, F. C.
Spencer, A. C.

P 7, UPPER TANANA AND WHITE RIVER BASINS.

Brooks, A. H.
Knopf, Adolph.
Moffit, F. H.
Schrader, F. C.

P 6, UPPER COPPER RIVER REGION.

Mendenhall, W. C.
Schrader, F. C.

O-P 5-6, EASTERN HALF KENAI PENINSULA.

Grant, U. S.
Higgins, D. F.
Moffit, F. H.

O 6, KACHEMAK BAY REGION.

Martin, G. C.
Stanton, T. W.
Stone, R. W.

O 5, KODIAK ISLAND.

Becker, G. F.
Dall, W. H.

N 3-4, O 4-5, ALASKA PENINSULA.

Atwood, W. W.
Martin, G. C.
Spurr, J. E.
Stanton, T. W.

O 4-5, P 5, ILIAMNA AND LAKE CLARK REGION.

Katz, F. J.
Martin, G. C.

P 6, MATANUSKA VALLEY.

Knopf, Adolph.
Martin, G. C.
Paige, Sidney.

P 5, SUSITNA BASIN.

Brooks, A. H.
Eldridge, G. H.
Spurr, J. E.

P 5-6, ALASKA RANGE.

Brooks, A. H.
Prindle, L. M.

Q 5-7, YUKON-TANANA REGION.

Brooks, A. H.
Prindle, L. M.
Spurr, J. E.

Q 7, PORCUPINE RIVER.

Kindle, E. M.
Maddren, A. G.

Q 6, CHANDALAR AND UPPER KOYUKUK.

Maddren, A. G.
Mendenhall, W. C.
Schrader, F. C.

P 4, Q 4-5, YUKON VALLEY.

Collier, A. J.

O-P 4, KUSKOKWIM VALLEY AND BRISTOL BAY REGION.

Spurr, J. E.

P 4, INNOKO REGION.

Maddren, A. G.

Q 4, YUKON RIVER AND NORTON BAY REGIONS.

Eakin, H. M.
Smith, P. S.

Q 4, KOBUK VALLEY.

Mendenhall, W. C.

Q-R 5, ENDICOTT RANGE AND ANAKTUVUK AND COLVILLE RIVER VALLEYS.

Schrader, F. C.

Q 3, SEWARD PENINSULA.

Brooks, A. H.
Collier, A. J.
Moffit, F. H.
Smith, P. S.

R 3, CAPE LISBURNE REGION.

Collier, A. J.
Kindle, E. M.

P 3, NUNIVAK ISLAND.

Dall, W. H.
Dawson, G. M.

P 2, ST. LAWRENCE ISLAND

Collier, A. J.

GREENLAND AND ICELAND (P-U 19-28).

Garde, Victor.
Hammer, R. R. I.
Holm, G. F.
Jessen, A.
Kornerup, A.
Low, A. P.
Nathorst, A. G.
Nordenskjöld, Otto.
Steenstrup, K. J. V.
Thoroddsen, Th.

CHAPTER II.

PRE-CAMBRIAN.

The pre-Cambrian of North America has been described in detail and with exhaustive consideration of the literature in the revised correlation bulletin on the pre-Cambrian by Van Hise and Leith.[828] That work makes any description of the terranes superfluous in this paper, which will confine itself to a list of the areas colored as pre-Cambrian (see fig. 3) and an account of the efforts made to reach a satisfactory classification for the purposes of the geologic map of North America.

Pre-Cambrian areas.

Keewatin (23a).[a]

L-M 15-16 .... Minnesota, Wisconsin, Michigan, Ontario.

"Laurentian" (23).

L 14-16 .... Wisconsin, Michigan, Minnesota, and North Dakota (undifferentiated pre-Cambrian, which is mapped with "Laurentian").
L 19-20 .... New Brunswick, Nova Scotia.
L-M 21-22 .... Newfoundland.
L 17-18, M 14-21, N 13-21, O 12-20, P 11-20, Q 9-20, R 8-19 .... Canadian shield: Ontario, Quebec, Manitoba, Saskatchewan, Alberta, Northwest Territories.
S 14-18, T 17-19, U 17-18 .... Arctic Archipelago.
P 22-23, Q 22, R 22, S 21, T 19-20 .... West coast of Greenland.
P 23-24, Q 25, R-S 26-27, T 27 .... East coast of Greenland.

Laurentian (23d).

L-M 15-16 .... Minnesota, Wisconsin, Michigan.

Earlier (?) pre-Cambrian unclassified (22).

L 12 .... Montana (Cherry Creek group, early Algonkian; mapped with Belt series, 21a, late Algonkian).
L-N 17-18 .... Ontario, Quebec.
M-N 15-16 .... Ontario, Northwest Territories.
M 21 .... Newfoundland.
N 13-14 .... Saskatchewan, Northwest Territories.
N 19-20 .... Quebec, Northwest Territories.
O 12 .... Saskatchewan.
O 20 .... Labrador.
P 12-15, Q 11 .... Northwest Territories.
T 19 .... Greenland.

[a] Numbers in parentheses refer to numbers of corresponding color blocks on the map.

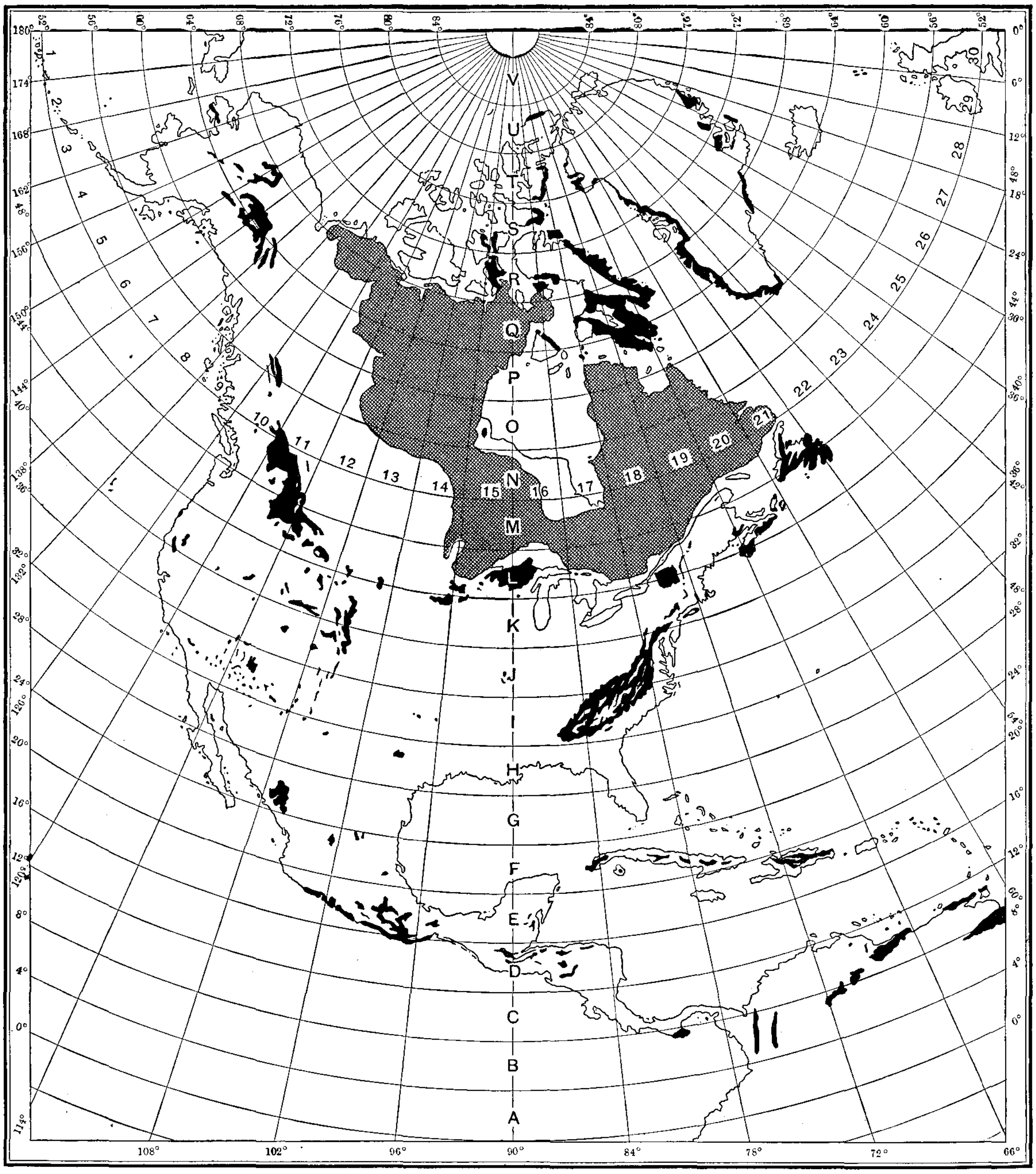

FIGURE 3.—Sketch map showing the distribution of pre-Cambrian rocks represented on the geologic map of North America and the key to references in the text. The large area covering northern Canada is shown by line pattern, smaller areas by solid black.

Hastings and Grenville (22a).

L 17–18........................Ontario and Quebec.

Middle and Lower Huronian (22b).

K 14–15........................South Dakota, Minnesota.
L–M 15–16......................Wisconsin, Michigan, Ontario.
L 17...........................Ontario.

Late (?) pre-Cambrian unclassified (21).

J 13...........................Colorado (Needle Mountains group; mapped with Belt series, 21a).
K 12...........................Utah, Colorado (quartzites of Uinta and Wasatch mountains; mapped with Belt series, 21a).
K–L 19–20......................Nova Scotia.
M 18...........................Quebec.
L–M 21–22......................Newfoundland.
N–P 18–19, N 20–21.............Quebec, Northwest Territories.
O 15...........................Northwest Territories.
O–Q 12–13......................Alberta, Saskatchewan, Northwest Territories.
P–Q 14, Q–R 10–13..............Northwest Territories.

Upper Huronian (21c).

L–M 15–16......................Minnesota, Wisconsin, Michigan, Ontario.

Keweenawan (21b).

L 15–16........................Minnesota, Wisconsin, Michigan.
M 16...........................Ontario.

Belt series (21a).

J 13...........................Colorado (Needle Mountains group, which is included with Belt series of map).
K 12...........................Utah, Colorado (late Algonkian, which is included with Belt series on map).
L–M 11–12......................Idaho, Montana, British Columbia, Alberta. In Montana the Cherry Creek group (early Algonkian) is mapped with the Belt series (late Algonkian).

Undifferentiated pre-Cambrian (23b).

H 13–14........................Texas.
I 11–13........................California, Arizona, New Mexico.
I 16–18........................Alabama, Georgia, North Carolina, South Carolina.
J 13...........................Colorado.
J 15...........................Missouri.
J 17–18........................North Carolina, Virginia, Maryland, Delaware, Pennsylvania, New Jersey.
K 12–13........................Utah, Wyoming, Colorado.
K–L 18–19......................Pennsylvania, New Jersey, New York, Connecticut, Massachusetts, Rhode Island.
L 11–13........................Idaho, Wyoming, Montana.
L–M 14–16......................Wisconsin, Michigan, Minnesota, North Dakota (mapped with "Laurentian").

Gneisses, schists, and metamorphosed sediments (23c). (Supposed pre-Cambrian, possibly in part Paleozoic and Mesozoic).

B 17–20........................Panama, Colombia, Venezuela.
C 19–20........................Venezuela.
D 14–16........................Mexico, Guatemala, Honduras, Nicaragua.
E 13–16........................Mexico, British Honduras.
F 13–14, G 13..................Mexico.
J 11...........................Nevada.
K 10–11........................Oregon, California, Nevada.
L 11...........................Washington, Idaho.
M–N 10–11......................British Columbia, Washington.
O 9–10.........................British Columbia.
P–Q 4–8........................Alaska, Yukon.
Q 3............................Seward Peninsula, Alaska.

Pre-Cambrian intrusive rocks (24).

I 14	Oklahoma.
I 16–17	Georgia, North Carolina, South Carolina.
J 17–18	North Carolina, Virginia, Maryland, Delaware, Pennsylvania.
K 18	Pennsylvania, New York.
L 17–19	Ontario, Quebec.
M 15	Ontario.
M 18–20	Quebec.
N 20–21	Quebec, Northwest Territories.
N–O 17–18, P 17–19	Northwest Territories.
O–P 22–24	Southern Greenland.
R 22	West coast of Greenland.

PRE-CAMBRIAN CLASSIFICATION.

The problem of pre-Cambrian classification has been difficult of adjustment under the requirements of the map of North America. The Canadian Survey adheres to its long-established divisions Laurentian and Huronian, which rest upon the work of Logan and his successors. The modifications developed by modern studies have not in the opinion of Canadian authorities rendered these terms less useful or justified substitutes or material changes of definition. The United States Survey adopted the divisions Archean and Algonkian in 1889 and they have been earnestly advocated by the geologists working in the Lake Superior region in their earlier as well as in their latest publications. These geologists maintain that the terms Archean and Algonkian stand for two great major divisions which constitute a "dual classification" of the pre-Cambrian that is thought probably to be of general occurrence and to distinguish two grand eras of the earth's history. The points of view of the Canadian and United States geologists have been presented by F. D. Adams [1, 2] and C. R. Van Hise [826, 827] and are also set forth in the report of the special (international) committee for the Lake Superior region.[3]

The classification of the pre-Cambrian which the compiler introduced in the map of 1906 was the result of an attempt to adjust differences of interpretation to the requirements of a general map, in which the number of distinctions was limited. In conformity with the terminology of the international congress the prefixes neo and eo were used for two major divisions of the post-Archean, both of which, according to the nomenclature employed by the United States Geological Survey, belonged to the Algonkian. Thus arose neo-Algonkian and eo-Algonkian. The classification could not, however, be carried through with perfect separation of the several systems—Archean, eo-Algonkian, and neo-Algonkian—and it became necessary to state that each of these systems *as represented on the map of 1906* might include masses belonging to one of the other two. The wording of the explanation in the legend of the map did not make it plain that the Keewatin was included under eo-Algonkian, for instance, only because of the requirements of cartography and in spite of the well-known fact that the two are separated by a great unconformity, and the classification was therefore criticized by American as well as by Canadian geologists. The latter objected to the term Algonkian; the former objected to the confusion of distinct systems in one.

These objections were entirely just from the point of view of the systematic geologist. The Keewatin does not belong to the Algonkian and is separated from the lowest terrane of that system by an unconformity which is regarded as equivalent to a long interval of time. But this interval and the distinction between these terranes can not be expressed on the map so long as it is true, as stated by Dr. Adams, that "It is impossible for us as yet to separate the Keewatin from the Huronian, these two divisions having been, up to the present time, both classed as Huronian." The legend of the map of 1906 does not, however, adequately express the fact that the mapping is less advanced than investigation. It should have stated plainly that eo-Algonkian comprised Lower and Middle Huronian, and that the areas so mapped included some undifferentiated Keewatin which belongs to the Archean.

In preparing the revised edition of the geologic map of North America, effective agreement on problems of classification and nomenclature was sought by the officers of the United States Survey. An international committee, composed of geologists representing the surveys of Canada and the United States, had brought about an understanding in regard to questions relating to the geology of the Lake Superior region and to that of eastern Canada and New York. At a meeting of that committee in New York on December 29, 1906, it was voted that a subcommittee consisting of three representatives from Canada and three from the United States be appointed to consider questions of classification and nomenclature in connection with the preparation of a geologic map of North America by the United States Geological Survey. Bailey Willis was designated chairman of this subcommittee, the other members to be selected later by correspondence between Messrs. Low and Hayes. The subcommittee thus nominated consisted of F. D. Adams, R. A. Daly, and James White, representing the Canadian Survey, and T. C. Chamberlin, C. R. Van Hise, and Bailey Willis (chairman), for the United States Survey. A meeting was held at Toronto March 7, 1907, and the entire scheme of nomenclature for the map was considered from Quaternary to pre-Cambrian. The following classification of the older rocks was agreed to:

Paleozoic	Cambrian and latest pre-Cambrian.
Proterozoic	Later Proterozoic, including unseparated earlier Proterozoic. Earlier Proterozoic, including unseparated later Proterozoic.
	Ancient schists and igneous rocks.
	Laurentian gneiss.

The action of the committee was a compromise which was designed to meet the needs of a legend for the general map but which did not go beyond that point in attempting to adjust existing differences of opinion. Prof. Van Hise dissented from the proposed division of the Proterozoic. The subcommittee did not indicate any areas to be mapped under any particular designation, that selection being left to the compiler, Mr. Willis.

From studies which followed the meeting at Toronto, the compiler concluded that a map prepared on the compromise there reached would not adequately present the known facts or express the existing uncertainties regarding the pre-Cambrian sequence and classification. At his instance a further conference was proposed and held at Chicago, February 21, 1908. The conferees were R. W. Brock, Acting Director, and F. D. Adams, for the Canadian Survey; W. G. Miller, for the Ontario

Bureau of Mines; and T. C. Chamberlin, C. R. Van Hise, and Bailey Willis (chairman), for the United States Survey. The discussion of the problem of pre-Cambrian classification was earnest and prolonged. It clearly developed the fact that knowledge of the pre-Cambrian terranes is not yet adequate to furnish criteria by which even some of the major divisions may be surely correlated or to offset the differences of opinion which spring from historical associations or personal experience. The discussion was in part as follows:

Mr. Willis presented as a basis for discussion a tentative classification of the pre-Cambrian, which is shown in figure 4 by the names printed in Roman type. It embodied Archeozoic and Proterozoic without definite delimitation; undifferen-

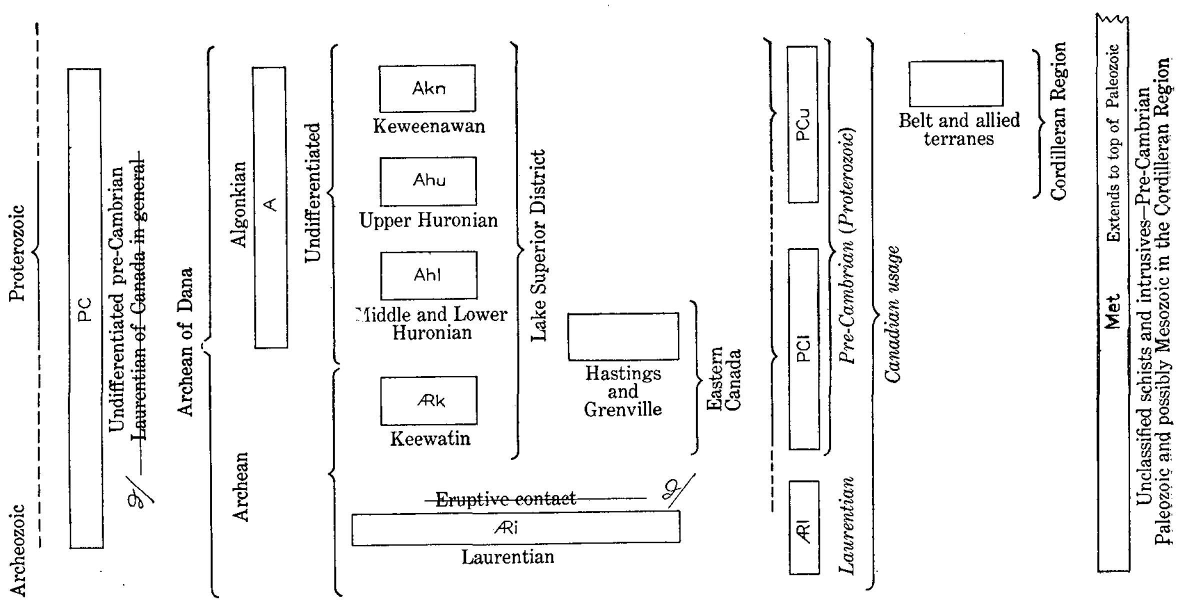

FIGURE 4.—Classification of the pre-Cambrian adopted by the international committee. The portion in roman type represents the table as originally presented by Mr. Willis. The corrections made by the committee are shown, the additions being in italics.

tiated pre-Cambrian, which was also designated Laurentian of Canada in general and Archean of Dana; Archean and Algonkian of the United States Geological Survey; the classification adopted by the international committee for the Lake Superior district; the Hastings and Grenville series of eastern Canada; the Belt series and allied terranes; and the unclassified schists and intrusives of the Cordillera.

Prof. Van Hise took up the discussion and emphasized the point that it is desirable in such a map as that under discussion to make clear the relation of the adopted color scheme to the various classifications in use by different organizations and in different textbooks, in order that the matter might be plainly understood.

Prof. Adams, speaking for the Canadian geologists, stated that if the requirements of cartography limited the classification to three divisions, they would wish one to indicate Laurentian and two others to represent two different parts of the Proterozoic. The divisions of the Proterozoic have to be made on grounds which seem valid now, but they may have to be shifted as the work goes on. The map represents the distinctions essentially as the Canadian geologists would like to have them made, even though in the course of eight or ten years the colors will have to be revised. Some great areas that are little metamorphosed lie in the neighborhood of areas that are highly metamorphosed, and it may be that those which are considered older may prove to be newer, but as we have no very definite line to divide newer from older, the Canadian Geological Survey would undertake to state how the distinctions should be made.

Mr. Willis called attention to the classification of the Paleozoic into metamorphic and nonmetamorphic and suggested that the same distinction might be applied to the Proterozoic of the northern shield.

After some discussion, in which Prof. Chamberlin urged that metamorphism was but one factor in discriminating older and newer Proterozoic and that the classification should be based on several factors, Prof. Adams stated that throughout northern Canada there are patches of rock that resemble very closely the Keweenawan. There is a very strong presumption, which Dr. George Dawson believed, that it is the most extensive of the Proterozoic formations of North America. In other places occur formations which resemble Huronian. There is a distinction of metamorphism which is also very largely a distinction of age.

The discussion also brought out the fact that in the region northwest of Hudson Bay the Keweenawan facies is predominant; whereas in the Labrador Peninsula, east of Hudson Bay, the resemblances to the Animikie appear to be closer. It appeared therefore that a classification into older and newer Proterozoic must be one which separates the Animikie and Keweenawan from the Huronian.

As a result of the discussion it was agreed that the Canadian Geological Survey should be responsible for the classification of the Proterozoic in two groups which should in a general way express a relation of older formations to younger ones but which should be clearly explained to be somewhat indefinite and subject to future revision.

The use of the term Laurentian in general was then considered at length. By reference to figure 4 it will be seen that four different interpretations were represented in the committee. The most comprehensive allied Laurentian in general with the Archean of Dana, Laurentian in general being understood to mean the pre-Cambrian rocks of the great northern shield, regarding which it is not definitely known whether they are prevailingly pre-Huronian or include also large areas of Huronian. The second interpretation of the Laurentian in general is that which relates it to the Archean according to the restricted definition comprising Keewatin and intrusives into the Keewatin—that is, the pre-Huronian formations to which Logan originally gave the name Laurentian. The third interpretation is that which is represented in the Canadian classification (italics in fig. 4) and which is closely related to the second but leaves the upper limit of the Laurentian in general somewhat indefinite, it being recognized that throughout the Canadian shield there are many intrusives whose age can never be precisely determined on account of the absence of overlying sedimentary rocks. The fourth interpretation is the restricted Laurentian of the international committee on the Lake Superior and Adirondack regions, which limits the term to acidic rocks intrusive into the Keewatin, except as it may be employed, "preferably with an explanatory phrase," to designate some "associated granites of large extent which cut the Huronian or whose relations to the Huronian can not be determined."

The first interpretation (Laurentian in general considered as the equivalent of undifferentiated pre-Cambrian), was found to be unacceptable to the Canadian representatives. Prof. Adams had earlier in the discussion expressed the opinion that the Laurentian in the sense of pre-Huronian constituted essentially 99 per cent of the northern part of the Canadian shield.

In answer to a question by Mr. Willis as to whether the Canadians were prepared to restrict Laurentian to the equivalent of pre-Huronian, Dr. Brock responded:

I think we were all agreed at Ottawa that this would be the most desirable thing to do if possible, but we overruled it on account of the difficulty in separating the Keewatin and Huronian. It was necessary to have some color which would indicate Keewatin and Lower Huronian for purposes of mapping. Economically they go together. If we could possibly do it we would very much prefer to have a general color to cover the lower part, but in mapping I do not think we can do it. We have many areas in which we can not differentiate the Keewatin and Lower Huronian.

Prof. Chamberlin asked:

What is your preference, Mr. Brock, in regard to the lower formation? Should it represent undifferentiated pre-Cambrian or should it represent Archean?

Dr. Brock responded:

We would prefer to see it represent the Archean. There is, of course, undifferentiated Huronian in that probably, but the main fact is that the great part of the northern area represents what Logan called Laurentian.

Prof. Chamberlin urged the recognition of Logan's definition of Laurentian. He said:

From my point of view I should like to see the general color [adopted for the Canadian shield] represent pretty closely Logan's idea, which involves Keewatin, Laurentian intrusive into Keewatin, and rocks of general Laurentian aspect—the old gneiss groups as confessedly an undifferentiated series but as a great series representing one of the greatest of the eras of the earth's history; so that if this conception is true we have the great nucleus of the continent. I am thinking of something more fundamental than pre-Cambrian, something nucleal to Huronian, Animikie, and Keweenawan. We need to find the general nucleus from which the Canadian formations have been derived.

Prof. Van Hise granted the fact that the nucleus described had existed for Paleozoic formations but did not admit that the Canadian region was a nucleus for the pre-Cambrian.

As a result of further discussion the term Laurentian in general as applied to the unclassified pre-Cambrian was stricken out. The use of Laurentian in general as equivalent to Archean in the restricted sense of pre-Huronian was recognized as one having a theoretical significance, but one which in the present state of knowledge does not represent a mappable thing. There remain the two usages, namely, (1) Laurentian equivalent to the Keewatin and the intrusive rocks cutting the Keewatin and including probably some Huronian [a] and (2) the Laurentian intru-

[a] In commenting on these minutes of the conference, Prof. Adams, under date of March 9, 1908, wrote: "In this usage the Laurentian includes not only rocks which are equivalent to Keewatin but any portion of the pretaxis which may be found to be older than Keewatin; that is to say, if in the great northern protaxis the base exists on which the Keewatin has been deposited, this also is of Laurentian age. It may easily be that a not inconsiderable proportion of the Laurentian protaxis is really pre-Keewatin in date."

sive in the Keewatin, which is restricted, in mapping at least, to areas that have been surveyed in detail. It was determined to recognize both of these divisions of the Laurentian to the extent that present knowledge justifies such distinction.

The arrangement of the classifications agreed upon was then taken under consideration and the schedule was corrected as shown in figure 4. The revised classification showing the various usages which are there set forth was then unanimously adopted on motion of Prof. Chamberlin, seconded by Prof. Adams.

The classification thus drawn up comprises the usage accepted for this publication by the Canadian Survey and the United States Survey, also the local sequence of eastern Canada, of the Lake Superior region, and of the Cordillera. It presents the presumed correlation of these various classes according to present knowledge and fixes the responsibility for the mapping of different sections upon that organization which has done most of the work in either district.

I 16-17, J 17-18. SOUTHERN APPALACHIAN MOUNTAINS.

The revision of the pre-Cambrian rocks of the Appalachian Mountains by Arthur Keith and the sources of information used by him are stated in the following memorandum, which he prepared for this work.

The geologic formations of the area between the Blue Ridge and the Coastal Plain and from Maryland to Alabama have been revised from those shown in published maps, according to detailed and reconnaissance work that I have done during the last 20 years.

In Virginia the boundary at the base of the Cambrian near the Blue Ridge and all boundaries east of that, except for the Richmond and the Danville Triassic basins, are new. They are based on detailed work as far south as latitude 38° 30′; south of that latitude they are founded upon reconnaissance work.

In North Carolina the detailed geology of the published folios for the western part of the State is supplemented by reconnaissance in the central part of the State; for the eastern part of the crystalline rocks, the mapping is based on the old map of North Carolina by W. C. Kerr, with some modification and reinterpretation of the areas.

In the western part of the State also the detailed but yet unpublished work extends from the mountains and the Blue Ridge 20 to 40 miles into the Piedmont Plateau.

In South Carolina the northwestern margin of the State has been mapped in detail and a detailed survey has been made of the Kings Mountain region in northern-central South Carolina and in North Carolina. The remainder of the mapping in the State is based on the old county maps of Lieber, somewhat modified by my reconnaissance.

For Georgia manuscript maps of C. W. Hayes have been used west of longitude 84° 30′ and north of 33° 30′. My detailed and reconnaissance work affords the basis for mapping formations north and northeast of Atlanta, including the belt of probable Cambrian strata (Brevard schist). Southeast and south of that line I have used the map of the granites of Georgia published by T. L. Watson, with slight modifications.

In the rocks southeast of the main Cambrian belt three divisions are made—(1) Paleozoic igneous rocks of post-Cambrian age; (2) undivided pre-Cambrian gneisses and schists; and (3) pre-Cambrian igneous rocks, mainly granites and granitoid rocks. Of the pre-Cambrian igneous rocks, only the granites are mapped in class 3, the Roan gneiss being omitted, although mainly igneous, because most of its areas are too small to show with the present map scale. The effusive pre-Cambrian igneous rocks are included with the granites in the mapping, as no provision is made in the color scheme to separate them.

Although most of the boundaries shown are those between different pre-Cambrian formations, considerable areas of Paleozoic intrusive rocks are distinguished, especially in Georgia and the Carolinas. In the areas so shown there are known to be minor areas of pre-Cambrian rocks, mainly granites, and similarly there are Paleozoic granites in the areas shown as pre-Cambrian. Separation of these minor areas is difficult, even with detailed work, and is not warranted by the present state of our knowledge. It is believed, however, that the present mapping is sufficiently accurate to give a fair idea of the distribution of the various igneous and metamorphic rocks of the Piedmont—a matter which has not previously been attempted. The divisions used consist of groupings of formations that have been distinguished in the detailed work in the Appalachian Mountains. I have described these in full in folios of the United States Geological Survey and my summary of them is given in Survey Bulletin 360 ("Pre-Cambrian geology of North America," by Van Hise and Leith), page 701.

CHAPTER III.

CAMBRIAN AND LOWER ORDOVICIAN.

Color, purplish red.
Symbol, 18.
Distribution: General throughout the continent. (See fig. 5.)
Content: In general comprises Lower Cambrian (Georgian) to Lower Ordovician (Beekmantown), inclusive, or so much as may be present; in the Appalachian zone, Virginia to Alabama, includes conformable formations below the Olenellus horizon; Ocoee group and other terranes; Brevard, Weverton, Harpers, and others not named. In the Cordillera includes upper Ordovician and Silurian where they are present and the bands of color are too narrow for distinct mapping.

Cambrian and lower Ordovician areas.

H 12. BISBEE DISTRICT, ARIZONA.

In southeastern Arizona, in the Bisbee district, Ransome [658] distinguishes the probable equivalents of the Tonto group as the Bolsa quartzite and Abrigo limestone. He says:

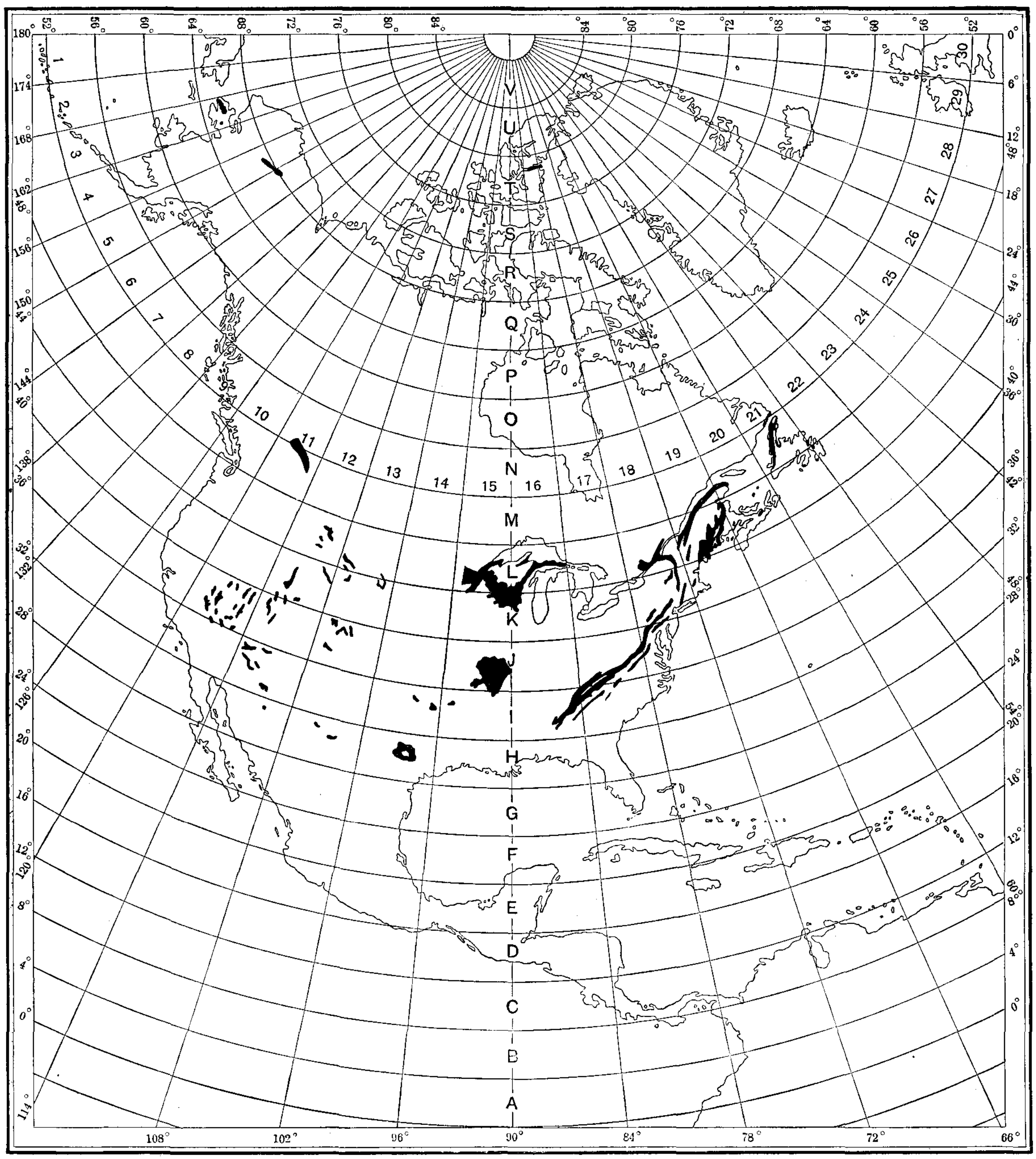

FIGURE 5.—Sketch map showing the distribution of Cambrian and lower Ordovician rocks represented on the geologic map of North America and the key to references in the text.

The Bolsa quartzite is constant in its lithological character and is readily recognized wherever it occurs. The base of the formation is exposed at many places along Escabrosa Ridge. It is invariably marked by a bed of conglomerate from 6 inches to a foot in thickness, resting upon the eroded edges of the pre-Cambrian schists. Most of the pebbles of this basal conglomerate are composed of white vein quartz and are rarely over 3 inches in diameter. This conglomerate is overlain by hard pebbly grits in beds from 10 to 20 feet in thickness, the change from conglomerate to grit being, as a rule, not very definitely marked. The scattered pebbles in these thick-bedded grits are usually white quartz, but their matrix frequently contains abundant small fragments of pink feldspar mingled with the predominant quartz grains. Cross-bedding is often a conspicuous feature in the lower part of the formation. The pebbly grits in turn pass upward into thinner bedded, more vitreous, fine-grained quartzites showing no feldspathic material, which are conformably overlain by the Abrigo limestone.

The Bolsa quartzite was deposited during an advance of the sea over a subsiding basement of pre-Cambrian crystalline rocks which had been worn down by long-continued erosion to a nearly level plain. The arkose character of some of the lower beds of the quartzite shows that this ancient crystalline basement is composed in part of granitic rocks. None of the latter, however, are exposed in the Bisbee quadrangle, where fine-grained sericitic schists are the only pre-Cambrian rocks known. The basal conglomerate of the Bolsa formation is a littoral deposit made up of the most durable materials of this schist terrane, chiefly fragments of quartz derived from the numerous irregular veins that occur within the schists, while the finer particles of quartz and flakes of mica were probably transported by currents into deeper water and contributed to the formation of the overlying quartzite beds. The general nature of the Bolsa formation, particularly the pebbly and cross-bedded character of its lower portion, indicate that deposition took place in comparatively shallow water, with probably a gradual increase in depth as the upper beds were laid down. The conditions were apparently not favorable to marine life, as no organic remains have yet been found in the Bolsa quartzite.

As no fossils have been found in the Bolsa quartzite its exact geological age is not directly determinable. It will presently be shown, however, that the Bolsa formation is conformably overlain by the Abrigo limestone which contains a middle Cambrian fauna. It is thus without very much doubt, the stratigraphic equivalent of the Tonto sandstone of the Grand Canyon section, considered by Walcott as also included within the middle Cambrian, the lower Cambrian being there represented by the unconformity between the Tonto and the Grand Canyon series. It is possibly the equivalent of at least the lower part of the thicker and more varied Apache group of the Globe district in central Arizona, about 110 miles north-northwest of the Bisbee quadrangle, and also correlated provisionally with the Tonto group. * * *

The Abrigo limestone is named from Abrigo Canyon, 3 miles southwest of Bisbee, where the beds composing the formation are well exposed. Like the Bolsa quartzite, the Abrigo limestone occurs principally in the northwestern part of the quadrangle, although a few small areas are found within the attenuated belt of Paleozoic rocks extending southeastward past Gold Hill toward Glance Creek. The most satisfactory occurrence, and the only one in the quadrangle where the entire sequence of the beds from base to top may be studied in a single continuous exposure, is that of the Mount Martin section, 1½ miles west of Bisbee. As measured in this section the Abrigo limestone is 770 feet thick. It rests conformably upon the Bolsa quartzite and is overlain by the Martin limestone (Devonian). * * *

The Abrigo limestone is distinguished from the other calcareous formations of the local Paleozoic section by its prevailing thin bedding, and particularly by a conspicuous laminated structure produced by the alternation of thin irregular sheets of chert with layers of gray limestone. The layers of limestone may be 2 or 3 inches in thickness, while those of chert are usually less. This cherty lamination is eminently characteristic of the Abrigo limestone in the Mule Mountains and serves as a ready means of identifying the beds belonging to this formation within the various fault blocks into which the region is dissected. Chert also occurs occasionally in the Devonian and Carboniferous limestones of the Bisbee quadrangle, but as irregular bunches, never in the form of the thin, more or less anastomosing sheets peculiar to the Cambrian Abrigo limestone.

The beds are commonly from 1 to 2 feet in thickness. Their dominant color as seen in large exposures is dark greenish yellow, whereas the prevailing tint of the overlying Martin limestone is dark gray, and of the still higher Escabrosa and Naco limestones white or light gray.

In the typical Mount Martin section the Bolsa quartzite is immediately overlain by about 40 feet of thin-bedded, very cherty limestones, which break up, on weathering, into thin rusty plates. Above this occur a few beds of gray limestone up to 2 feet in thickness, alternating with fissile yellowish calcareous shales, and with laminated cherty beds, such as have just been described. The upper 100 feet of the formation is made up of rather soft, sandy, thin-bedded gray limestone, with one bed of harder gray limestone 6 feet in thickness about 40 feet from the top. The upper limit of the Abrigo formation is defined in the Mount Martin section by a bed of pure white quartzite about 8 feet in thickness.

This quartzite is a persistent stratum and is always found immediately underlying the Martin limestone, which carries Devonian fossils. Its thickness, however, is variable and it sometimes grades downward into the upper sandy limestones of the Abrigo formation. It apparently records the consummation of an increasing supply of sandy sediments during the later phases of the deposition of the Abrigo limestone and contrasts with the more purely calcareous beds of the overlying Devonian formation. * * *

The fossils collected from the Abrigo limestone were submitted to Dr. Charles D. Walcott, who kindly examined them and reported that they are middle Cambrian, indicating a fauna closely resembling that of the middle Cambrian of Texas.

H 13. TRANS-PECOS TEXAS.

With reference to the Cambrian and Lower Ordovician in the district about El Paso and to the southeast, Richardson[668] states:

The formations which are the subject of this paper outcrop in the Franklin and Hueco mountains in the El Paso quadrangle, and in the Sierra Diablo, Delaware Mountains, and associated groups of hills in the Van Horn quadrangle. These two quadrangles, which have recently been mapped by the United States Geological Survey, are situated about 60 miles apart and they include practically all of the known occurrences of lower Paleozoic rocks in trans-Pecos Texas. The following table summarizes the Paleozoic formations in the El Paso and Van Horn quadrangles:

Paleozoic formations in the El Paso and Van Horn quadrangles, Texas.

El Paso quadrangle.		System.	Series.	Van Horn quadrangle.	
Formation.	Thickness (feet).			Thickness (feet).	Formation.
Absent.		Carboniferous.	Permian? (Guadalupian).	500+	Capitan limestone.
Absent.		Carboniferous.	Permian? (Guadalupian).	2,000+	Delaware Mountain formation.
Hueco limestone.	3,000	Carboniferous.	Pennsylvanian.	2,500+	Hueco limestone.
Absent.		Carboniferous.	Mississippian.		Absent.
Absent.		Devonian.			Absent.
Fusselman limestone.	1,000	Silurian.	(Niagara [fossils]).		Absent.
Montoya limestone.	250	Ordovician.	Upper and Middle Ordovician.	250	Montoya limestone.
El Paso limestone.	1,000	Ordovician.	Lower Ordovician.	750	El Paso limestone.
Bliss sandstone.	0–300	Cambrian.	Saratogan or Acadian.	0–700	Van Horn sandstone.

The main occurrence of the Bliss sandstone is along the eastern slopes of the Franklin Mountains, but the considerable faulting to which the range has been subjected causes its distribution to be very irregular. The Bliss is a massive, fine-textured, brownish sandstone that varies from a few feet to slightly more than 300 feet in thickness. The lower beds are indurated and are practically quartzites and at the base of the formation the strata are coarser textured, locally are conglomeratic and contain pebbles of the underlying rocks. The sandstone is composed of small grains of quartz embedded in a matrix of sericite and kaolin. In places the Bliss sandstone is in contact with granite of post-Carboniferous age and elsewhere it rests on rhyolite porphyry, of which it contains rounded pebbles in the basal beds. In the central part of the Franklin Mountains the sandstone thins out and locally disappears, and the overlying limestone, containing a basal conglomerate, lies directly on the rhyolite porphyry.

Annelid borings both perpendicular and parallel to the bedding occur abundantly in the Bliss sandstone. Other fossils are rare, but in places in the lower strata some brachiopod shells have been found. Of these Mr. Walcott has identified *Lingulepis acuminata*, *Obolus matinalis* (?), and fragments of Lingulella which determine the Cambrian age of the rocks and indicate that either the upper or middle division of the system is here represented.

The Van Horn is a medium to coarse-textured cross-bedded sandstone that is banded with thin lenses of conglomerate. The formation is of a prevailing brick-red color in its lower part, which becomes paler toward the top, where the color fades away and the sandstone is white. The conglomerate lenses vary from a few inches to about a foot in thickness and are irregularly distributed throughout the formation. At the base the pebbles are composed of fragments of the underlying rocks and consist of quartz schist, fine-textured red sandstone, cherty limestone, porphyry, and quartz, while the conglomerate in the upper part of the formation consists chiefly of well-rounded quartz pebbles. The sandstone likewise varies in composition, its lower part being composed of quartz and decomposed feldspar grains while the upper portion is prevailingly quartzose. The formation varies from a few feet to 700 feet in thickness and averages about 400 feet.

The Van Horn sandstone unconformably overlies highly tilted metamorphosed rocks and is overlain in places by the El Paso limestone (Ordovician), and elsewhere by the Hueco limestone (Carboniferous). The upper part of the formation contains numerous annelid borings and fucoid-like remains, but no characteristic fossils have been found in the sandstone and its age therefore is undetermined.

The presence of sandstone at the base of the Paleozoic section in southwestern United States has been noted wherever observations have been made, and it is suggested that the Bliss and Van Horn sandstones are the probable equivalent of the Tonto sandstone of the Grand Canyon, the Bolsa quartzite of Bisbee, the Coronado quartzite of Clifton, the Reagan sandstone of Oklahoma, and the Cambrian sandstone of the central Texas Paleozoic area.

The El Paso limestone outcrops in the Franklin and Hueco mountains in the El Paso quadrangle and in Beach and Baylor mountains in the Van Horn quadrangle. The formation is typically a massive gray magnesian limestone which contains the same fauna in both regions. In the El Paso area the formation is about 1,000 feet thick, the lower 100 feet of which is characteristically arenaceous and weathers brownish. A distinctive feature of the middle portion of the formation is the presence of thin connected nodules of brown chert arranged in irregular steaks parallel to the bedding. This limestone lies apparently conformably on the Bliss sandstone, but, as already stated, in the central part of the Franklin Mountains the Bliss sandstone is locally absent and the El Paso limestone rests directly on pre-Cambrian (?) rocks with a basal conglomerate varying up to 20 feet thick composed of rounded pebbles of rhyolite porphyry in a calcareous matrix. In the Van Horn quadrangle the El Paso limestone does not contain the cherty layers that are characteristic of the middle parts of the formation in the Franklin Mountains, and 50 feet above the base of the formation a thin bed of white sandstone is present. In this region there are indications of an unconformity at the base of the limestone marked by a slight undulatory contact between the El Paso and Van Horn formations.

Mr. Ulrich reports that the fossils obtained from the El Paso limestone in both the El Paso and Van Horn quadrangles represent essentially the same Beekmantown fuana. Most of the species are undescribed, but all are of unmistakable types. The more characteristic forms are the following:

Calathium sp. nov. (coral-like sponge), Maclurea? sp. nov. The small hornlike opercula are very common. The shell itself is of the type of *M. oceana* Billings. Solid siphuncles of endoceratoid cephalopod, evidently a close ally of *Cameroceras brainardi*. Besides these there are a number of less easily recognized small gastropods.

H 14. LLANO DISTRICT, TEXAS.

In Mason, Llano, and Burnet counties, Tex., the pre-Cambrian rocks are unconformably overlain by Upper Cambrian sediments. Shumard [854c] originally described the section. During 1908 and 1909 detailed surveys have been carried out by A. C. Spencer and Sidney Paige, and the following description is abstracted from notes furnished by them.

UPPER CAMBRIAN.

The Upper Cambrian of this area is essentially the equivalent of the Reagan sandstone in Oklahoma, agreeing with that formation not only in age but in lithologic succession.

The Cambrian sediments rest upon a complex of metamorphic rocks which include schists, gneisses, and enormous masses of granitic intrusives.

The Cambrian beds have been divided into three formations, namely, from the base upward, the Hickory sandstone, the Cap Mountain formation, and the Wilberns formation.

Conglomerate and sandstone reaching a maximum thickness of about 250 feet constitute the lower formation. Following, but with a gradual transition from sandstone to limestone, are beds consisting predominantly of limestone, capped by 15 to about 75 feet of cross-bedded glauconitic sandstone. These strata, about 90 feet thick, constitute the second formation. The third formation includes limestones and shales from 170 to 220 feet thick, the shales occupying approximately the upper third of the formation.

The following section is characteristic of the lithology of the formations, though the thickness of the basal beds varies considerably, owing largely to the unevenness of the pre-Cambrian floor.

Section of Hickory, Cap Mountain, and Wilberns formations on Packsaddle Mountain.

	Feet.
Grayish slabby, slaty crystalline limestone; very little glauconite; more massive beds toward top of peak	40
Thinner-bedded crystalline limestone; some glauconite	20
Heavy-bedded pink limestone, somewhat oolitic; contains some glauconite	10
Yellow and white sandstone with small percentage of glauconite, grading up into pink sandy limestone	14
Glauconite sand and coarse quartz sands; iron concretions on surface	6
Massive-bedded grayish-brown crystalline limestone, somewhat oolitic; glauconite increasing toward top	35
Flaggy subcrystalline limestone with small amount of glauconite; yellowish discolorations	30
Grading into purer limestone. Several red bands of sandstone alternating with beds of hard subcrystalline limestone and fine-grained whitish sandy limestone; crystalline limestone contains some glauconite grains	35
Thin-bedded calcareous dirty-white sandstone, grading upward into very fine-grained hard reddish-brown sandstone. Weathers rough but generally shows a brown sand on surface. Broken surface shows reddish-brown sandstone with crystalline faces of calcite. Makes cliffs which weather irregularly and show bands of red, yellow, and dirty-brown cross-bedded sandstone alternating with very calcareous beds	200
Ledge of calcareous sandstone, conglomeratic and containing a few shell fragments, also few glauconite grains	2
Massive and thin-bedded red and yellow sandstone, with some shale, probably covered	35

	Feet.
Covered; mostly sandy shales. At bottom a 2½-foot bed of red conglomerate sandstone with flat pebbles; a few shell fragments in this ledge	10
Mostly fine-grained dirty-white, brown, yellow, and red sandstone	45
Massive pink and white, conglomerate sandstone, with white quartz pebbles mostly one-half inch in diameter; cross-bedded; prevailingly reddish tones. Near top grains are smaller and more rounded. Secondary infiltration of quartz in cross fractures gives honeycomb structure on weathering	85
	567

It will be noted that the sections are not complete. The following measurements include the upper portion of the Cambrian, or the Wilberns formation:

Generalized section of Wilberns formation on east bank of Colorado River about one-third mile above old Tanyard Crossing.

Ellenburger limestone at top.	Feet.
Impure limestone	30
Heavy-bedded limestone containing abundant exceedingly small shell fragments, also abundant minute globular remains	10
Impure sandy limestone having conglomerate aspect in the hard layers	10
Débris-covered slope	10
Débris-covered slope; contains layers of shale conglomerate consisting of cemented flat fragments of thin shale accompanied by layers containing bowlder-like forms composed of limy mud	60
Slope of impure limestone layers breaking down to 1 inch in thickness, carrying fine sand, weathering light brown	30
Pink flaggy semicrystalline limestone	10
Crystalline and semicrystalline bedded limestone, weathering into hard layers	11
Heavy layer of mottled light-brown impure limestone	4
Alternating beds of crystalline limestone, 4 inches to 1 foot thick, with crinkly-weathering beds that are slightly more sandy, the whole carrying finely disseminated glauconite, locally concentrated in layers	23
Base, recent silt of Colorado River.	

Another section of the Wilberns is as follows:

Generalized section of Wilberns formation near head of Little Llano River.

Ellenburger limestone at top.	Feet.
Calcareous shale, with subcrystalline to crystalline oolitic limestone bands; alternating hard and soft	39
Thin flaggy limestone with some sandy layers	10
Shale and shaly limestone and subcrystalline layer with shell fragments	11
Conglomerate containing slightly rounded half-inch to 1-inch pebbles, weathering yellow, with limestone matrix	1
Greenish-gray shales	6
Two beds of conglomerate, about 8 inches each, separated by 8 inches of shale; small, slightly rounded calcareous pebbles weathering yellow	2
Fine-grained greenish-gray shaly limestone	3
Conglomerate of long, flat, thin, shaly calcareous fragments, overlain by fine-grained calcareous muds	3
Greenish shaly limestone	5
Conglomerate composed of small, slightly rounded calcareous pebbles weathering yellow	1½
Light-gray shaly limestone, weathering to a covered slope	25
Thicker-bedded gray crystalline limestone, with scattered grains of glauconite; a few hard layers about 9 inches thick	20
Light-pink to gray thin-bedded flaggy crystalline limestone, mottled brown by fine-grained sand	17
Pink and gray crystalline limestone; glauconite grains at base	6
Pinkish subcrystalline limestone	7
Sandy limestone and a little glauconite	2
Base at top of glauconite sand.	
	158½

This section was measured in dipping beds and the total thickness as stated is believed to be somewhat short of the actual thickness. The section is of value, however, as indicating the succession.

Certain characteristics of these formations deserve a more detailed description.

A wide diversity exists in the basal members. Locally they are fine-grained, cleanly washed sands; elsewhere they are coarse conglomerates with pebbles ranging from 6 to 8 inches in diameter. A marked relation was noted between the underlying pre-Cambrian and the basal layer. Certain coarse granites rich in pink feldspar have produced a pinkish-white conglomerate, in which the rounded quartz grains average a quarter of an inch in diameter and which contains numerous angular fragments of feldspar. A clean white cement consisting of small quartz grains and feldspar fragments with calcium carbonate binds the whole. In another place a coarser conglomerate stained red contains subangular quartz fragments as large as half an inch and feldspar fragments an inch long. A fine-grained quartz cement which included particles of iron oxide was the matrix. In another place a coarse sandstone containing 1 to 2 inch fragments of hematite makes up the basal layer, the iron having been derived from the underlying schists probably in the form of magnetite and later altered to hematite. In yet another place where the underlying formation is rich in pegmatite dikes, large angular masses of quartz are abundant in the lower beds. Here and there the lower member, where resting on a coarse-grained granite surface, is a granite arkose.

In different localities the conditions of sedimentation undoubtedly varied, and this variation is expressed in the inadequacy of a hard and fast line between the Hickory sandstone and the Cap Mountain formation. The sandstones become gradually more limy, until the beds are predominantly limestone. In drawing a boundary line between two such formations, it is often difficult to decide upon a satisfactory line, though taken as a whole the two sets of beds fully justify such a separation.

The distribution of glauconite in the Cambrian strata is interesting. Beginning in the Cap Mountain formation, it appears in scattered grains in the pure limestones and reaches its greatest development in cross-bedded sandstones, the top of which is used as the boundary between the Cap Mountain formation and the Wilberns formation. Above this sand the glauconitic material gradually disappears. Though where observed in limestones the glauconitic grains exist essentially as such, in the sandstones the material is more likely to form the matrix in which the well-rounded clean quartz grains are embedded.

UPPER CAMBRIAN AND LOWER ORDOVICIAN.

The rocks overlying the Wilberns formation are of late Cambrian and early Ordovician age and have not been subdivided. They have been given the local name Ellenburger limestone. They are regarded by Ulrich as equivalent to a small portion of the rocks of similar age in the Missouri section and also to the lower part of the Arbuckle limestone of Oklahoma. In the greater number of places where the base of the Ellenburger limestone was observed, it is apparently conformable with the Wilberns formation. Many observations were made where no unconformity could be detected and where an apparent transition between the two formations could be followed. It must be noted, however, that the basal beds of the Ellenburger limestone vary in texture and appearance, and that this phenomenon is in itself a suggestion of unconformity. Any decision, therefore, must for the present remain tentative.

At the top of the Ellenburger limestone there is usually, though not always, a conglomerate limestone bed, succeeded by the lowest portion of the Pennsylvanian (upper Carboniferous). The upper surface of the Ordovician on Doublehorn Creek just south of the road crossing half a mile north of the mouth of Cordova Creek gives an excellent example of the pre-Carboniferous surficial conditions.

The upper 25 feet of the Ordovician is composed of large angular blocks, very irregularly disposed, revealing a condition of peculiar surface breakage prior to submergence beneath the sea. As no coarse sediment is present, shallow, quiet Carboniferous seas must be inferred. The same type of breakage may locally be observed in stream channels and must not be confused with the basal conglomerate. Beds including the Mississippian (lower Carboniferous), Devonian, Silurian, and later Ordovician are therefore absent.

As the Ordovician rocks lie immediately above the Cambrian, they occur at the crest of the Paleozoic scarp (unless faulting has intervened) and form the greater part of the Paleozoic surface in Llano and Burnet counties.

Complete sections of the Ellenburger limestone are not easy to obtain. The general massiveness of the beds and the gentle folds and faults combine to prevent continuous record. Thicknesses up to 600 feet may be observed in the bluffs of the Colorado between Tanyard Crossing and Deer Creek. It is probable that the formation is 1,000 feet or more thick.

The following section represents the upper portion measured near the mouth of Flat Rock Creek, Burnet County.

Section measured in the upper part of the Ellenburger limestone near the mouth of Flat Rock Creek.

	Feet.
Carboniferous	50
Grayish crystalline limestone with much chert	15
Crystalline limestone, brown and gray, sugar-grained texture, with light-colored chert; coarsely crystalline near top, greenish stains in calcite crystals	25
Massive, hard, smooth-textured beds at base, grading up into brown crystalline and coarse gray limestone; some chert	22
Alternating sugary and smooth-grained beds; at top a bed of cherty limestone, weathering honeycomb fashion	11
Alternating sugary and smooth-grained beds; but little chert	11
Brown, sugary banded limestone with some chert	5
Smooth light-gray limestone with whitish chert, weathering bluish gray; smooth rounded pieces simulating waterworn bowlders on surface	50
Light-gray smooth limestone, conchoidal fracture; contains some chert which weathers out into rough surface; alternating thin and massive	22
Brown, sugar-grained limestone containing layer of white chert	2
Irregularly bedded dark and light brown, sugar-grained limestone; tesselated weathering in cliff.	11
Brown and gray crystalline limestone; lowest portion contains some chert	3½
Rough-weathering, somewhat concretionary limestone, sugar-grained, brown and mottled pink	2
Massive beds of brownish-gray smooth limestone, irregular fracture	4
Gray crystalline limestone, massive bedded, sugar-grained, mixed with smooth noncrystalline variety	5½
Brown and light-colored fine sugar-grained crystalline limestone, mostly thin and irregularly bedded	17
Local bowlder bed resembling conglomerate, sandy material	1½
Brown and light-colored fine sugar-grained crystalline limestone, mostly thin and irregularly bedded but makes jagged cliff	27½
Bottom at level of Colorado River.	

Certain characteristics of the Ellenburger limestone are pronounced. The bedding as a rule is ill defined, preventing correlation by lithologic units. Repetitions of coarse or fine grained phases of the limestone occur in alternating succession, but the position of individual beds, because of their great similarity, was not determined. An abundance of white and yellow chert characterizes the series, though some layers are free from this material. Where relief is considerable and dissection of the plateau has taken place, the surface of the formation is exceedingly rough, and in general the formation may be recognized by this irregularity of surface. This condition does not apply to the high rolling grass lands to the north. In certain layers the chert has evidently been dissolved and replaced by crystalline quartz filling irregular cavities.

I 12. ARIZONA.[a]

The Tonto group is recognized by Reagan,[663] who states:

The Tonto formation is composed of coarse to fine grained, often cross-bedded vitreous sandstones and sandy shales, varying in color from brown to red, purple, and white. The formation is the surface rock of a large area. The Sierra Ancha Mountains are capped with it. It is exposed all around the rim of the Tonto-Cherry Creek basin and continues on the east from that basin beyond the headwaters of Oak Creek in the latitude of Chiddessky on Canyon Creek. From this point it extends in an ever-widening strip along the plateau south across Salt River to the Apache and Nantan mountains. Patches of it also occur in the Apache and Pinal mountains. In short, the Tonto exposures completely encircle the Archean and Algonkian areas of the Salt River and Canyon Creek region. That it once covered the entire Archean and Algonkian area is attested by the vitreous sandstone points and buttes scattered over the country, among which are points Chiddesche and the Twin and Sombrero buttes.

I 13. NEW MEXICO.

Lindgren[542a] gives the following account of the Cambrian and Ordovician of New Mexico:

The pre-Cambrian history of the Territory, though imperfectly known, indicates a period of sedimentation followed by mountain building and igneous intrusion, which was in turn succeeded by long-continued erosion that exposed the intrusive cores. At the base of the Paleozoic section is a strongly pronounced unconformity. In general it has a fundamental appearance, as, for instance, where sandstones and limestones rest horizontally on vertical gneisses.

In the whole of northern New Mexico the Pennsylvanian or upper Carboniferous rests directly on the pre-Cambrian, and these conditions appear to continue as far south as Socorro. Cambrian rocks were first definitely recognized in New Mexico in 1905 by C. H. Gordon,[b] who found fossils of this age in the Caballos Range, along the thirty-third parallel. The thickness of the Cambrian quartzite and shales, which here underlie the Ordovician limestone, is only 55 feet. In the Mimbres Mountains, near Kingston, the thickness is 75 feet, and in the Florida Range, southeast of Deming, 135 feet of quartzites were measured in the same stratigraphic position. Toward the west, near Silver City, L. C. Graton measured a thickness of nearly 1,100 feet of quartzitic sandstones, including some strata of limestone. Across the Arizona line in the same latitude Waldemar Lindgren[c] found 280 feet of quartzites, with some shales, resting on granite underneath the Ordovician and obtained near the top of these rocks some fossils suggestive of the Cambrian. In the Franklin Mountains G. B. Richardson[d] found 150 feet of sandstone containing Upper Cambrian fossils. At Bisbee, in southern Arizona, F. L. Ransome measured 400 feet of nonfossiliferous, probably Cambrian sandstone, covered by 750 feet of fossiliferous Middle Cambrian limestone. This is the only known occurrence of heavy Cambrian limestone in this region, although it is possible that some of the limestone which in southwestern New Mexico covers the quartzite may also be of Cambrian age.

All this indicates beyond doubt that during the period preceding the Cambrian the whole of western New Mexico, so far as available exposures permit a judgment, was a land area which gradually became planed down from a very high to a more moderate relief. During the Cambrian period the sea appears to have advanced northward, but only to about latitude 33° 30′, where the Cambrian deposits seem to thin out. The greatest thickness of sediments is found

[a] See also I-J 12, Grand Canyon, Arizona (pp. 88–89).

[b] Gordon, C. H., and Graton, L. C., Lower Paleozoic formations in New Mexico: Am. Jour. Sci., 4th ser., vol. 21, 1906, pp. 390–395.

[c] Clifton folio (No. 129), Geol. Atlas U. S., U. S. Geol. Survey, 1905.

[d] Tin in the Franklin Mountains, Texas: Bull. U. S. Geol. Survey No. 285, 1906, pp. 146–149.

at Silver City. In the Caballos Range there appears to exist a gradual transition between quartzitic sandstone and underlying granite, suggestive of secular decay of the granite, preceding deposition.

It is interesting to note that the Ordovician, Silurian, Devonian, and lower Carboniferous (Mississippian) are likewise lacking in northern New Mexico, and that they begin to appear prominently at about latitude 33° 30′; some exposures of the Mississippian have been recognized at about the latitude of Socorro, or 34°. * * *

The Ordovician rests conformably on the Cambrian and consists of 450 to 1,200 feet of usually cherty limestone, very poor in fossils. It has been recognized in the Caballos Range, in the Mimbres Range, and at Silver City and other places.

I 14–15. OKLAHOMA.

In the Arbuckle Mountains of Oklahoma the Upper Cambrian and Lower Ordovician are represented by the Reagan sandstone and Arbuckle limestone. Taff [808] gives the following descriptions:

In pre-Cambrian [late Cambrian] time the region of the Arbuckle uplift was submerged, and the Reagan sandstone, the lowest Cambrian sediment, was laid down upon the eroded surface of the granite and porphyry as a beach and off-shore deposit. The pre-Cambrian land, composed of igneous rocks, possessed some relief at the time of submergence, as is shown by the uneven contact of the igneous rocks with the Reagan sandstone and also by the variable nature of the sandy deposits. The land in the immediate vicinity of the uplift was soon submerged, however, as is shown by the presence of fossiliferous horizons representing the same mid-Cambrian time in the upper member of the Reagan sandstone wherever it is exposed.

CAMBRIAN ROCKS.

Reagan sandstone.—This sandstone is a variable formation, as regards both its thickness and the nature of its materials. In the eastern part of the uplift, in contact with the granite, it varies in thickness from a few thin beds to approximately 500 feet, with an average thickness of about 300 feet. In its thickest portion, at the western and of the granite, the lowest beds are composed for the most part of coarse arkose grit. The following is a record of the thickest section of the Reagan sandstone as it occurs at the western end of the granite area, beginning at the base:

Section of Reagan sandstone.

	Feet.
Quartzite and arkose conglomerate, composed of poorly sorted granitic materials	30
Coarse grit and sand, with some clay and green sand in upper part, generally well stratified	370
Thin-bedded and laminated sandstone, becoming calcareous in the upper part	60

This section is followed by generally thin-bedded siliceous limestone and shaly strata through several hundred feet to the top of the middle Cambrian. The calcareous beds at the top and above the Reagan contain numerous fossils of well-defined middle Cambrian forms.

The Reagan sandstone overlying the porphyry in the southern sides of the East and West Wooded hills has a section similar to that in contact with the granite. The coarse materials which make lentils of conglomerate near the base, however, are here composed of porphyry and associated dike rock. In the upper part of the formation greenish clays are probably more abundant, and the green sand continues higher up into the more calcareous beds. As in the occurrence near the granite, here the calcareous rocks contain numerous middle Cambrian fossils.

CAMBRO-ORDOVICIAN ROCKS.

Arbuckle limestone.—The Arbuckle limestone, with the exception of thin, shaly strata and occasional siliceous and cherty beds, is composed entirely of light-blue and white limestone and cream-colored to white crystalline dolomite. The section ranges in thickness from 4,000 to 6,000 feet, and includes the whole of the upper Cambrian and the Calciferous of the Ordovician. From the base of the formation upward to the top of the middle Cambrian the rocks are composed of thin-bedded and, in part, intraformational conglomerate and shaly limestones. While pursuing stratigraphic field work in connection with the study and collection of the fossils, Mr. E. O. Ulrich noted the occurrence of what appeared to be shaly lentils at the top of the middle Cambrian, indicating to his mind an unconformity between the upper and lower Cambrian.

Beginning with the upper Cambrian the rocks are composed of massive and hard, pink to yellow crystalline limestone and dolomite, which weather to various shades of brown and almost black. Rocks of this character have a thickness of 500 to 600 feet, and are followed by lighter-colored massive dolomite and limestone, without any indication of time interval, up into the Ordovician. Beginning approximately 450 feet below the top of the Arbuckle formation the limestones become more thinly bedded and are associated with thin and, in places, shaly strata. Very near the top occasional sandy beds occur.

In the massive beds in the central part of the formation fossils are found, but not in great abundance. Near the top, however, where the rocks become argillaceous, fossils are more common. Fossils of a number of genera, mostly undescribed, occur in the upper 1,250 feet of the Arbuckle limestone.

The Reagan sandstone and the Arbuckle limestone in the Wichita Mountains of Oklahoma are described by Taff[808] as follows:

The Reagan sandstone is the lowest Cambrian formation in the Wichita region, and it rests on the eroded uneven surface of the granite porphyry, from which most of its materials have been derived. * * *

The Reagan sandstone is approximately 300 feet thick and is composed of hard and soft sandstone, grit, conglomerate, shales, and siliceous shell limestones. The section of the formation is essentially the same as in the western end of the Arbuckle Mountains. In each case porphyry is beneath it, and the limestone which overlies the Reagan is of the same nature and contains the same fossil fauna. In both localities the Reagan formation is made up of conglomerate composed of porphyry pebbles and included basic rocks, gritty light-brown to gray and greenish sandstones, greenish clay shales, and siliceous limestones, interstratified. The limy layers contain many species of Cambrian fossils, which were carefully collected, but which have not yet been thoroughly studied. The conglomerate occurs invariably near the base as local beds or lentils, while the calcareous sandstone and limestone beds are without exception in the upper part of the formation. * * *

Above the Reagan formation in conformable succession is a great limestone section essentially the same as the Arbuckle formation in the Arbuckle Mountains, where the lower part, practically the lower third, was found to be Cambrian and the upper two-thirds Ordovician in age. Near the transition zone, between the rock of the two periods, very few fossils have been found, so that precise distinctions as to age can not be made at the present time. The same conditions of deposition seem to have occurred in the Wichita region as in the Arbuckles, and the rocks must be classified in the same manner. There seems to be no reason to doubt that the formation is continuous from one region to the other beneath "Red Beds" deposits.

E. O. Ulrich contributes the following note regarding the Reagan sandstone:

The Reagan sandstone includes most of the Cambrian deposits exposed in the uplifts of the Arbuckle and Wichita mountains, in south-central and southwestern Oklahoma, respectively. The formation as described by J. A. Taff[a] and as observed by me consists of two members. The lower is a brown sandstone, coarse grained and ill bedded below; finer grained, laminar, and slightly calcareous above; varying greatly in thickness because it rests directly on the uneven pre-Cambrian granite floor. The upper member, though not sharply separated

[a] Tishomingo folio (No. 98), Geol. Atlas U. S., U. S. Geol. Survey, 1903.

from the lower, is the more persistent and is readily distinguished lithologically, being composed of interbedded thin glauconite limestones and thin layers of greenish shale, together making up a thickness of about 80 feet. Some of the limestone layers in the upper half are conglomeratic and many of those in the lower half are filled with fossils. This upper member is an easily recognized and widely distributed division.

A basal sandstone, overlain by a thin-bedded limestone carrying glauconite and containing the same fauna as that found in this upper member of the Reagan sandstone, occurs at the base of the eo-Paleozoic column in the Llano and Burnet quadrangles, in central Texas. Very similar, apparently contemporaneous deposits and faunas are found also in New Mexico, Arizona, and the Bighorn Mountains of Wyoming. Further, the same fauna, though the rocks depart somewhat lithologically, is yet easily recognized in the Lamotte sandstone and Bonneterre limestone, perhaps also in the Elvins formation of the Ozark uplift and in the "St. Croix group" of the upper Mississippi Valley.

I 16. ALABAMA AND GEORGIA.[a]

The Cambrian of the southern Appalachian Valley region is represented by the Weisner quartzite, Beaver limestone, and Rome formation, by the Conasauga shale, and by part of the Knox dolomite. The upper part of the latter is of Lower Ordovician age. Hayes[428a] described these formations as follows:

The Weisner quartzite includes the oldest rocks that come to the surface within the limits of the Rome quadrangle. It is confined to the extreme southwest corner; and since it contains the most resistant rocks, the areas of its outcrop are marked by the greatest elevation within the quadrangle—that is, Indian Mountain. The most prominent member of the formation is a hard, vitreous quartzite, but it contains also conglomerates, sandstones, and sandy shales. The coarser elements of the formation constitute a series of lenses, variable in extent and thickness, which are interbedded with the finer-grained rocks. The latter make up the bulk of the formation, although they are much less prominent than the more resistant coarser beds. The quartzite when exposed to atmospheric agencies breaks up into angular blocks, which nearly everywhere cover the surface, and exposures of the beds in place are rarely seen. For this reason, and also because of the enormous faults which intersect the formation, its thickness is difficult to determine. On a section from Bluffton to Rockrun its apparent thickness is over 10,000 feet, but it is by no means certain that this apparent thickness is not due in some measure to repetition by faulting and the minute folding of the less resistant beds. The section is limited by a fault on the west, and the foundation upon which the formation was originally deposited is nowhere exposed. Some of the conglomerate beds contain numerous feldspar pebbles, showing that the material composing the conglomerate was derived, in part at least, from granites. It probably came from a source to the southeast, and the beds which form Indian Mountain have the appearance of massive delta deposits. No fossils have as yet been found in these beds, but their relations to adjacent formations are such that there is little hesitation in correlating them with the lower Cambrian.

The beds of the Weisner quartzite generally dip to the southeast and, where not limited by a fault, pass under a narrow belt of red clay soil containing many angular fragments of quartzite and a few masses of cellular chert. This red soil is derived from the decay of the Beaver limestone, which is itself rarely seen. It is a gray, semicrystalline, dolomitic limestone, generally massive, but sometimes slightly shaly. The exposures of this limestone are so infrequent that its thickness can not be determined, but, judging from the width of its outcrop and the prevailing dip of the adjoining beds, it is probably between 800 and 1,200 feet thick. The principal areas of the Beaver limestone are in the vicinity of Indian Mountain, but a small area is found at a considerable distance from any outcrop of the quartzite, a few miles southwest of Rome.

[a] See also I-J 16-17, Tennessee and North Carolina (pp. 89-98).

The Rome formation consists of thin-bedded, fine-grained sandstones and sandy shales. Its most striking peculiarity is the brilliant coloring of its beds. The prevailing colors are various shales of red, purple, green, yellow, and white. The changes in color are often very abrupt and the exposures of the formation present a distinctly banded appearance. The base of the formation, where it is found resting upon the underlying Beaver limestone, consists of thin-bedded red sandstones, and the top of the formation is characterized by a rather heavy bed of white sandstone. Northeast of Rome the upper portion of the formation consists chiefly of shale and is distinguished on the map as a lentil in the formation. In its type locality, south of Rome, the formation is between 700 and 1,000 feet in thickness. Its beds are always more or less folded, so that it is impossible to make exact measurements of its thickness. The formation is confined to a narrow belt crossing the quadrangle diagonally from northeast to southwest at the eastern margin of the Coosa Valley. Its rocks are somewhat more resistant than the limestones which occur above and below, and it forms a line of low ridges between the lowlands on either side.

The Conasauga formation presents a number of widely differing phases within the limits of this quadrangle. At its type locality, in the Dalton quadrangle to the northeast, it consists of a great thickness of fine clay shales with occasional beds of limestone. The latter vary in thickness from a few inches to several hundred feet, and are always rather pure, blue limestone. In the vicinity of Rome and northeastward to the margin of the quadrangle, the formation consists at the base of several hundred feet of fine olive clay shale, then beds of oolitic limestone, and finally 1,000 or more feet of calcareous shales, interbedded toward the top with blue limestones. Southward from Rome the formation changes considerably by an increase in the amount of limestone. A typical section is exposed on Big Cedar Creek, where it crosses Vans Valley. The lower part of the formation consists of olive shales, above which are oolitic limestones, the same as at Rome. The upper portion of the formation, however, consists largely of heavy beds of limestone. Some of these limestone beds are gray and crystalline, closely resembling the Knox dolomite, but free from the compact nodular chert of the latter formation. Other beds contain considerable earthy matter, which often retains the form of the rock after the calcareous matter has been removed, and also masses of characteristic cellular chert. The two phases of the Conasauga formation above described are confined to the strip of lowland between the Rome sandstone ridges and the Knox dolomite plateau which occupies the southeastern half of the quadrangle.

Northwest of the Rome sandstone ridges there is a much larger area of the Conasauga formation, occupying the greater part of the Coosa Valley. The formation here varies somewhat widely from the type to the east, and is capable of subdivision into three rather distinct phases. The upper portion of the formation, along the eastern margin of the Coosa Valley, consists of characteristic greenish siliceous shales. These have been separately mapped and are indicated on the sheet as a lentil in the formation. In some cases the shales are replaced by greenish micaceous sandstone, which is always highly contorted and crushed into a series of lenticular masses from a fraction of an inch to 4 or 5 inches in thickness. The sandstone is always filled with cracks or fissures, which have the appearance of having been produced by contraction of the bed. These cracks are partially filled with quartz, and where they are unweathered the remaining space is occupied by calcite. The sandstone is confined to the southeastern margin of the valley. Northwestward the siliceous beds become fewer, being replaced by fine olive-green shales, and throughout the central portion of the valley this division is represented by olive shales, in which occur numerous flat concretions composed of gray siliceous rock intermediate in character between fine-grained quartzite and chert. Along the northwestern border of the valley this division becomes very much more calcareous. The concretions are similar in appearance to those above described, but are composed of siliceous limestone. As the shale holding these siliceous concretions weathers they collect upon the surface and resemble deposits of waterworn gravel. The intermediate division of the Conasauga as it occurs in the Coosa Valley is composed of clay shales containing varying amounts of limestone. The limestone appears in some places as a few thin beds scattered through the shales, and in others as massive beds, frequently several hundred feet in thickness. In some places the limestone, instead of forming continuous beds, occurs as flat lenticular masses, an inch or less in thickness, rather closely crowded in the fine shales. The lower portion of the formation consists wholly of fine clay or slightly sandy shales, which appear yellow or brown at the surface and dark bluish gray or black below drainage.

These three subdivisions merge into one another without sharp boundaries. The formation contains no single stratum sufficiently characteristic to be identified at different outcrops and thereby used as a datum for the subdivision of the formation, so that the siliceous beds are represented only as a lentil in the formation. The rocks of the Coosa Valley are everywhere highly contorted and are probably also intersected by numerous faults. For these reasons, and also because large areas in the valley are deeply covered by recent gravels, it is impossible to estimate even approximately the thickness of the formation as a whole or of any of its subdivisions. The fact that the formation occupies such a broad area suggests, however, that its thickness must be very considerable, probably several thousand feet. In addition to the areas already described, the Conasauga forms a number of narrow belts in the northwestern portion of the quadrangle. These occupy the axes of narrow anticlinal rolls or are brought to the surface by faults. The formation here has much the same character as in the type locality; that is, it consists of fine clay shales with occasional beds of blue limestone. The Conasauga formation differs so widely in character in the closely adjoining regions that, except for the evidence derived from the fossils, the two phases would scarcely be correlated. Nothing resembling the upper siliceous division occurs in the region east of the Rome sandstone belt, and, on the other hand, the characteristic oolitic limestone of this eastern region is wholly wanting in the Coosa Valley.

Two explanations of these differences are suggested. The first is that there may have been a barrier of land between the two areas of deposition, so that the rocks of the Coosa Valley and those south of the Coosa fault were laid down in separate, though contiguous, basins. Deriving their sediments from different sources, they would differ in lithologic character, while the faunas might be essentially the same. No trace of such a land barrier, however, has yet been found, and the rocks in question contain none of the characteristic marks of littoral deposition. The second explanation is that the rocks now occupying adjacent areas at the surface were originally deposited in comparatively remote parts of the same sea, but have been brought side by side by folding and faulting, and that the observed lithologic differences are due to the gradual change which is always found upon tracing a bed for a considerable distance. The contrast in character is greatly heightened by the elimination of the intermediate varieties and by the most widely different types being brought into immediate contact, where comparison reveals differences which in the normal relation of the beds might escape notice. The two regions are separated by the Coosa fault, which will be more fully described later. It is quite possible that rocks now in contact on opposite sides of this fault were originally separated by an interval of 10 or 15 miles, and that the intervening rocks, now entirely concealed, would, if restored, present all the intermediate varieties between the two sharply contrasted phases of the formation.

The Knox dolomite consists of from 4,000 to 5,000 feet of massively bedded and somewhat crystalline gray magnesian limestone. From the few fossils which have been found it appears probable that a transition from Cambrian to Silurian occurs in the lower third of the formation, but it is generally impossible to determine this line of division, so the whole formation is classed as Silurian on the historical-geology sheet. This limestone, or, more properly, dolomite, contains a large amount of silica in the form of nodules and layers of chert, an impure variety of flint. Upon weathering, that part of the rock which consists of the carbonates of lime and magnesia is dissolved, leaving behind the chert, usually embedded in red clay. This residual material covers the surface to a great depth, and the dolomite is seldom seen except in the stream channels. Unlike the underlying Conasauga formation, the Knox dolomite affords some indication of having been deposited in proximity to land toward the east. In a few places the chert beds are replaced by coarse sand disseminated through the dolomite, in some cases making it a calcareous sandstone. This sand increases in abundance toward the east, in which direction, therefore, its source probably lays.

The Knox dolomite occurs in a number of belts, from 1 to 3 miles in breadth, in the northwestern portion of the quadrangle, and also forms the surface in a much broader area which occupies nearly the whole of the southeastern third of the quadrangle. These areas are characterized by a hilly surface which is usually several hundred feet above the adjoining lowlands. Since exposures of the dolomite are rare, the extent of the formation is determined by means of the residual chert which covers its outcrops. In the vicinity of faults the chert is frequently altered by partial recrystallization of the silica and converted into a white granular rock which readily crumbles on exposure to the air. Hence, those portions of the formation which have undergone this alteration weather to a red siliceous clay soil. This can not be easily distinguished from the soil derived from the Beaver limestone and from portions of the Conasauga formation. Considerable uncertainty, therefore, pertains to the mapping of these three formations, particularly in a much faulted region, as in the vicinity of Indian Mountain.[a]

The Ocoee group of Safford, which comprises a great thickness of coarsely clastic strata, together with some finer sediments, is very widely developed in Alabama and Georgia. The strata are in general much metamorphosed. Hayes[428b] states:

The Ocoee series, whose age is not definitely known, was deposited for the most part near the margin of the sea, where the supply of land waste was abundant but subject to great fluctuations. Fine sediments alternate with coarse material, and few of the formations retain the same characteristics for long distances, except in a very general way. During a part of the Ocoee epoch there were in this region several granite islands, whose waste was deposited about them as basal conglomerates. Later these islands were entirely covered by the sea and by the sediments derived from more distant lands and spread over the sea bottom. The extreme metamorphism which the rocks of this series have undergone toward the east renders it difficult to determine their original limit in that direction or their relation to the older rocks beyond.

Hayes and Eckel[429] give the following more detailed account of certain aspects and relations of Safford's Ocoee in Bartow County, Ga.:

The rocks on the opposite side of the Cartersville fault, occupying the eastern half of the district, present considerable variety in composition and age. A large area, extending from Stamp Creek southward across the Etowah River, to the Atlantic & Western Railroad, is occupied by the Corbin granite, which is, for the most part, a massive coarse-grained rock, containing large porphyritic crystals of feldspar (microcline), in a groundmass of plagioclase feldspar, muscovite mica, and blue quartz. Some portions of the rock have undergone considerable alteration, by which it has been converted into an augen gneiss. This area of Corbin granite at one time probably formed an island, since it is surrounded, in part at least, by rocks derived from its waste. These are feldspathic conglomerates in which the blue quartz and the porphyritic crystals of microcline, which characterize the granite, can be readily distinguished. In some places the transition from granite to conglomerate is so gradual that it is difficult to determine the exact boundary between the two formations. The development of the gneissoid structure in the granite evidently took place after it was deeply buried by sediment, for the alteration of the latter is even more marked than that of the granite itself. Wherever the granite is not bordered by coarse conglomerate or quartzite it is in contact with black graphitic slates, which generally overlie the coarser sediments.

These conglomerates and slates associated with the granite belong to the Ocoee series, which reaches its greatest development in eastern Tennessee and western North Carolina. No fossils have yet been found in the rocks of this series, although many of them are only slightly altered. They contain limestones and slates similar to portions of the adjacent valley forma-

[a] See also quotation from report on the Birmingham district, pp. 164-165.

tions, but the latter are always found to contain more or less abundant traces of life. In the absence of fossil evidence their age can not be definitely determined, but on structural evidence, obtained chiefly in Tennessee, they are believed to be Lower Cambrian with possibly some pre-Cambrian.

The rocks of the Ocoee series generally show an increasing degree of metamorphism toward the southeast; and within a few miles of this region they pass into schists and gneisses, the original form of which, whether igneous or sedimentary, can not be readily determined. This increased metamorphism toward the southeast is due in part to the greater compression which that region has suffered, and in part to the presence of considerable bodies of various igneous rocks which have been intruded into the sedimentary beds. These intrusive rocks present considerable variety in composition, varying from extremely basic diabase to acid granites. The most common variety is a diorite, which was among the earlier intrusions, and has been subsequently converted for the most part into amphibolite schist. Two belts of this basic schist pass across the southeastern corner of the district. Its southeastern corner is occupied by the Acworth gneiss, which, like the Corbin granite, is probably Archean in age, and formed the foundation on which the oldest sediments of the region were deposited.

Among these probably pre-Cambrian schists occur some strata which, though highly metamorphosed, are of late Paleozoic age. Thus E. A. Smith records the discovery of plant remains near Mosely, Clay County, Ala., in "semicrystalline (sericite) slates of the Ocoee type * * * at the eastern base of the main range of the Talladega Mountains * * * 8 miles or more from the contact of the 'Ocoee' with the unaltered Cambrian of the valley." David White[747] reported on the plants as follows:

Your specimens represent several fragments of large cones in which the axes, the basal, sporangiferous portions of the spirally arranged bracts, the rhomboidal compressed sporangia, and the megaspores are well defined. Precise identification of the material is deferred pending the study of thin sections and the determination of certain points regarding the sporangial walls and their attachment to the basal portions of the bracts. It is clear, however, that we have here fragments of cones whose superficial features appear to represent the common Lepidostrobus type of the upper Paleozoic. Beds containing lepidophytic remains of this type can hardly be older than Devonian at earliest, and should not antedate the Middle Devonian.

The general proportions and aspect of the cones are suggestive of some of the Carboniferous forms. Although the internal structure of the strobili may be found to indicate a more highly organized genus than Lepidostrobus, we may rest assured that the material is not older than the upper Paleozoic lepidophytes.

I-J 12. GRAND CANYON, ARIZONA.

The Tonto group comprises a sandstone at the base and shales and limestones above. Walcott[851a] gives the following section:

The Tonto section at the head of Nunkoweap Valley is as follows, from top downward:

	Feet.
1. Massive mottled limestone	60
Fossils: Lingulepis and Ptychoparia.	
2. Evenly bedded yellowish sandstone	25
3. Mottled and variegated calcareo-arenaceous rocks	340
4. Thin-bedded sandstones	325
Fossils (near base): Lingulella, Acrothele, *Iphidea ornatella,* Hyolithes, Leperditia (three species), Dilichometopus, Olenoides, and Ptychoparia.	
5. Fine-grained passing into coarse reddish-brown sandstone in layers	300
	1,050

The base rests unconformably upon the Chuar shales, etc. Nos. 4 and 5 are referred to the Middle Cambrian, and the strata above to the Upper Cambrian.

In 1883 Walcott[846] wrote:

The geologic age of the Tonto group is determined by the presence of numerous specimens representing the genera Cruziana, Lingulepis, Iphidea, Conocephalites, Crepicephalus and Dicellocephalus that occur at various horizons in the upper 700 feet of sandstone, shales and limestone. No fossils were obtained from the coarse sandstone forming the lower 300 feet. The fauna above, however, shows close relations to that of the Potsdam sandstone horizon of central Nevada, the Mississippi Valley, and Saratoga County, N. Y.

The base line of the Tonto is quite uniform and rests unconformably on the varied strata beneath; here and there a knoll, point or ridge is seen on the pre-Tonto surface that rises nearly through the massive Tonto sandstones that were deposited against and over them, the sea breaking off, and burying with the drifting sand, fragments of the rocky islands.

The great unconformity beneath the Tonto has been described by Prof. J. W. Powell, who examined it in his boat trips down through the Grand Canyon, and by Capt. C. E. Dutton, who viewed it from the summit of the Kaibab Plateau, 5 miles away. Prof. Powell estimated the strata beneath the Tonto and above the Archean at 10,000 feet, and as this is all cut across the unconformity is very great. A detailed study adds to the thickness of the strata; it shows that the original summit of the pre-Tonto group had undoubtedly been cut away more or less before the deposition of the Tonto group; that the plane of erosion cut deeply into the Archean, and that besides the 13,000 feet of strata, that have been planed off, of which the record is found in the section preserved, there was also a problematical amount of considerable thickness.

I-J 16-17. TENNESSEE AND NORTH CAROLINA.

In eastern Tennessee and North Carolina two distinct sequences of strata are assigned to the Cambrian. One consists of the sparsely fossiliferous siliceous group to which Safford applied the name Chilhowee sandstone but which has been subdivided by Keith into several formations, and the overlying richly fossiliferous, generally calcareous deposits which constitute the Apison, Beaver, Rome, Conasauga, and Knox formations and some minor divisions of local extent; these are found in the valley region of east Tennessee. The other sequence is the more or less metamorphosed unfossiliferous Ocoee group of Safford, composed in part of coarse clastic deposits with slate and subordinate limestone, which form large masses of the Great Smoky Mountains. Keith[480] has demonstrated the conformity of Safford's Ocoee to the fossiliferous Cambrian and classes it as Cambrian on grounds of physical relationship. He says:

With the deposition of the Cambrian rocks there came a great change in the physical aspect of this region. The sea encroached upon areas which were until then dry land. Eruptions of lava and erosion of the surface were replaced by deposition of sediments beneath a sea. Extensive beds of these were laid down in some areas before others were submerged. Here the sediments lapped over lavas and plutonic granites alike, and the waste from them all was combined in one sheet of gravel and coarse sand which now appears as sandstone, conglomerate, and quartzite. Some of this waste consists of epidote and jasper, the products of alteration in the Linville meta-diabase. It is thus seen that the interval between the Algonkian and Cambrian was at least long enough to permit dynamic movements and chemical changes to effect considerable results, even before the period of erosion and reduction began.

The two sequences generally do not occur in their original relations, which are therefore indeterminate over wide areas. The Ocoee of Safford is usually overthrust from the east upon younger strata to an extent which obliterates the normal sequence. An exception to this general fact occurs in northeastern Tennessee, where a complete conformable sequence from Safford's Ocoee into the fossiliferous Cambrian has been worked out by Keith. (See section, Greeneville and Roan Mountain quadrangles, pp. 95–96.) The discovery of Carboniferous plants near Mosely (now Erin), in Clay County, Ala., in metamorphosed rocks which have been regarded as a part of Safford's Ocoee (see Chapter VIII, p. 363), shows that the metamorphic terrane of which his Ocoee there has been considered a part locally comprises rocks of various ages.

The fossiliferous Cambrian formations of Tennessee range from Lower Cambrian (Georgian) up through the entire system and pass into Lower Ordovician in the Knox dolomite. Beneath the fossiliferous strata occur others which have no fossils but which are conformable to those that have. The strata vary along the valley from southwest to northeast and more markedly across the valley from southeast to northwest. Some typical sequences are as follows:

Generalized section west of Southern Railway.[424a]

Period.	Formation.	Thickness (feet).	Character of rocks.
Silurian. [Ordovician.]	Chickamauga limestone.	1,800–2,100	Blue flaggy limestone with some mottled, earthy beds.
	Knox dolomite.	3,800–4,200	Magnesian limestone, white, gray, or light blue; generally granular and massively bedded, containing nodules and layers of chert.
Cambrian.	Conasauga shale.	500–1,600	Blue seamy limestone. Greenish clay shale. Thin beds of oolitic limestone.
	Rome formation. (Rome sandstone.)	1,800–2,600	Greenish or brown shale with thin siliceous layers. Purple, brown, and white sandstone interbedded with sandy shale.
	Apison shale.	1,500+	Sandy shale or clay shale in brightly colored bands.

Generalized section east of Southern Railway[424a]

Period		Formation	Thickness (feet)	Character of rocks
Silurian [Ordovician.]		Chickamauga limestone	300–650	Blue flaggy limestone
		Knox dolomite	4,200–4,400	Magnesian limestone, white, gray, or light blue, generally granular and massively bedded, containing nodules, layers of chert, and beds of coarse sand
Cambrian [fossiliferous to Nichols shale, inclusive]		Conasauga shale	1,100–6,000	Blue seamy limestone Greenish calcareous clay shale and beds of limestone Thin beds of oolitic limestone in shale
		Rome formation (Rome sandstone.)	1,600 (1,100)	Brownish shale Purple, brown, or white sandstone interbedded with sandy shale
	[Chilhowee of Safford.]	Murray shale	200+	Sandy shale
		Nebo sandstone	250–600	White quartzite or quartzose sandstone
		Nichols shale	440–1,140	Micaceous sandy shale
	[Ocoee of Safford.]	Cochran conglomerate	200–1,500	Quartzite, quartzose sandstone, and conglomerate
		Sandsuck shale	750–1,900	Blue shale, locally calcareous
		Stairs conglomerate	0–660	Conglomerate, generally feldspathic
		Sandsuck shale	(?)	Blue shale

Generalized section west of Clinch and Tennessee rivers[420a]

Period	Formation	Thickness (feet)	Character of rocks
Silurian [Ordovician.]	Chickamauga limestone	1,300–1,700	Blue flaggy limestone
	Knox dolomite	3,300–3,500	Magnesian limestone, white, gray, or light blue, generally granular and massively bedded, containing nodules and layers of chert
Cambrian	Conasauga shale	300–500	Blue seamy limestone Greenish clay shales Thin beds of oolitic limestone
	Rome formation (Rome sandstone.)	2,800–3,400 (1,800–2,200)	Greenish or brown shales with thin siliceous layers Purple or brown sandstones interbedded with sandy shales
	Apison shale	1,000+	

Generalized section southeast of Bays Mountain.[475a]

Period.		Formation.	Thickness (feet).	Character of rocks.
Silurian. [Ordovician.]		Athens shale.	1,000-1,200	Light-blue calcareous shale, black calcareous shale.
		Chickamauga limestone.	0-50	Gray argillaceous limestone.
Cambrian [fossiliferous to Nichols shale, inclusive].		Knox dolomite.	3,500	Magnesian limestone, white, gray, light and dark blue, with nodules of chert.
		Nolichucky shale.	450-550	Yellow and brown calcareous shale and limestone beds.
		Maryville limestone.	350-550	Massive dark-blue limestone.
		Rogersville shale.	180-220	Bright-green clay shales, with a limestone bed.
		Rutledge limestone.	350-450	Massive dark-blue limestone.
		Rome formation. Rome formation sandstone.	250 500-700	Red, green, yellow, and brown shales and sandy shales. Red, white, and brown sandstones and sandy shales.
		Beaver limestone.	300	Massive blue limestone.
		Apison shale.	200 900+	Green argillaceous shale. Bright-red, green, and brown sandy shales.
	[Chilhowee of Safford.]	Hesse sandstone.	500+	Fine white massive sandstone.
		Murray shale.	300	Grayish-blue sandy shale.
		Nebo sandstone.	500	Massive white sandstone, coarse and fine.
		Nichols shale.	550-800	Grayish-blue sandy shale.
[Ocoee of Safford.]		Cochran conglomerate.	600-900 0-100 500-700	Massive white sandstone, coarse and fine. Red sandstone, gray sandy shale. Coarse conglomerate, quartz and feldspar pebbles.
		Sandsuck shale.	1,000+	Grayish-blue argillaceous shale.

Generalized section for the Briceville quadrangle.[478a]

Period.	Formation.	Thickness (feet).	Character of rocks.
Silurian. [Ordovician.]	Chickamauga limestone.	1,600–2,000	Blue and gray limestone, argillaceous limestone, flaggy limestone, and calcareous shale. Blue and gray massive limestone with a few nodules of black chert.
—?—	Knox dolomite.	2,800–3,500	Magnesian limestone, white, gray, light blue, and dark blue, with nodules of chert.
Cambrian.	Conasauga shale: {Nolichucky shale. {Maryville limestone.	650–800 (250)	Yellow, red, and brown calcareous shale with thin beds of limestone, those at the base assuming the importance of a separate formation in the extreme southeast.
	Rome formation.	600–800	Bright-colored red, green, and brown sandy shale interbedded with layers of thin sandstone.
	Rome sandstone lentil.	500+	Red, yellow, and brown sandy shale with thick beds of sandstone.

Generalized section of the sedimentary rocks in the Great Valley (Greeneville quadrangle).[481a]

System.	Formation.		Thickness (feet).	Character of rocks.
Ordovician.	Athens shale.		1,000±	Black and bluish-black calcareous shale.
	Moccasin limestone.		450–500	Red, blue, gray, and drab massive and shaly limestone.
	Chickamauga limestone.		0–450	Blue and gray limestone, shaly in part, and variegated marble.
—?—	Knox dolomite.		3,000–3,500	Magnesian limestone, light and dark blue, white, and gray, with nodules and layers of chert and a few beds of calcareous sandstone.
Cambrian.	Nolichucky shale.		500–750	Yellow, green, and brown calcareous shale, with limestone beds.
	Honaker limestone.	Maryville limestone.	700–950	Massive dark-blue and dark-gray limestone.
		Rogersville shale.	180–200	Bright-green clay shales, with thin limestone beds.
		Rutledge limestone.	400–450	Massive dark-blue limestone, with shale beds at bottom.
	Rome formation. Sandstone lentil.		200± 400±	Red, green, and brown shale and sandy shale. Red, white, and brown sandstone and sandy shale.

Generalized section for portion of Bristol quadrangle south of Clinch Mountain.[125a]

Period.	Formation.	Thickness (feet).	Character of rocks.
Silurian. [Ordovician.]	Athens shale.	1,000-1,200	Sandy shale and thin sandstones, with occasional beds of impure limestone and limestone conglomerate. Dark argillaceous shale at the base.
Cambrian.	Knox dolomite.	2,800-3,500	Blue and gray limestone. Very cherty along Walker Mountain, but farther toward the southeast the chert disappears and the formation merges with and becomes indistinguishable from the Honaker limestone beneath, and the whole is called the Shenandoah limestone.
	Nolichucky shale.	0-300	Blue calcareous and sandy shale. Toward the east this changes to limestone.
	Honaker limestone.	1,200-1,400	Blue and gray limestone. Toward the east this formation merges with the Knox dolomite and the whole is known as the Shenandoah limestone.
	Russell formation.	400+	Red and green shales and thin-bedded sandstones.

The development of the Ocoee group in part of eastern Tennessee and North Carolina is shown in the following six sections, which represent the group from southeastern to northeastern Tennessee:

Generalized section east of Beans Mountain.[424a]

Period.	Formation.	Thickness (feet).	Character of rocks.
Ocoee series, age unknown. [Cambrian of Keith, Ocoee of Safford.]	Thunderhead conglomerate. Thunderhead slate. Thunderhead conglomerate.	300± 1,500± 800-1,000	Massive conglomerate interbedded with black slate. Black slate, with beds of conglomerate and sandstone, generally schistose. Massive conglomerate of blue quartz and feldspar.
	Pigeon slate.	(?)	Blue or black slate, with local beds of sandstone and conglomerate, generally schistose.
	Citico conglomerate.	500-1,100	Conglomerate and sandstone, with beds of sandy shale.
	Wilhite slate.	(?)	Blue slate with lenses of quartz conglomerate, sandy limestone, and limestone conglomerate.

Generalized section southeast of Chilhowee Mountain.[475a]

Period.	Formation.	Thickness (feet).	Character of rocks.
Age unknown. [Cambrian of Keith, Ocoee of Safford.]	Clingman conglomerate.	1,000+	Gray sandstone and coarse and fine conglomerate, with blue quartz and feldspar.
	Hazel slate.	600–800	Black slate, with small beds of sandstone and fine conglomerate.
	Thunder Head conglomerate.	3,000+	Gray sandstone and coarse and fine conglomerate, with blue quartz and feldspar.
	Cades conglomerate.	2,400+	Gray sandstone and fine conglomerate, with many beds of sandy slate.
	Pigeon slate.	1,300–1,700	Banded gray and bluish-gray slate and sandy slate; a few gray sandstone beds.
	Citico conglomerate.	50–800	Coarse quartz conglomerate. Fine quartz conglomerate. Coarse white sandstone. Fine white sandstone.
	Wilhite slate.	0–1,000	Limestone conglomerates and sandy limestone. Bluish-black argillaceous and calcareous slate.

Generalized section of the sedimentary rocks in the Bald Mountains, Greeneville quadrangle.[481a]

System.		Formation.	Thickness (feet).	Character of rocks.
Cambrian.	[Knox of Safford.]	Shady limestone.	1,000±	Gray, bluish-gray, mottled gray, and white limestone, with nodules and masses of chert.
	[Chilhowee of Safford.]	Hesse quartzite.	700–800	Massive white quartzite and sandstone.
		Murray slate.	300–400	Bluish-gray to gray argillaceous and sandy shale and slate, with thin sandstone seams.
		Nebo quartzite.	200–900	Massive white quartzite and sandstone, coarse and fine, with a few layers of sandy shale and reddish sandstone.
		Nichols slate.	400–700	Bluish-gray to gray argillaceous and sandy shale and slate, with thin sandstone layers.
	[Ocoee of Safford.]	Cochran conglomerate.	200–1,600	Massive quartz conglomerate and quartzite, light and dark gray, with seams of dark slate.
		Hiwassee slate.	1,200–1,500	Blue, gray, black, and banded slate, with a little fine mica schist. Includes layers of sandstone and conglomerate and beds of calcareous sandstone.
		Snowbird formation.	700–2,000	Gray and white feldspathic quartzite and sandstone, with dark slate beds. Locally becomes conglomerate and dark-purplish sandstone. Coarse and fine quartz conglomerate and arkose.
		Unconformity.		
Archean.		Granites.		

Generalized section of the sedimentary rocks of the Roan Mountain quadrangle in the vicinity of Erwin.[484]

System.		Formation.	Thickness (feet).	Character of rocks.
Ordovician.		Athens shale.	800–1,600	Black and bluish-black calcareous shale below, blue-gray banded slaty shale above.
Ordovician.		Knox dolomite.	3,000–3,700	Magnesian limestone, light and dark blue, white, and gray, with nodules and layers of chert and a few beds of calcareous sandstone.
Cambrian [fossiliferous to Hesse quartzite, inclusive].		Nolichucky shale.	50–600	Yellow, green, and brown calcareous shale with limestone beds.
		Honaker limestone.	1,800–2,200	Massive dark-blue and dark-gray limestone. White and blue limestones.
		Watauga shale.	1,000–1,100	Purplish, red, green, and variegated shales, sandy shales, and thin sandstones, with calcareous shales and thin blue limestones interbedded.
	[Knox of Safford.]	Shady limestone.	750–1,000	Gray, bluish-gray, mottled-gray, and white limestone, with nodules and masses of chert.
	[Chilhowee of Safford.]	Hesse quartzite.	700–1,000	Massive white quartzite and sandstones.
		Murray slate.	300–400	Bluish-gray to gray argillaceous and sandy shale and slate, with thin sandstone seams.
		Nebo quartzite.	200–900	Massive white quartzite and sandstone, coarse and fine, with layers of sandy shale, slate, and reddish sandstone.
		Nichols slate.	400–700	Bluish-gray to gray argillaceous and sandy shale and slate, with thin sandstone layers.
	[Ocoee of Safford.]	Cochran conglomerate.	200–1,600	Massive quartzite, sandstone, and conglomerate, white or gray, with seams of dark slate.
		Hiwassee slate.	300–1,500	Bluish-gray to black and banded slates, with a little fine mica schist. Includes layers of sandstone and conglomerate.
		Snowbird formation (amygdaloid).	700–2,000	Gray and white feldspathic quartzite and sandstone, with dark slate beds and lentils of amygdaloid. Locally becomes conglomerate and dark-purplish sandstone. Fine quartz conglomerate and arkose at base.
Archean.		Granites.		

Generalized section of the sedimentary rocks of the Cranberry quadrangle.[480a]

Period.	Formation.	Thickness (feet).	Character of rocks.
Cambrian. [Knox of Safford.]	Watauga shale.	1,000–1,100	Purplish, reddish-brown, and yellow shales, sandy shales, and thin sandstones, with calcareous shales and thin blue limestones interbedded.
Cambrian. [Knox of Safford.]	Shady limestone.	750–800	Gray, bluish-gray, and mottled-gray limestone, with nodules and masses of black chert.
Cambrian. [Chilhowee of Safford.]	Erwin quartzite.	500–700	Massive white quartzite and sandstone.
Cambrian. [Chilhowee of Safford.]	Hampton shale.	600–800	Bluish-gray and gray argillaceous and sandy shales, with thin sandstone layers.
Cambrian. [Ocoee of Safford.]	Unicoi formation.	1,500–2,500	Massive white sandstone, feldspathic sandstone, and quartzite, with interbedded shales and sandy shales in the upper part, a thin bed of amygdaloid near the middle, and conglomerate, arkose, and graywacke in the lower part.
	Unconformity.		
Pre-Cambrian.	Gneisses, granites, and ancient volcanic rocks.		

Generalized section of the sedimentary rocks of the Mount Mitchell quadrangle.[482]

System.	Formation.	Thickness (feet).	Character of rocks.
Cambrian.	Shady marble.	600+	White and blue massive banded marble.
Cambrian. [Chilhowee of Safford.]	Erwin quartzite.	600+	Massive white quartzite.
Cambrian. [Chilhowee of Safford.]	Hampton shale.		Blue and gray shale and slate.
Cambrian. [Ocoee of Safford.]	Brevard schist.	1,000+	Fine-grained black schist, in places graphitic.
	Unconformity.		
Archean.	Gneisses and granites.		

A somewhat different development of Safford's Ocoee group is found in extreme southwestern North Carolina, as shown by the following section:

Generalized section of the sedimentary rocks of the Nantahala quadrangle.[483]

System.	Formation.	Thickness (feet).	Character of rocks.
Cambrian [Ocoee of Safford].	Nottely quartzite.	150+	Fine white quartzite.
	Andrews schist.	200-350	Light-colored calcareous schist with ottrelite and iron ore.
	Murphy marble.	150-500	Thick-bedded white, blue, and blue and white banded marble.
	Valleytown formation.	900-1,200	Graywacke and fine-grained gneiss, interbedded with dark garnet and ottrelite schists.
	Brasstown schist.	1,200-1,500	Blue and black banded ottrelite schist, garnet schist, and slates, with a few layers of fine graywacke. Black slate usually at the base.
	Tusquitee quartzite.	20-500	Coarse and fine white quartzite with some quartz conglomerate.
	Nantahala slate.	1,400-1,800	Black, bluish-black, and gray slate; in places altered to fine black schist with some fine ottrelite and garnet. Contains a few beds of gray sandstone and graywacke. Thick bed of staurolite-garnet schist usually at the base.
	Great Smoky conglomerate.	5,500-6,000	Blue quartz and feldspar conglomerate. Massive beds of quartz and feldspar conglomerate and coarse gray sandstone with beds and seams of black slate. Altered toward the southeast into coarse and fine graywacke and quartzite with beds of black schist and ottrelite schist.
	Hiwassee slate.	500	Blue and gray banded slate.
	Unconformity.		
Archean.	Gneisses and granite.		Light-gray granite, fine granite, and gneissoid granite.

J 11-12. CALIFORNIA, NEVADA, AND UTAH.

In 1890, with reference to the Great Basin province in general, Walcott[851] summed up the Cambrian stratigraphy as follows:

In this province there appears to have been a large accumulation of more or less coarse, arenaceous sediment, commingled with considerable argillaceous material, before the deposition of the sediments of the Olenellus zone. As far as shown, the Olenellus fauna appeared at the time the character of the sediments was changing to finer sands and argillaceous clays, and then to calcareous clays. The sedimentation is unlike that of the sections on the eastern side of the continent. The southern portion of the province is found in the Great Basin region of Utah and Nevada, between the Wasatch range and the Sierra Nevada range. In the eastern or Wasatch area *Lingu[l]ella ella, Olenellus gilberti,* and Cruziana sp.? occur in a thin band of fine micaceous sandstone, about 200 feet from the summit of the Cambrian rocks, which are conformably subjacent to strata of Ordovician age. The Olenellus-bearing sandstones are covered with trails of annelids, etc., and are evidently a littoral or shore deposit.

In the Eureka district of central Nevada the fauna is confined to a narrow belt of arenaceous shales, with some intercalated limestone. The fauna consists of but seven species: Girvanella? sp.?, *Kutorgina prospectensis, Scenella conula, Olenellus gilberti, O. iddingsi, Olenoides quadriceps, Ptychoparia subcoronata,* and *Anomocare parvum.* Of these, two species, *Olenoides quadriceps* and *Scenella conula,* are found 500 feet higher up in the section. In the Highland Range section of Nevada the rocks are essentially of the same character as in the Eureka section; the two species, *Olenellus gilberti* and *O. iddingsi,* occur in an arenaceous shale associated with Cruziana sp.? In the Pioche section more limestone is interbedded in the arenaceous shale and the fauna of the Olenellus zone is larger. It includes *Eocystites??, Lingulella ella, Kutorgina pannula, Acrothele subsidua, Acrotreta gemma, Orthis highlandensis, Olenellus gilberti, Zacanthoides levis, Crepicephalus augusta, C. liliana,* and *Oryctocephalus primus.* Of these, *Kutorgina pannula, Acrothele subsidua, Acrotreta gemma,* and *Hyolithes billingsi* pass to the zone above that carrying Olenellus. In limestones of the Olenellus zone at Silver Peak, in western Nevada, the following species were collected by Mr. Clayton: Girvanella? sp.?, *Spirocyathus atlanticus, Ethmophyllum meeki, E. whitneyi, Kutorgina cingulata, Hyolithes princeps, Olenellus gilberti.*

Detailed sections are given in a bulletin by Walcott[848] published in 1886. In 1895 Walcott[856] stated:

The only Lower Cambrian rocks of California known to me occur in the White Mountain Range of Inyo County, east of Owens Valley, with the single exception of one small mass west of Big Pine, which is in the foothills of the Sierra Nevada.

* * * * * * * * *

During the summer of 1894, accompanied by Mr. F. B. Weeks, I crossed the range over the toll road leading from Big Pine to Piper's ranch, in Fish Lake valley, and penetrated into it from the western side in Waucobi, Black, and Silver canyons.

The ascending section exposed in the ridge on the north side of Black Canyon is as follows:

		Feet.
1. Gray and yellowish arenaceous limestone, occurring in low hills above the Quaternary		200
2. Massive-bedded compact fine-grained, often saccharoidal light-gray siliceous and arenaceous limestone (strike N. 10° W. (mag.), dip 20° E.). At 100 feet from base of this division a dike of basalt 40 feet in thickness cuts through and displaces the limestone in the vicinity of the dike, so as to give it a dip of from 70° to 80° E. Above the dike the dip of 20° is very quickly resumed. At 160 feet from the base a band of white limestone occurs, which contains numerous small concretions of limestone. At 230 feet above the dike occurs a band of shaly limestone, which has buff-colored partings; and irregular, buff-colored, sandy laminations occur in thin layers in the thick-bedded limestone.		
No. 2 may be subdivided as follows:		
a. Light-gray and white limestone	500	
b. Buff and gray, more arenaceous limestone, with a band of cherty limestone 20 to 25 feet thick at 125 feet from its base	170	
c. Gray arenaceous limestone, cherty at top	115	
d. Shaly and thick-bedded sandy limestone, cross-bedded in places, with yellowish-buff layers, also with two bands of brown thick-bedded and shaly quartzite	145	
e. Massive-bedded coarse arenaceous gray limestone, passing into buff-colored and cherty beds above	85	
f. Buff-colored shaly limestone	5	
g. Bluish-gray banded limestone	30	
h. Gray arenaceous limestone, with bands of buff-colored, mostly thick-bedded limestone	70	
i. Thick-bedded bluish-gray limestone	10	
j. Brownish and buff-colored calcareous sandstone, with inclosed brecciated thin-bedded brown sandstone	5	
k. Dark banded quartzite	30	
l. Massive-bedded gray arenaceous limestone	225	
		1,525
3. Dark irregular thin-bedded siliceous slates with interbedded dark quartzitic sandstone (dip 25°–30° E. (mag.), strike north and south)		635

The section is terminated at this point by a fault line.

On the north side of Silver Canyon, No. 3 is well exposed and is estimated to have a thickness of 2,000 feet. Above this a series of limestones and calcareous and siliceous shales occurs and some interbedded dark quartzitic sandstones, that extend upward 1,000 feet. Near the base a massive-bedded limestone 100 feet in thickness occurs, in which great quantities of Lower Cambrian corals (Archæocyathinæ) occur. This series is capped by about 200 feet of compact thin-bedded arenaceous argillite, with interbedded layers of dark-brown fine-grained quartzite.

The entire section, briefly summarized from summit downward, is as follows:

	Feet.
4. Upper arenaceous beds	200
3. Alternating limestones and shales	1,000
2. Siliceous slates and quartzites	2,000
1. Siliceous limestones	1,700
	4,900

In round numbers the section exposed in the White Mountain Range, between White Mountain Peak and Waucobi Canyon, is 5,000 feet in thickness.

No fossils were found in the lower limestone. Numerous annelid trails occur in the lower siliceous series, and in the slaty portion near the summit heads of Olenellus were found. In places the lower portion of the upper limestone series is almost a solid bed of different forms of the Archæocyathinæ. *Ethmophyllum whitneyi* Meek is very abundant, and the genera Protopharetra, Coscinocyathus, and probably Archæocyathus occur. Ethmophyllum ranges throughout the limestone series into the base of the shales in Tollgate Canyon, where it is associated with cystidean plates and fragments of Olenellus. On the north side of Silver Canyon the Archæocyathinæ are so abundant in the limestone that it may practically be called a Lower Cambrian coral reef. This reef was traced for nearly 30 miles, and the same types are also known to occur in the Silver Peak Range, about 25 miles to the eastward.

So far as known to me, this is the oldest of the Cambrian faunas known in the western portion of the United States. Just what its relations to the Olenellus fauna of central Nevada and British Columbia are I am unable at present to state, except that I believe it to be older than the Olenellus fauna of central Nevada.

It is not impossible that a fauna will be found in the lower limestone, but in the hasty reconnaissance in which I was engaged only a portion of one day was given to the examination and measurement of the section. I hope in the future to extend the study of the White Mountain Range, as Mr. Fairbanks has written me that he has discovered *Fusilina cylindrica* in the southern end of the range, east of Keeler, which is about 50 miles south of Tollgate Canyon. If the section is unbroken, the Middle and Upper Cambrian and Ordovician faunas should be found before reaching the Carboniferous horizon discovered by Mr. Fairbanks.

In recent papers Walcott[261] has supplemented the data regarding the earliest Cambrian stratigraphy and faunas as follows:

The oldest known Cambrian fossils are found deep down in the Lower Cambrian strata of southwestern Nevada and the adjoining Inyo County area of eastern California. In sections 120 miles apart the Lower Cambrian has a thickness of over 5,000 feet, with a great limestone forming the upper 700 to 2,000 feet. Below this limestone calcareous strata occur, but the predominating rocks are sandstones and arenaceous, siliceous, and calcareous shales. In the lower 400 feet of the Waucoba Springs section and the Barrel Spring section south of Silver Peak in western Nevada the fauna includes—

Annelid trails.
Protopharetra sp. undt.
Archæocyathus sp. undt.
Ethmophyllum cf. whitneyi Meek.
Mickwitzia occidens Walcott.
Trematobolus excelsis Walcott.
Obolella sp. undt.
Orthotheca sp. undt.
Holmia rowei n. sp.
Holmia weeksi n. sp.

Although this fauna, according to our present knowledge, is the oldest known Cambrian fauna, it includes representatives of the several classes of invertebrates which I will enumerate.

Actinozoa.—The corals are represented by a very primitive form of Protopharetra, a small form of cup-shaped Archæocyathus, and a small Ethmophyllum closely allied if not identical with *Ethmophyllum whitneyi* (Meek), which occurs higher in the section. The latter is not a notably simple or primitive form of the Archæocyathinæ; on the contrary, it is nearly as far advanced as any species known in the Cambrian.

Vermes.—The annelid borings and trails that occur in and on the sandstones and shales are much like those of the Middle and Upper Cambrian.

Molluscoidea.—The two species of brachiopods represent widely separated genera. *Mickwitzia occidens* Walcott is one of the primitive forms of the Paterinidæ, while *Trematobolus excelsis* Walcott is a typical form of the Siphonotretidæ. The interval represented by the relative development of Mickwitzia and Trematobolus is sufficient to convince us that we must look far back in Cambrian or it may be pre-Cambrian time for the progenitors of the inarticulate brachiopods.

Pteropoda.—The forms representing Orthotheca are abundant, large, strong, and evidently as well developed as those of the Middle Cambrian.

Crustaceans.—The trilobites thus far found at this horizon are confined to two species of the genus Holmia. One of them, *Holmia weeksi* n. sp., has many segments and is more primitive than such forms as *Olenellus thompsoni* Hall and *Holmia bröggeri* (Walcott), of the upper portions of the Lower Cambrian section. The other species, *Holmia rowei* n. sp., is of the same general type as *Holmia bröggeri*. The absence of all other trilobite genera is the most marked feature of this early Cambrian fauna.

In the section 100 miles to the south, at Resting Springs, Inyo County, Cal., a brachiopod closely related to *Billingsella highlandensis* Walcott occurs 2,800 feet below the upper limestone in association with the trilobite *Holmia rowei.*

Comparing the species in the early Lower Cambrian fauna with the Olenellus fauna, in strata 5,000 feet higher in the section, we find a marked advance in the variety of the later fauna, but we do not know how much of this may be due to the absence, from our collections, of genera and species that may have existed during the deposition of the earlier sediments. In the earlier fauna of the Waucoba section the class characters of the Arthropoda, Mollusca, Molluscoidea, Vermes, and Cœlenterata were developed, and while the study of the genera and species adds a little more to our knowledge of the rate of convergence backward in geologic time of the lines representing the evolution of animal life, it, at the same time, proves that a very long time interval elapsed between the beginnings of life and the epoch represented by the Olenellus fauna.

This fauna is described by Walcott,[860] in the Smithsonian Miscellaneous Collections. In his latest contribution Walcott[862] says:

The evidence afforded by the few traces of pre-Cambrian fossils is inconclusive as far as determining whether their habitat was in marine, brackish, or fresh water.

The fossils from the Chuar group of Arizona are not sufficiently characterized to prove their origin or habitat. The protozoan *Cryptozoon? occidentale* Dawson is very abundant in Arizona, also in the Belt series of Montana, Alberta, and British Columbia. It occurs in limestones similar to those deposited in the fresh-water lagoons of Florida, and similar to the limestones of the lake deposits of the Tertiary formations of the Great Plains region of North America. The fossils of the Beltina zone of Montana and Alberta could as readily have been developed in fresh or brackish waters. There is nothing about the crustacean remains incompatible with their living in fresh water, in fact, the fragments indicate a form more nearly related to the fresh-water Brachiopoda with very thin test, rather than the strong Merostome (Eurypterus, etc.).

The oldest Cambrian fauna now known, with *Nevadia weeksi* and *Holmia rowei*, is limited to a few forms, but with a careful examination of the region where it occurs in southwestern Nevada it is highly probable that a considerable fauna will be found. The strata in which it occurs were deposited in a depression opening out toward the Pacific Ocean, where southwestern California is now located; this depression soon extended northward and presumably connected through to British Columbia and Alberta, as the same species of Olenellus occur in the central and upper portions of the Lower Cambrian both in Nevada and Alberta.

I do not know of a Cambrian fauna as old as that of *Nevadia weeksi* on the eastern side of the continent, or on the European continent. It appears to be a portion of the older fauna that is missing everywhere except in southwestern Nevada. I think it was brought in by the advancing Lower Cambrian sea from a sea to the west, the sediments of which are buried beneath later strata or are off the present shore line of the continent beneath the sea.

The theory that life originated and developed in fresh-water ponds and lakes does not appeal to me. More uniform conditions of temperature and environment would be present in the ocean and the sediments of the fresh-water deposits of pre-Cambrian and Cambrian time, if such exist, do not show sufficient evidence of life having existed at the time of their deposition. The Algonkian fossils of the Belt and Grand Canyon series (Walcott, 1899, pp. 227–239) probably came from the marine fauna when a temporary connection existed between the interior fresh or brackish water lakes and the ocean.

Spurr[772] gathered in one volume the observations made by himself and others on the occurrences of Cambrian strata and faunas in 25 widely distributed ranges of the Great Basin. Ball[54] supplemented Spurr's descriptions for southwestern Nevada and eastern California and gave a columnar section showing the relations of the Paleozoic strata among themselves and to the post-Carboniferous and Tertiary igneous rocks.

Darton[243] has noted the occurrence of Cambrian strata resting on older granite at Iron Mountain, in eastern San Bernardino County, Cal. He observed 1,200 feet of shale and limestone with quartzite at the base and collected "fragments of trilobites and mollusks which proved not to be specifically determinable," but which according to Walcott are "undoubtedly Cambrian, probably Middle Cambrian."

J 13. COLORADO.

The Upper Cambrian is represented in southwestern Colorado in Animas Valley by the Ignacio quartzite, a basal deposit, unconformable on the Algonkian. Cross[188] describes the Ignacio as follows:

The lowest lithologic division of the Paleozoic section in the Animas Valley is made up of quartzites and varies in thickness, in the area thus far examined, from a few feet to 200 feet. In layers near the middle of these quartzites a single generically determinable shell has been found. From the stratigraphic relations and the evidence of this fossil it is assumed that in this region the Cambrian system is represented only by a thin series of quartzites belonging probably to its upper division, and for those the name Ignacio formation or quartzite is proposed, from the lakes in the Animas Valley about 18 miles west of south from Silverton, near which the formation is well exposed. It is at present believed that all of the Paleozoic quartzites beneath the "Salt shales" belong to the Ignacio.

The Ignacio consists of nearly pure siliceous strata, with some feldspar locally in the lowest beds. The greater part is fine grained, white, gray, or pinkish, and highly indurated. The lower portion is commonly a massive quartzite of prevalent pink or reddish color, while the succeeding strata are nearly white. Distinct bedding is common, as is an irregular jointing.

Above this the strata are often wavy in bedding, with shale partings, in which mud cracks, trails, and other markings are common. These layers are friable sandstones in places. More massive quartzite layers generally succeed this series, but not in a thickness equal to those below.

At the very base of the formation a true basal conglomerate is often found but only in hollows of the granite, schist, or Algonkian quartzite floor. The hard Algonkian quartzites are most abundant among the pebbles, which range in size up to a diameter of (rarely) 1 foot.

The only identifiable fossil invertebrate yet obtained from the Ignacio beds was found on a remnant capping Overlook Point, one of the hills of Mountain View Crest, in the Needle Mountains quadrangle, south of Needle Creek. Specimens of this fossil were found scattered through a hard, dark quartzite above the middle of the formation, which was there 110 feet thick. Mr. Walcott identifies this shell as an Obolus but is unable, from the material at hand, to determine its species. Three forms that are much like this are *Obolus matinalis*, *O. tetonensis*, and *O. loperi*, the latter occurring in the passage beds between the Cambrian and the Ordovician in the Crested Butte quadrangle, Colorado. Since the Cambrian is known in Colorado only in thin representatives of the upper division, it seems best to assume for the present that the Ignacio quartzite also belongs in that series.

A common apparent fossil of the Ignacio is thought by Mr. Walcott to be Cruziana, a problematic plant remain.

J 15. MISSOURI AND NORTHERN ARKANSAS.

The "Magnesian Limestone series" of Missouri is thus described in general terms by Broadhead:[98]

The chief rocks of the Ozark Plateau include a series of magnesian limestones and sandstones amounting to 1,000 feet in thickness. In 1891 I applied to these rocks the name "Ozark series." The lower one-half to two-thirds may be Cambrian, including rocks of the age of the Potsdam of New York. The upper portion may be the equivalent of Dana's Canadian, or the lower part of the Lower Silurian. The evidence shows that the life of the Cambrian sea in Missouri was limited to but a few species. We find a few Orthocerata, a Lituite, a small Orthis, a Pleurotomaria, a Maclurea, two species of Ophileta, two or three species of Straparollus, probably two species of Murchisonia, an Obolella, three or four species of trilobites, while in the Potsdam of Wisconsin and Minnesota several other trilobites may be found. Where the waters were shallow sea worms lived and left their track in irregular windings in the rocks. In the later seas seaweeds abounded, as shown by certain beds of the Second Magnesian limestone. That the Ozark series was subject to erosions and slight elevations and depressions is shown by the occasional appearance of a few feet of sandstone at intervals of a few feet to over a hundred. Near the close of the Ozark terrane it is probable that a large area of the plateau was elevated above water.

The general stratigraphy is stated as follows by the same authority:

	Feet.
Trenton limestone	
First Magnesian limestone	100
First or St. Peters (saccharoidal) sandstone	130
Second Magnesian limestone	200
Second sandstone	125
Third Magnesian limestone	300
Lower Magnesian limestone and sandstone	300
	1,155

Several classifications of this series of rocks have been proposed, but the variable character and lenticular form of many of the formations or members have rendered generalization difficult. A systematic study of the whole area was made in 1905 by Ulrich,[52] who arranges the formations as follows:

Classification and synonymy of the formations of the "Magnesian" or "Ozark series" in Missouri.

System.	Series.		Formation.	Thickness (feet).	Synonyms.
Ordovician.	Saratogan and Lower Ordovician.		Joachim limestone.	0–150	First Magnesian limestone. Folley limestone.[a]
			St. Peter ("Crystal City") sandstone.	0–200	First or Saccharoidal sandstone. Cap-au-Grès sandstone. Pacific sandstone. "Key sandstone" in Yellville district of Arkansas.
		Potosi or Yellville group.	Jefferson City limestone.	50–250	Second Magnesian limestone. Winfield limestone. Finley limestone.[b] ?Marshfield sandstone.
?			Roubidoux formation.	70–225+	Second sandstone. Moreau sandstone. St. Elizabeth formation and Bolin Creek sandstone member. ?Marshfield sandstone. ?Bolivar sandstone.
Cambrian.			Gasconade limestone.	450–650	Third and Fourth Magnesian limestones and Third sandstones. Includes Osage limestone; Cole Camp sandstone of Winslow; also Gasconade limestone, Gunter sandstone, and Proctor limestone of Ball and Smith. Lesueur limestone.
		True Saratogan.	Elvins formation.	0–120	Basal part of the Potosi limestone and the "Potosi slates and conglomerates" of Nason.
	Acadian.		Bonneterre limestone.		?Fourth Magnesian limestone (in part). Decaturville limestone.
			La Motte sandstone.	0–300	Second sandstone of Shumard (in part).
Archean.			Granites and porphyries.		

[a] The names "Folley limestone," "Cap-au-Grès sandstone," and "Winfield limestone," together with a number of other new names, were published by Keyes in Some geological formations of the Cap-au-Grès uplift: Proc. Iowa Acad. Sci., vol. 5, 1898, pp. 58–63.

[b] The names "Finley limestone," "Marshfield sandstone," and "Decaturville limestone," appear in a provisional table of geologic formations in Missouri, by Shepard, E. M., Bull. Bradley Geol. Field Sta., 1904, p. 42.

Ulrich remarks:

As has already been stated, none of the classifications and subdivisions of the Ozark series of rocks, briefly discussed in the foregoing pages, has proved wholly satisfactory. An arrangement that would be above criticism is perhaps impossible. Some of the beds vary so greatly from place to place that it is difficult to follow them over any considerable area. The difficulties are greatly enhanced by the apparent scarcity and imperfect preservation of the fossils and by the general similarity in lithologic character exhibited by widely separated beds in the series. The occurrence of beds of sandstone at intervals in the mass of magnesian limestones was early seized upon as affording a ready means for dividing the series into formations; but experience gradually taught that most of the sandstones were mere lenses, irregularly developed at unequal intervals and occurring locally as many successive beds or with only two or three. In the northern and central parts of the Ozark Plateau the sandstone beds seem to be more regularly developed than elsewhere, and here they are of considerable use in working out the stratigraphy. Along the southern border, however, only the First or St. Peter sandstone seems to have been so well developed as to mark a definite horizon. Along the eastern border, especially in Ste. Genevieve County, the upper half of the series is thicker than usual. It here contains so many beds of sandstone that it is very difficult to establish the boundary line between the Gasconade and Roubidoux formations and between the latter and the overlying Jefferson City limestone.

A careful study of the cherts has yielded perhaps the most reliable of the lithologic criteria employed in discriminating the three formations of the Potosi group. As this group covers by far the greatest part of the Ozark area, the opportunities for studying and testing the value of certain varieties of chert as indices of particular horizons are unusual. Having checked the results in many instances by evidence afforded by fossils, which really are much commoner in these rocks than is generally believed, we have gradually become convinced that the story as told by the cherts is rarely at fault. The mere presence of considerable quantities of chert is at once reliably indicative of the Potosi group, the underlying limestones being practically free from it, as is true also of the Joachim limestone at the top of the series. It is to be remembered, however, that the proportion of chert in a given bed may vary greatly in near-by exposures. This is shown often very strikingly in opposite faces of a hill, the one side of which forms a bluff, the other a gentle, soil-covered slope. In cases of bluff exposure, where side erosion is active and takes place under conditions very different from those prevailing on gentle slopes, the limestone beds may often seem to be almost entirely without chert, but on the other side of the hill the surface may be thickly strewn with it.

The classification presented in tabular form on page 104 is based upon more or less extended investigations in all parts of the field. The formations are discriminated chiefly by lithologic differences and limited in most cases by at least local stratigraphic discordances. As the formations are intended to express as much as possible lithologic units deemed worthy of being mapped separately, the evidence of the fossils found in them was accorded secondary rank. However, in the determination of the age of the deposit the faunas were depended upon almost exclusively.

It will be observed that the division between the Ordovician and Cambrian is drawn as a dotted line opposite the Roubidoux member of the Potosi. This seeming indecision concerning the point at which the line should be drawn is not due to the absence of a fauna, for we have succeeded in collecting a large one, but because of the conflicting elements contained in it. The trilobites from the Gasconade and the lower part of the Roubidoux are, so far as observed, nearly all of types that hitherto have been regarded as strictly indicative of the Upper Cambrian. On the other hand, the numerous gastropods and fewer brachiopods found in the same beds are nearly all of Lower Ordovician types.

Ulrich [52a] also gives detailed descriptions of the formations.

The latest classification of the rocks of this series is that made by Buckley, [106] who in 1909 published a paper in which several new names were introduced for the rocks lying between the Roubidoux and the Bonneterre.

K 12. IDAHO AND UTAH.

Walcott[859a] has recently classified the Cambrian of northeastern Utah and southern Idaho. The localities lie in the vicinity of Logan, between Great Salt Lake and Bear Lake. The classification below is taken from his paper:

Cambrian formations in northeastern Utah and southern Idaho.

Formation.	Character.	Thickness (feet).	
		Blacksmith Fork.	West of Liberty.
Upper Cambrian.			
St. Charles formation	Bluish to gray arenaceous limestones, with some cherty and concretionary layers, passing at the base into thin-bedded gray to brown sandstones.	1,225	1,197
Middle Cambrian.			
Nounan formation	Light-gray to dark lead-colored arenaceous limestones	1,041	814
Bloomington formation	Bluish-gray, more or less thin-bedded limestones and argillaceous shales. Small rounded nodules of calcite occur scattered irregularly through many of the layers of limestone.	1,320	1,162
Blacksmith formation	Gray arenaceous limestone in massive layers	570	23
Ute formation	Blue to bluish-gray thin-bedded fine-grained limestones and shales, with some oolitic, concretionary, and intraformational conglomerate layers.	759	731
Spence shale	Argillaceous shales	30	30
Langston formation	Massive-bedded bluish-gray limestone with many round concretions.	107	30
Brigham formation	Massive quartzitic sandstones	1,250+	1,000+

In a recent paper Blackwelder[84b] writes as follows regarding the Cambrian of northeastern Utah:

Just below the fossiliferous Cambrian shales and limestones there is a quartzite 1,000 to 1,500 feet thick. This quartzite rests now on the eroded surface of the Algonkian quartzite and slate, and now on the much older gneiss and schist which are generally referred to the Archean. Walcott has named it the Brigham quartzite, but it may be seen most clearly at places such as Ogden and Willard, rather than at Brigham. The oldest fossils found in the shales are referred by Walcott to the Lower Cambrian. The Brigham quartzite may therefore be assigned also to the early Cambrian and the quartzites and slates beneath the unconformity to the Algonkian. There is, however, an alternative view, advocated by Daly and others, that the oldest Cambrian faunas in the Rocky Mountains are Middle Cambrian and that the thin Brigham quartzite is the same in age; that the unconformity represents a brief time interval and that the great quartzite slate series is not Algonkian, but simply early Cambrian. Critical studies over a wide area are a necessary preliminary to the settlement of this question. It is to be remembered that the unconformity seems to imply the complete removal of the great quartzite series during the erosion interval and over wide areas. The time involved should therefore be more than a brief interruption.

The House Range, which lies near the western boundary of Utah, between the 39th and 40th parallels, comprises a section which according to Walcott, "extends from well down in the Lower Cambrian to the base of the Ordovician, and is the best and most complete of the Basin Range sections so far studied."

Walcott's published section [859b] (condensed) is as follows:

Section of Cambrian rocks in House Range, Utah.

Formation.	Character.	Thickness (feet).
Upper Cambrian.		
Notch Peak formation	Gray arenaceous limestone in more or less massive layers	1,890
Orr formation	Gray slightly arenaceous limestones and shales	1,825
Middle Cambrian.		
Weeks formation	Thin-bedded shaly limestones, with a few bands of oolitic and arenaceous limestones.	1,390
Marjum formation	Gray to dark, more or less thin-bedded arenaceous limestone	1,092
Wheeler formation	Alternating bands of thin shaly limestone and calcareous shale	570
Swasey formation	Bluish-gray oolitic and arenaceous limestone, with some calcareous and argillaceous shales.	238
Dome formation	Massive-bedded gray siliceous limestone	355
Howell formation	Dark, more or less massive limestone and pinkish argillaceous shales	640
Lower Cambrian.		
Pioche formation	Arenaceous and argillaceous shaly layers with some thin layers and bands of limestone more or less irregularly interbedded and limited in horizontal distribution.	125
Prospect Mountain formation	Gray to brown quartzitic sandstones	1,200+

Regarding the Pioche shale, Walcott [859c] states:

Thickness.—At Pioche, Nev., 210 feet. On the west face of the Highland Range, 18 miles west of Pioche, this formation is 170 feet thick. In the Eureka district of Nevada, 135 miles northwest of Pioche, this formation lies between the Prospect Mountain quartzitic sandstone and the great limestone series and is about 200 feet in thickness. In the House Range section, 105 miles north-northeast of Pioche, the formation is 125 feet thick. In the Big Cottonwood section of the Wasatch Range, about 125 miles northeast of the House Range, near the old shore line, the Pioche formation is represented by the lower portion of the arenaceous shales which are here 250 feet in thickness. The Pioche formation horizon is next met with to the north where the line of the Canadian Pacific Railroad crosses the Continental Divide. At this place the formation is called the Mount Whyte formation.

K 18. PENNSYLVANIA.

The results reached by Stose in the study of the Chambersburg quadrangle, Pennsylvania, comprising part of South Mountain and the valley about Chambersburg, may be taken as representative for southeastern Pennsylvania. The following statement [800] is taken from an article in the Journal of Geology:

The rocks in this area are largely concealed by the sandstone débris which covers the mountain tops as well as the valleys and slopes. Their character, thickness, and relation are therefore not readily determined. The structure is also complicated by schistosity and jointing which exist in all these rocks. The mountains are composed of Georgian (Lower Cambrian) quartzites, sandstones, and shales and older igneous rocks; the adjacent portions of the valley of Cambrian and Ordovician limestones and shales.

Old volcanics.—The basement rocks exposed in the area are ancient volcanic rocks, greenstone and altered rhyolite, which underlie the basal Cambrian unconformably. They occupy the plateau-like tract overlooked by higher peaks in the center of the mountain area shown on the map and in the extreme southeast corner and are extensively developed to the eastward.

The volcanic origin of these ancient rocks is clearly shown by flow banding, amygdaloidal structure, and spherulites, as described by Williams and Bascom. The greenstones are sheared dense rock, veined with asbestos and chlorite. The original structure is seldom preserved, but the rock is apparently an altered basalt. The rhyolitic rocks are of purple and red tints, often porphyritic and frequently banded by flow structure or spherulitic streaks. The rhyolitic rocks predominate in this area and apparently overlie the greenstone, for the basal Cambrian sediments are composed largely of rhyolitic fragments and not of basaltic detritus, as would be the case if the greenstone were younger and had been eroded from most of the area.

Basal sandstones.—Overlying these softer rocks are about 4,500 feet of sandstone, quartzite, and shale of Georgian (Lower Cambrian) age. The basal beds, forming the higher and more rugged portions of the mountains, are composed of coarse purple and yellowish banded sandstones, fine conglomerate, and arkose, with white feldspathic and vitreous sandstones above. The purplish conglomerate bed is composed of small pebbles and grains of quartz, feldspar, and purplish slate or tuff, the flat slaty fragments often having a diameter of 2 inches. This grades almost imperceptibly through soft purplish arkose into the reddish rhyolitic eruptives below, demonstrating their derivation largely from similar volcanic rocks exposed along the near-by shore of the Georgian sea. In Maryland, and also at Mount Holly, at the north end of South Mountain, basal conglomerates contain numerous large quartz pebbles, probably in part derived from the granitic basement complex of the Piedmont.

This basal sandstone, on account of its hardness, forms high, rugged ridges in the heart of the range, such as Rocky Mountain and Snowy Mountain. It is continuous with the Weverton sandstone of the Catoctin and South mountains, Maryland, as mapped by Keith, and the name is therefore used here. The underlying Loudoun formation, which is described by Keith as variable in composition and thickness in Maryland, was not recognized as a distinct formation in this area but may be represented in the soft arkose at the very base of the sedimentary series.

Upper shales and sandstones.—Above the Weverton sandstone there are about 3,200 feet of shale and soft sandstone in which are two horizons of hard, ridge-making sandstone. The softer beds are poorly exposed, being everywhere covered by the débris from the adjacent sandstones. Their presence is inferred from the fact that their outcrop is always occupied by valleys and depressions. Their character is indicated in part by occasional fragments of thin shaly sandstone and black banded slate or red ferruginous shale. The hard sandstone beds form the ridges along the mountain front and cap the high, flat-tipped Sandy Ridge, as well as Big Flat Ridge north of Fayetteville. The lower of the two sandstones is the more massive and is composed of a hard quartzitic stratum, usually of dark-gray color and veined with quartz, and a softer, granular, white layer containing long, slender scolithus tubes. The upper hard bed at the top of the shale is a milk-white or slightly pinkish granular calcareous sandstone, frequently disintegrating by the removal of the soluble cement to yellowish quartz sand, which is quarried for building purposes. This bed also contains numerous *Scolithus linearis* borings, and in places *Camarella minor* and fragments of Olenellus have been found, by which its age has been determined to be Georgian (Lower Cambrian).

In the Catoctin and South mountains of Maryland Keith has mapped above the Weverton sandstone 800 to 1,200 feet of shale (Harpers) and 500 to 700 of sandstone (Antietam). The Harpers shale is typically exposed at Harpers Ferry, on the Potomac River, and, as described by Keith, consists of a bluish-gray shale with a few thin sandstone beds. Northward these sandstone beds are said to thicken, some attaining 50 feet, but do not have an appreciable effect on the topography. On the road from Monterey to Waynesboro, in the southeast corner of the area shown on the map, this series is fairly well exposed, but, according to Keith, the structure is complicated by folding and faulting. Above the Weverton sandstone in this section, as seen by the writer, are shales or slates, in part dark-banded, containing a conspicuous white scolithus-bearing sandstone 20 to 30 feet thick, all of which is mapped by Keith as Harpers shale. Above the shale is the scolithus sandstone in which Walcott found Olenellus and *Camarella minor*, as noted above, and which is mapped by Keith as Antietam sandstone.

North of Little Antietam Creek there are two ridge-making sandstones above the Weverton sandstone, one composing Sandy Ridge and the other Curve Mountain, and between them is black-banded slate with thin ferruginous sandstones. The upper bed forming Curve Mountain is undoubtedly the Antietam sandstone, and it is apparent that one of the sandstone beds in the Harpers shale of Maryland increases in prominence northward, so that in Pennsylvania it reaches such dimensions that it forms a distinct ridge. The Harpers formation in this area therefore consists of shales and soft sandstones, with a quartzitic member near the middle which is here named the Montalto quartzite, from Montalto Mountain. Northward the shale gradually thins, and the sandstone continues to expand until at the northern border of the area it occupies almost the whole interval of the formation, indicating a gradual change from a fine mud deposit in the south to coarser siliceous sediments in the north. Similar conditions may have continued into Antietam time and have affected the deposition of the Antietam sandstone. The patchy occurrence of the Antietam in the Maryland area, as mapped and described by Keith, may be due to its irregular deposition in that area, instead of to infolding in the Harpers shale and to faulting, as previously supposed. Irregularity of Antietam sedimentation in the Pennsylvania area also is indicated by the absence of ridge-making character east and southeast of Montalto, where the bed is thin, disintegrated, and inconspicuous.

In the columnar section of the Mercersburg-Chambersburg folio these older strata are given the following thicknesses by Stose:[802]

	Feet.
Shenandoah limestone.	
Antietam sandstone	500–800
Harpers schist and Montalto quartzite member (20–850)	2,750
Weverton sandstone	1,250
Old volcanics.	

In an article on the Cambrian and Ordovician limestones of the Appalachian Valley, Stose[801a] says:

The limestones of the Appalachian Valley, which in the South are separated into many formations, have generally been treated as a unit in the North under the name Shenandoah, or other local terms, such as Valley, Lancaster, Kittatinny, and York. These rocks include all the strata between the Cambrian quartzites of Georgian age and the Martinsburg ("Hudson") shale of Ordovician age.

In a paper on the sedimentary rocks of South Mountain the author briefly described the formations comprising the Shenandoah group in southern Pennsylvania. Later studies of these rocks in the Cumberland Valley of Pennsylvania have furnished data for a more complete description of the group, including the faunal content and correlation, based on determinations by E. O. Ulrich.

The formations comprising the Shenandoah group in southern Pennsylvania are as follows:

	Martinsburg formation	Eden. Utica. Upper Trenton.	Ordovician.
Shenandoah group.	Chambersburg limestone, 100–600 feet	Lower Trenton. Black River. Lowville. Upper Chazy.	
	Stones River limestone, 800–1,000 feet	Lower and middle Chazy.	
	Beekmantown limestone, 2,250–2,300 feet [including Stonehenge limestone member at the base, 500 feet]	Beekmantown.	
	Conococheague limestone, 1,635± feet	Saratogan.	Cambrian.
	Elbrook formation, 3,000± feet	Acadian.	
	Waynesboro formation, 1,250± feet		
	Tomstown limestone, 1,000± feet	Georgian.	
	Antietam sandstone		

The Tomstown limestone * * * is composed largely of limestone, both massive and thin bedded, in part cherty, with some shale interbedded near the base. * * * [The more characteristic fossils which it has yielded are Salterella sp. undet., Kutorgina n. sp., and fragments of Olenellus. These definitely determine its age as Georgian (Lower Cambrian).—G. W. S.]

In central Virginia a formation 1,600 to 1,800 feet thick, occupying about the same interval but apparently including beds which in the Chambersburg area are calcareous sandstones and are mapped with the overlying Waynesboro formation, has been named Sherwood limestone by H. D. Campbell. * * *

The Waynesboro formation is a series of sandstones, purple shales, and limestones overlying the Tomstown formation. At the base are very siliceous gray limestones that weather to slabby porous sandstone, large round masses of rugose chert, and white vein quartz. In the middle of the formation are dark-blue to white subcrystalline limestones and dolomites, which become siliceous upward and merge into mottled slabby sandstone and dark-purple siliceous shale at the top. * * * A few poorly preserved shells, two of which are identified as Obolus (Lingulella) sp. undet., obtained from sandy shale at the very top of the formation, suggest Acadian (Middle Cambrian) age but are not conclusive.

In central Virginia the Buena Vista shale, described by H. D. Campbell, is at this general horizon, but, as previously stated, apparently has a different lower limit. It is described as bright variegated shale, 600 to 900 feet thick, with mottled limestone and shale in the lower part. Mr. Walcott found in it a species of Ptychoparia related to Acadian (Middle Cambrian) species of Tennessee.

The Elbrook formation is the thick series of gray to light-blue shaly limestone and calcareous shale that overlies the purple Waynesboro formation. The formation is decidedly shaly, most of the included limestones being minutely laminated and weather readily into calcareous shaly plates. * * * Near the middle are massive beds of dolomite and very siliceous or quartzitic limestone that weathers to porous slabby sandstone and frequently forms knobs and ridges. The formation is limited above by limestone conglomerates containing rounded vitreous quartz grains and others containing tabular fragments of limestone, which characterize the base of the overlying formation. * * * The only fossils found in this formation were fragments of trilobites, which suggest Acadian.

The Conococheague limestone is characterized by beds containing thin sandy laminæ and quartz grains that weather into hard shale fragments and thin slabby sandstones which generally give rise to rocky hills and rugged topography.

The base of the formation is usually easily determined because it is marked by siliceous beds and conglomerates that produce a ridge. The conglomerates are of two kinds; one is composed of rounded limestone pebbles, 1 inch or more in size, in a matrix containing numerous round coarse grains of vitreous quartz; the other is composed of long slender fragments of limestone in a calcareous matrix, which, because the fragments are tilted at various angles, is called "edgewise" bed. Interbedded with the conglomerates are oolites and dark shaly limestones with red clay partings.

The body of the formation is a closely banded dark blue limestone, the bands varying from one-half inch in width to minute laminæ. The banding is inconspicuous in the fresh rock but is brought out in weathering as yellowish sandy streaks across a light-blue or gray surface. Toward the top these partings become more numerous and sandy, and weather into hard sandy plates and sheets. Chert is not an important constituent of the formation in the Chambersburg and Mercersburg quadrangles. * * * The fossils found in this formation comprise *Dikelocephalus hartii* Walcott; D. sp. undet.; and Billingsella like *B. desmopleura*. The trilobites place this part of the formation definitely in the Saratogan (Upper Cambrian). In the basal conglomeratic beds a species of Cryptozoon, probably *C. proliferum* Hall, characterized by a mammiferous surface, the elevations one-half to 1 inch in diameter, is rather generally present.

The Beekmantown is a rather pure limestone lying between the siliceous Conococheague below and the very pure Stones River above. A minutely laminated appearance on weathered surfaces of many of the beds, due to their impurities, and pink to white fine-grained limestone or marble are characteristic features of the formation. Near the base are siliceous banded beds and large "edgewise" conglomerate, closely resembling the Conococheague formation. These have been separated as a transition phase under the name Stonehenge member of the Beekmantown.

Although sparingly fossiliferous as a whole, the Beekmantown has yielded a large variety of forms, which are listed in Stose's paper and in accordance with which the Pennsylvania occurrence is correlated by Ulrich with the New York formation of the same name.

For descriptions of the overlying later Ordovician limestones see Chapter IV (pp. 176–179).

The Cambrian and Ordovician limestones are exposed in Center County, Pa., on the Nittany anticline, where Ulrich has distinguished several subdivisions of the Beekmantown.

In eastern Pennsylvania, in the vicinity of Philadelphia, the early Paleozoic rocks are highly metamorphosed. The Wissahickon mica gneiss, which has been considered to be of Cambrian or Ordovician age, is now regarded as pre-Cambrian. Its relations to the Paleozoic are clearly described by Bascom.[58a] The Cambrian is represented by the Chickies quartzite and part of the Shenandoah limestone. The upper part of the Shenandoah is of Lower Ordovician age, probably Beekmantown. The middle and possibly later Ordovician are represented by the Octoraro schist, in some part at least. (See pp. 177–178.)

Regarding the Cambrian and Lower Ordovician (Chickies quartzite and Shenandoah limestone), Bascom says:

The Chickies quartzite usually shows a conglomeratic lower member, which is largely composed of elongated pebbles of the blue quartz that characterizes the pegmatites and some facies of the Baltimore gneiss. This lower member of the quartzite is not often exposed. * * * The conglomerate passes upward into a gray, compact, crystalline quartzite, which, in turn, grades into a siliceous slate or a sericitic quartz schist, or is altogether supplanted by the quartz schist. * * *

Thirty miles west of the Philadelphia district a section through the Chickies quartzite shows a considerable thickness of micaceous feldspathic material interbedded with the quartzite. Such beds occur as the uppermost member of the series, separating typical quartzite from the overlying limestone, and also as a lower member. Toward the east these micaceous beds become very thin and are altogether absent from the Philadelphia district. * * *

The thickness of the formation varies; it never exceeds and is often less than 1,300 feet, although the isoclinal folding in some localities gives the appearance of greater thickness. An overturned synclinorium with stratification and cleavage dips to the southeast is the prevailing structure. * * *

The name of the formation is taken from the locality of its finest exposure and greatest thickness, on Susquehanna River north of Columbia. At this locality the quartzite shows abundant traces of *Scolithus linearis*, as is the case also in the North Valley Hills, and underlies quartzite in which Olenellus fragments have been found by Walcott, thus establishing its age as Georgian ("Lower Cambrian"). The quartzite of the Philadelphia district deposited farther to the east than this typical exposure of Georgian quartzite on Susquehanna River may have been laid down in an encroaching sea and thus belong to a later stage in the Cambrian than the Georgian. No forms of life save *Scolithus linearis* have been found in it, hence it can not positively be stated to be of Georgian age. It can, however, be safely affirmed to be Cambrian and is to be correlated with the Cheshire quartzite of New England, the Poughquag quartzite of New York, the Hardyston quartzite of New Jersey and provisionally with the Setters quartzite of Maryland. It is the Primal sandstone of H. D. Rogers and the Formation No. 1, Chickies sandstone of the Second Geological Survey of Pennsylvania. * * *

The Shenandoah ("Chester Valley") limestone is a heavily bedded crystalline white or blue magnesian limestone. Its surface exposure in the Philadelphia district is confined, with a few scattered outcrops along the Huntingdon and Cream Valley faults, to Chester Valley, where it covers an area 20 miles long and 2 to 2½ miles wide. * * * The limestone is highly siliceous and magnesian. The analyses show great variation in the percentages of SiO_2 and MgO, but no analysis gives a sufficiently high content of MgO to warrant calling the formation a dolomite. It is everywhere crystalline, and increasingly so from west to east. Associated with increasing crystallinity is a lighter color, though blue and white limestone may occur in the same quarry.

It is in places quite micaceous, and always so in the neighborhood of the overlying mica schist. The beds immediately underlying the mica schist are siliceous, micaceous, and schistose and are to be characterized as calcareous schist. The limestone is abundantly traversed by calcite and quartz veins. Quartz, feldspar, phlogopite, graphite, pyrite, and siderite are accessory constituents, disseminated in minute grains and crystals. Limonitic iron ore occurs in pockets in the limestone.

Intercalated with the limestone are beds of siliceous or micaceous schists. These intercalations, which are lenticular in character, are conspicuous in the limestone west of the Philadelphia district but occur infrequently in that portion of the limestone confined to Chester Valley. Near Pomeroy, 25 miles west of the Philadelphia district, an intraformational calcareous conglomerate shows near the top of the formation. * * *

If the interpretation of the structure given above is correct the thickness of the formation must be much less than the width of its outcrop. It is not determinable exactly, but probably is not greater than 1,000 feet.

Fossils of Chazy, Beekmantown, and Trenton ages have been found in the limestone occurring to the west of Chester Valley and stratigraphically continuous with the limestone of Chester Valley. Fossils have also been found in Chester Valley in somewhat ambiguous material. This material is a drusy, geodiferous rock which seems to have originated through the replacement of calcareous material by silica. A mass of the rock is exposed just south of Bridgeport, near the Trenton branch of the Philadelphia Railroad. Elsewhere it is found only in scattered fragments which rest on the limestone and accompany more or less persistently the contact of limestone and Octoraro schist. It thus seems to mark a definite horizon whose persistence between the schist and the limestone precludes the possibility of a faulted or an unconformable contact.

The material has not proved fossiliferous except at one locality, near Henderson station, where fragments resting on the surface of the ground have been found to contain gastropod and cephalopod forms.

The following determinations were made by E. O. Ulrich, of the United States Geological Survey: Raphistoma, two species, Maclurea, Lituites, Cyrtoceras. These are Ordovician forms and indicate a horizon in the lower half, probably Beekmantown. The limestone overlies conformably Georgian ("Lower Cambrian") quartzite and is therefore Cambro-Ordovician in age. It is correlated with the Stockbridge limestone of New England and New York, doubtfully with the Cockeysville marble of Maryland, and with the Shenandoah limestone of Virginia. It is the most easterly representative of the great belt of limestone, the Auroral limestone of H. D. Rogers and Formation No. II of the Second Geological Survey of Pennsylvania. Aside from a few scattered and very minor exposures, the limestone of the Philadelphia district is confined to and controls the form of Chester Valley, a conspicuous topographic feature of the district. For this reason it has long been locally known as the "Chester Valley limestone."

It is here called the Shenandoah because it has the same limits and stratigraphic associations as the extensive and well-known limestone of that name.

That calcareous sedimentation, which began in Cambrian time, continued into Ordovician time is shown by the presence of Lower Ordovician fossils in an upper member of the Shenandoah limestone.

Further sedimentation in Ordovician time is represented by the Octoraro. This is the best-known Paleozoic deposit in this region and, like the preceding Paleozoic sediments, is dynamically metamorphosed and free from igneous intrusions.

K 18. NEW JERSEY.

The Cambrian and Lower Ordovician strata of New Jersey have been described recently by Weller[880a] and Kümmel[513] on the basis of earlier reports and recent field work. From Kümmel's paper we take the following general description:

The Hardyston quartzite is the lowest formation of the Cambrian system, and is probably to be correlated with the Poughquag quartzite of Dutchess County, N. Y., and the Chickies quartzite of Pennsylvania. It is unconformable on the pre-Cambrian complex and is the oldest fossiliferous rock in New Jersey. It varies considerably in composition and thickness. Typically it is a quartzite, at many places conglomeratic and containing pebbles of quartz, feldspar, granite, gneiss, and slate. Locally the formation is a calcareous sandstone. It is usually but not invariably feldspathic. In some localities its arkose character is so marked that it is not readily distinguishable from a coarse granite. Beds of slate occur in its upper portion.

Its thickness ranges from a few feet to 200 or more, and it passes into the overlying sandstone through slaty or shaly layers, several of which are in places interbedded with limestone layers, so that its upper limits are indefinite. Since it contains a species of Olenellus, it is regarded as of Georgian (Lower Cambrian) age.

The Hardyston quartzite grades upward into the thick magnesian Kittatinny limestone of the Kittatinny Valley. Above, it is limited by an unconformity at the base of the Jacksonburg (Trenton) limestone. The presence of thin shales and scattered seams of sandstone in the great mass of limestone shows an influx of land sediments at recurrent intervals during its formation.

The known fauna of the Kittatinny is not extensive and is found at but few localities, but it suffices to establish the Cambrian age of the greater part of the formation. No Middle Cambrian fossils have been found, but as the Olenellus fauna of the Hardyston quartzite is considered to be of Lower Cambrian age, and as no evidence of a break in sedimentation has been observed, a Middle Cambrian fauna would naturally be expected between the Olenellus fauna below and the Dikelocephalus fauna above. In one locality a fauna of Ordovician (Beekmantown) age has been found in beds near the top of the Kittatinny limestone. This formation, therefore, where complete, represents a period extending from the middle or upper part of the Lower Cambrian to the lower part of the Ordovician, inclusive.

From a discussion of the fossils found in the Kittatinny limestone, probably mostly from its upper portion, Weller[880a] concludes:

The position of these various fossiliferous beds of the Kittatinny limestone in the formation as a whole can not be determined with certainty, but it may probably be stated, with a degree of safety, that all of these fossiliferous localities, with the exception of that near Carpentersville, are in the upper portion of the formation. The Carpentersville locality is probably somewhere in the lower third of the entire series. So far as the fossils afford any definite evidence, the age of all is upper Cambrian. No middle Cambrian faunas have been recognized, although the Olenellus fauna of the Hardyston quartzite is usually considered to be of lower Cambrian age, and a middle Cambrian fauna would naturally be expected to occur somewhere in the formation.

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K 18. SLATE BELT, EASTERN NEW YORK AND WESTERN NEW ENGLAND.

The stratigraphy and structure of eastern New York and adjacent New England were worked out by Walcott in 1886 and 1887, and the results were published in part in a paper entitled "The Taconic system of Emmons."[849] Dale[207a] subsequently studied the "slate belt," of which the Taconic Range is a central feature, and incorporated Walcott's manuscript material and other data in a report from which the following extract is taken. (See also references to Cambrian and Lower Ordovician in Chapter IV, pp. 183–192.)

The formations shown [on the geologic map] are but two—Lower Cambrian and Lower Silurian (Ordovician). The larger part is Cambrian. This includes the "sea-green," the "unfading green," the purple, and the mottled slates, while the "red" slates, with the accompanying "bright-green" slates, are in the Ordovician. An area of about 8 square miles in Benson containing black roofing slates is of uncertain age—certainly Cambrian or Ordovician, quite possibly Ordovician. The Ordovician areas are very irregular—in some places isolated lenticular masses, compound synclinal in structure, surrounded by and overlying the Cambrian. Some very small isolated Ordovician areas—as near Hillsdale, west of Middle Granville, and west of Lake St. Catherine, near the Wells and Poultney line—probably represent single and overturned synclines. The Ordovician also surrounds lenticular masses of Cambrian, probably compound anticlinal in structure, which protrude through the Ordovician. The central belt of Ordovician sends out long, narrow spurs into the Cambrian area, which alternate with tapering, baylike recesses of Cambrian, the formations being thus dovetailed into one another. On the eastern side the Cambrian slate series comes into contact with the Ordovician schist mass of the Taconic Range; but north of Rupert and east of West Pawlet, Vt., for a space of 6 miles there appears to be a transition from the Ordovician slate into the Ordovician schist. The central Ordovician belt, with all its complex ramifications, thus appears to be merely a continuation of the mass of the Taconic Range itself, and 40 miles south, in Petersburg, Rensselaer County, N. Y., a continuation of the same Ordovician area again merges into the schists of the Taconic Range. Hudson graptolites also occur quite close to the schist mass in Pawlet. * * *

Owing to excessive and minute folding, as well as cleavage and the friable character of some of the shales, it has been found very difficult to construct an entirely satisfactory columnar section of the strata. The relative position of some of them is doubtful, owing to their intermittent character and the possibility of their merging along the strike into other members of the series. The thickness of several of them is uncertain, owing to scarcity of measurable sections. As the lower limit of the Cambrian is nowhere reached within the slate belt the section starts with an uncertainty, and the prevalence of shales in the Ordovician makes the top of the column indefinite.

Dale gives a table showing the probable equivalence of the various divisions recognized in the great sequence of Cambrian and Ordovician shales.

For an account of the Cambrian and Ordovician of Mount Greylock and adjacent areas in western Massachusetts, see Chapter IV (pp. 192–194).

K 19. EASTERN MASSACHUSETTS.

The Cambrian rocks of the Boston Basin were thus described by Crosby:[181]

The oldest rocks which we have found are the Primordial slates and quartzites; and the age of these is certainly and definitely known only at the Paradoxides quarry, in Braintree. We appear to be justified, however, in regarding them, provisionally at least, as all of about the same age, partly on account of a general lithologic resemblance, but mainly because their relations to the different classes of eruptive rocks are everywhere the same. In Weymouth and

Braintree, where we first met these rocks, they are either typical clay slates or slightly calcareous; but along the northern base of the Blue Hills occasional layers are distinctly siliceous. They probably underlie a large part of the Boston Basin, being covered by the conglomerate and the newer slate; and north of the basin they occur in isolated areas among the eruptive rocks. In some of these areas, especially in the Middlesex Fells and Melrose, and in Woburn, clay slate similar to that in Quincy and Braintree is repeatedly interstratified with quartzite; while toward the southwest, in Natick, and also in Reading and Lynnfield, there are extensive developments of quartzite with little or no slate. It is very clear that the quartzite north and west of the Boston Basin is the source of the quartzite pebbles which play such a prominent part in the composition of the conglomerate, especially in the central and northwestern sections of the basin. In general, the quartzite is more and the slate less abundant northwestward, indicating that the ancient shore line along which these strata were deposited lay in that direction; and originally the Primordial strata were probably spread continuously over all the region to the southeast of that line.

Crosby [180] in his earlier work included in the Cambrian the Roxbury conglomerate, which he [182] and others now assign to the Carboniferous.

The fossiliferous slates of Braintree are referred to in the literature on the geology of eastern Massachusetts since 1818. Fossils were described by W. B. Rogers, who stated: [675]

The rock in which these fossils occur is a compact, dense, rather fine-grained silico-argillaceous slate or slaty sandstone, containing little or no carbonate of lime. * * * One of the most curious facts relating to the trilobite of the Quincy and Braintree belt is its seeming identity with *Paradoxides harlani*, described by Green in his monograph of North American trilobites.

Recent finds of fossils belonging to the Braintree slate are reported by Shimer,[739] who says:

Some time ago while having a driveway excavated at his home on Quincy Avenue, in East Braintree, Mass., Mr. Thomas A. Watson found a rather angular slate bowlder, about 2 feet in diameter. He kindly turned it over to the Massachusetts Institute of Technology.

The slate is quite similar in appearance to that of the celebrated Paradoxides quarry on Hayward Creek; it is similarly metamorphosed but is lighter gray in color and lacks the peculiar purplish tinge of the Hayward Creek slate.

In it the following fauna was found:

Name.	Abundance.[a]	Previous occurrence.	Age.
Acrothere gamagei (Hobbs)	r	Hayward Creek	Middle Cambrian.
Hyolithes shaleri Walcott	r	Hayward Creek	Middle Cambrian.
Paradoxides harlani Green	C	Hayward Creek	Middle Cambrian.
Strenuella strenua (Billings)	R	North Attleboro, North Weymouth, and Nahant.	Lower Cambrian.
?Strenuella strenua (Billings)	R		
Olenellus (Holmia) bröggeri Walcott	R	North Weymouth	Lower Cambrian.
Ptychoparia rogersi Walcott	r	Hayward Creek	Middle Cambrian.
Agraulos quadrangularis (Whitfield)	C	Hayward Creek	Middle Cambrian.

[a] C=very common; c=common; r=rare; R=very rare.

This fauna includes five species of the Middle Cambrian, two of which are very abundant, and two of the Lower Cambrian. There is thus a great predominance of the Middle Cambrian element, though it indicates a persistence of the Lower Cambrian element into Middle Cambrian times. So while we have here a transition fauna, the rock must be assigned to the Middle

Cambrian period. This very interesting transition fauna is the first recorded from this region to show in any way a passage from the Lower to the Middle Cambrian.

Shaler and Foerste[732a] found other localities of occurrence of Cambrian strata at North Attleboro, Mass. The fossils belong to the Olenellus zone and occur in red shales and limestone. At the several separate localities the following forms have been collected:

Locality 1, *Hyolithes princeps?*, *Hyolithes micans*, *H. billingsi*, *Stenotheca rugosa* var. *pauper*, *Salterella curvata*, *Pleurotomaria* (*Raphistoma*) *attleboroensis*, *Fordilla troyensis*. In red shale near by occurred *Agraulus strenuus*.

At locality 2 were found: *Obolella atlantica* Walcott, *Obolella crassa* Hall, *Scenella reticulata* Billings, *Stenotheca curvirostra* S. & F., *Stenotheca rugosa* var. *abrupta* S. & F., *Platyceras primævum* Billings, *Hyolithes americanus*, *Hyolithes communis* var. *emmonsi* Ford, *Hyolithes quadricostatus* S. & F., *Microdiscus bellimarginatus* S. & F., *M. lobatus* Hall, *Olenellus walcotti* S. & F. (probably a young form of some known species), *Ptychoparia attleboroensis* S. & F. (probably the young form of some species of trilobite), *Agraulus strenuus?* Billings.

K–L 12–13. WYOMING.

Cambrian strata which outcrop around the crystalline rocks of the Bighorn Mountains constitute the Deadwood formation. They consist of sandstones, shales, and limestones from 850 to 1,050 feet in thickness.

Darton[239a] gives many details of local variation in character. The following is a representative section:

Section of Deadwood formation in Wolf Creek canyon, west of Sheridan, Wyo.

	Feet.
White massive sandstone at base of Bighorn limestone.	
Thin-bedded limestone, gray, greenish, and pinkish tints, with flat-pebble limestone conglomerate and glauconite	300
Gray and greenish shale with thin limestones and sandstones	300
Brown to buff massive sandstone; many fossils	50
Thin-bedded brown and gray sandstones	50
Gray sandstones and shales	35
Hard brown cross-bedded sandstone	6
Brown sandstone and sandy shale	30
Dirty-buff to brown and reddish soft cross-bedded sandstone; much glauconite; many fossils	20
Soft greenish-gray sandstone	12
Buff sandstone with fossils	8
Dark-gray and greenish shales with thin sandstone beds above	200
Coarse-grained cross-bedded buff to brown, massive sandstone	30

The distribution of the Deadwood formation in central Wyoming has recently been described by Darton[244a] as follows:

General relations.—The sandstone of the Deadwood formation is at the base of the sedimentary series in northern and central Wyoming. It thins out to the southeast and apparently ceases at no great distance east of longitude 107°, so that in Converse, Albany, and Laramie counties the Carboniferous rocks lie directly on pre-Cambrian granites and schists. In the Shirley Hills a hard, massive sandstone and conglomerate underlying Madison limestone may be Deadwood. On the West Fork of Troublesome Creek, 9 miles northwest of Difficulty post office and about Leo, this sandstone, 30 feet or more thick, is hard and in part conglomeratic. Near North Platte River, north of the mouth of the Medicine Bow, it is about 100 feet thick. Whether in these areas it is a shore deposit of Madison age or the Deadwood formation was not ascertained. In the basal sandstone in the gorge of North Platte River, 3 miles northeast of Pathfinder, Mr. Walcott found a few fragmentary fossils which he regards as Cambrian.

The hard sandstone at the base of the sedimentary series in the Casper Range and in the ridges to the southeast appears to be a shore deposit of the Casper formation.

Rattlesnake Mountains.—The Deadwood formation outcrops along a portion of the crest of Rattlesnake Mountains west of Oil City. It is about 800 feet thick. At the base and near the middle are 25 to 40 feet of brown to buff fossiliferous sandstone and the basal beds are somewhat quartzitic. Sandy gray shale with thin gray sandstone layers constitute the greater part of the formation, but there is a small amount of impure slabby limestone and reddish shale near the top. Glauconite is a conspicuous ingredient in most beds.

Wind River Mountains.—On the northeast slope of Wind River Mountains the Deadwood formation is about 750 feet thick, and it presents all the features which are characteristic in the Bighorn and other ranges northeastward. Its presence was recognized by Comstock and its distribution was shown in part on maps of the Hayden Survey.

The basal member, which lies on granite, is about 100 feet thick and is the usual hard brownish sandstone. Next are sandy shales and slabby limestone, the latter including more or less of the typical flat-pebble conglomerate of gray limestone pebbles covered with glauconite. The top layer of this limestone contains many trilobites. At the top of the formation is a hard, coarse, fossiliferous sandstone.

Owl Creek Mountains.—Extensive exposures of the Deadwood formation extend along the upper slopes of Owl Creek Mountains and in the canyon of Bighorn River. It also appears along Crow Creek northeast of Circle and in Owl Creek canyon. The thickness is 900 feet and the succession of rocks is similar to that in the Bighorn and Wind River mountains. At the base is hard coarse-grained reddish-brown sandstone, locally conglomeratic below and lying on a remarkably smooth plain of the pre-Cambrian rocks. It varies from 50 to 100 feet in thickness and is succeeded by 200 to 300 feet of sandy shales and thin-bedded sandstones, with a prominent bed of sandstone in their lower portion. In Bighorn Canyon this bed is 50 to 60 feet thick and of bright reddish brown color. The medial member is 400 feet or more of soft greenish-gray shale with a conspicuous gray to buff limestone in its lower part. This limestone, usually 50 feet thick, consists partly of flat pebble limestone conglomerate. Southwest of Embar it is 30 feet thick and 300 feet above the base of the formation. At the head of Muddy Creek it is 40 feet thick and underlain by a somewhat thicker mass of sediments. The top member of the formation is slabby light colored limestone over 100 feet thick at most localities, but apparently either very thin or absent in Owl Creek canyon. It contains frequent layers and masses of the characteristic intraformational conglomerate of flat limestone pebbles more or less intermingled with thin, twisted, and broken layers of limestone in a matrix of shale and fine limestone sand. Many of the pebbles are so thickly covered with grains of glauconite that they appear to be green, but inside they are gray or pinkish, similar to the associated beds.

Fossils.—Fossils at various horizons in the Deadwood formation are of middle Cambrian age, and *Dicelamus politus* and *Ptychoparia oweni* are the principal forms. The former is a small oval shell, which occurs in great abundance in the middle sandstones and in the limestone layers in the shales, as well as in the upper limestone series. The Ptychoparia is a trilobite which often abounds in the basal sandstone. In the middle sandstone of the formation, a short distance west of Garfield Peak of Rattlesnake Mountains, the fossils included a new species, which Mr. Walcott has designated *Obolus* (*Westonia*) *dartoni*. In the top sandstone west of Lander, *Orthis* (*Plectorthis*) [*Eoorthis*] *wichitaensis* was found.

Blackwelder, in an unpublished manuscript (1910), says:

The Deadwood formation of central Wyoming expands westward without suffering much change in lithologic character. Near the south end of the Teton Range the basal sandstone is still only 160 feet thick, but it is overlain by fossiliferous shales and striped limestones, which are locally conglomeratic and oolitic, to a thickness of 1,000 to 1,100 feet. The supposed Cambrian beds are not sharply separated from the overlying massive limestones which contain Ordovician and Silurian fossils.

K–L 13. BLACK HILLS, SOUTH DAKOTA.

The Cambrian Deadwood formation of the Black Hills is described by Darton [232a] in detail in his paper on the geology of the hills. A convenient summary of the facts is given in a later paper,[237a] as follows:

Deadwood formation.—The outcrop of this formation encircles the Black Hills, appearing usually in the base of the great infacing limestone escarpment. It lies on a relatively smooth surface of Algonkian rocks, although there are many local irregularities of shore lines and beach phenomena. The rocks are mostly sandstones and sandy shales, with frequent occurrences of basal conglomerate. In the southern hills the thickness varies from 4 feet to 50 feet in greater part, and the principal material is a coarse dark-brown massive sandstone. To the northward the formation gradually thickens, apparently by the addition of higher beds comprising dark-gray shales, mostly sandy, and beds of sandstone. In the region about Deadwood, where the formation attains its greatest thickness of over 400 feet, it comprises about 30 feet of basal conglomerate overlain by 30 feet of coarse dark-brown sandstone; 200 to 400 feet of gray shales, with layers of flaggy limestone, limestone conglomerate, and sandstone; a conspicuous member of hard massive sandstone 5 to 12 feet thick; and at the top 20 to 45 feet of green shales. The limestone conglomerate is a very characteristic rock, consisting of flat pebbles and flakes of limestone more or less thickly sprinkled with glauconite grains, and is of the intraformational type.

Throughout its course the formation contains fossils of which the following middle Cambrian forms have been reported by C. D. Walcott: Obolus, Hyolithes, Dicellomus, Asaphiscus, Olenoides, Ptychoparia, and Acrotreta.

K–L 15–16. MINNESOTA, WISCONSIN, AND MICHIGAN.

Sardeson [700] suggests that the "New Ulm" quartzite of southern Minnesota may be of Cambrian age, as it contains pebbles of "quartzite conglomerate like the rock (Huronian?) which is in situ at Redstone." The well records,[394] however, which have been carried across southern Minnesota, from the type region of the Sioux quartzite (Algonkian) to and beyond New Ulm, have served to correlate this quartzite with the Algonkian Sioux quartzite.

The Cambrian and lower Ordovician strata of the upper Mississippi Valley have been divided by recent writers into the following formations, all of which are well established in the literature of several States:

- Ordovician:
  - St. Peter sandstone.
  - Prairie du Chien group (formerly called "Lower Magnesian limestone"):
    - Shakopee dolomite.
    - New Richmond sandstone.
    - Oneota dolomite.
- Cambrian:
  - Jordan sandstone.
  - St. Lawrence formation
  - Dresbach sandstone.
  - Shales and sandstones.

The Cambrian strata in southern Wisconsin were described as the "Potsdam sandstone" by Chamberlin,[133] who stated the synopsis of characters thus in part:

Rocks mainly light-colored sandstone in central and southern Wisconsin and red sandstone in the Lake Superior region, but embrace some beds of limestone and shale. Maximum known thickness about 1,000 feet.

Following this synopsis is an account of the conditions of deposition of the sandstone and of the life of the epoch, from which the following is taken:

On the southern side of the Archean island the lower part of the formation usually consists of coarse quartzose sand, of an exceeding open, porous nature, with but little aluminous or ferruginous and almost no calcareous matter. Higher in the series the sandstone becomes finer grained and the accessory substances named more abundant. Somewhat above the middle of the series a stratum of shale occurs, attaining a known thickness of 80 feet. This is not everywhere present and seems to be mainly developed at some distance from the ancient shore line. It appears to indicate that for a time there was a deepening of the waters, admitting of the accumulation of fine sediment, except near the shore, where the deposit of sand continued. Above the shale, sandstone reaching a thickness of 150 feet is again found. This is medium or coarse grained and slightly calcareous. It in turn is overlain by a deposit of associated shale and limestone (the Mendota limestone), which attains a thickness of 35 feet in the vicinity of the lake from which it derives its name. These beds indicate a modification of the conditions of deposition, such as to permit not only the settling of fine sediment but the accumulation of calcareous mud as well. The latter was doubtless derived from the calcareous remains of life, since the sea then swarmed with living organisms whose shells and skeletons are found entombed in the strata. The frequency of broken and worn fragments implies that the greater portion were ground to powder, forming the calcareous flour that subsequently hardened into limestone. These beds appear to point quite surely to a moderate deepening of the waters.

Overlying this impure limestone is a third and thinner bed of sandstone (the Madison) with which the Potsdam series closes. This, on the whole, is finer grained than that below and is bound more firmly together by cementing material, which is mainly a calcareous and ferruginous infiltration. The thickness of this bed is about 30 feet.

The "Lower Magnesian limestone" (Prairie du Chien group), which overlies the Cambrian strata, is described by Chamberlin as the equivalent of the "Calciferous" (Beekmantown) of New York, and as a "cherty magnesian limestone, from 65 to 250 feet thick," which "contains but few fossils." Chamberlin[133a] says further:

During the previous epoch the accumulation of sandstone gave place for a time to the formation of limestone (the Mendota). At the close of the epoch, without any very marked disturbance of existing conditions, the formation of limestone was resumed and progressed, with some interruption, till a thickness varying from 65 feet to 250 feet was attained. This variation in thickness is mainly due to irregularities of the upper surface of the formation, which is undulatory and, indeed, in some localities may appropriately be termed billowy, the surface rising and falling like the swells of a subsiding sea. In the localities where these phenomena are best developed, these petrous billows vary in height from a gentle swell to elliptical domes rising a hundred feet above their bases, while their length ranges from a few rods to a quarter of a mile or more, and their width from one-third to one-half their length. The symmetry of outline here indicated is frequent and typical, though not universal. It finds its best-observed expression in Green Lake and Winnebago counties, where the axes of the domes lie in an east-westerly direction much more commonly than otherwise, or, in other words, are at right angles to the trend of the formation. While not equally conspicuous everywhere, this undulatory surface is prevalent throughout the State and beyond.

The internal structure of these rock billows is interesting. In the more typical ones at least, and perhaps universally, the superficial strata dip in every direction from the center, most rapidly at the sides (the dip sometimes reaching 30°), and less so at the extremities; or, in other terms, the beds are generally concentric with the surface. The rock of this superficial portion is as homogeneous and even grained a dolomitic limestone as is common to the formation and presents no unusual evidence of fracture or disturbance. Indeed, the rock gives the impression of having been laid down as a mantle of calcareous sediment over an irregular surface.

Where erosion has exposed the interior, however, a very different structure is exhibited. The core of the dome appears to be composed of a brecciated mass formed of limestone fragments bound together by calcareous material that seems to have been a mud derived from the wear of the rocks themselves. Although the base of the formation has never been seen immediately beneath one of these prominences, yet from all that can be ascertained from the study of the lower beds in the vicinity, it is probable that the basal strata are homogeneous and horizontal, and unaffected by the peculiarities that lie above.

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In addition to the foregoing peculiarities of stratification, the unity of the formation in eastern Wisconsin is interrupted by a shaly stratum in its subcentral portion, and in northwestern Wisconsin by a sandstone layer of very irregular thickness, sometimes merely consisting of a layer of lenticular or pocket-like deposits. Locally there are seams of sand and shale intercalated in the series, particularly in the basal portion.

The bedding of the rock is usually uneven and heavy, and its texture is coarse, rough, and irregular, though exceptionally it becomes uniform in bedding and grain, forming a beautiful and serviceable rock.

In composition it is, in the main, a magnesian limestone, or, more technically, a dolomite. But it contains in addition much siliceous material, most commonly in the form of flint or chert nodules but sometimes in disseminated sand grains and not infrequently as an oolite, in which the center of the spherules is a grain of sand, about which concentric layers of calcareous material are gathered. Silica also often constitutes a crystalline lining of cavities, forming beautiful little geodes lined with variously colored quartz. A varying amount of aluminous impurity is also present throughout the rock.

A notable feature of the formation is the occurrence, at various heights, of brecciated layers interstratified with others more homogeneous. These are composed of fragments of limestone in a matrix of finer material, derived from the same source. They seem to indicate that the formation, during its deposition, suffered successive variations of conditions, from comparative quiet to forcible wave action, probably due to slight oscillations of level. The comparative absence of fossils under such circumstances is not surprising. There seems little doubt, however, that the material of the formation was derived mainly from the calcareous remains of life.

Chamberlin and later writers have described the St. Peter sandstone, which overlies the Prairie du Chien group ("Lower Magnesian limestone") as Ordovician. (See p. 180.) Walcott[854b] quotes the descriptions of the Cambrian strata by Irving, Strong, Wooster, and Winchell, in addition to the account by Chamberlin. The descriptions of Chamberlin have been supplemented in later work by more extended investigation and correlation of the faunas by Sardeson[699] and by Ulrich.[821]

K–L 18. ADIRONDACK REGION, NEW YORK.

The Potsdam sandstone of the Adirondack region has been recently studied by Cushing,[203a] from whose detailed account the following passages are taken:

Lying unconformably on the old and much eroded pre-Cambric surface, a great sandstone formation appears, on the north and east and on the eastern half of the southern border of the Adirondack region. This is a water-deposited formation and, so far at least as its upper portion is concerned, a marine formation. It is thickest on the northeast, thinning out to disappearance both to the south and west. As, furthermore, it appears to be the upper beds which persist and the lower ones which disappear in these directions, it seems certain that, so far as the immediate region is concerned, the marine invasion came on it from the northeast and extended progressively southward and westward.

In Clinton County, where the formation is thickest, the basal portion is rather sharply differentiated from the rest in character, and this portion has considerable thickness, though how much and how large a part of the whole thickness it constitutes, is wholly uncertain. The writer was the first to show this, and it has lately been reaffirmed by Van Ingen. This portion consists in part of coarse basal conglomerates, in part of poorly indurated sand beds of small durability, and in smaller part of thoroughly indurated sandstones. It is nearly everywhere characterized by a considerable feldspar content, in addition to the quartz, and this feldspar is for the most part fresh. Considerable magnetite also appears in places, along with grains of garnet and occasional zircons. The rock has therefore an arkose character in this portion, while above it is prevailingly of pure quartz sand. Red is the predominant color of the base, and there is but little white sandstone in it, while above the latter is the prevailing color. As a general proposition, a feldspar content and a prevalence of red beds go together and are certain signs of the basal portion.

Basal conglomerates are a prominent feature in Clinton County wherever the proper horizon is exposed. For the most part these are not extra coarse, the larger pebbles seldom exceeding an inch in diameter. The pebbles are prevailingly or exclusively of quartz, derived from the quartz veins of the pre-Cambrian rocks, and are embedded in a coarse sand matrix in which there is a large feldspar and considerable magnetite content. Along most of the northern border the general lack of pebbles of the underlying rocks, which are mostly Saranac gneisses, is indicative of quite prolonged wear of the material, so that only the extra-resistant pebbles of vein-quartz origin were sufficiently durable to persist as pebbles. The undecayed character of the feldspar grains of the sands in these conglomerates indicates that all soil and largely weathered rock had already been removed and carried offshore to be deposited and that the waves were working on tolerably fresh rock, whose grinding to sand had to be performed by water action alone, unaided by any special weakness due to previous weathering.

In some few localities conglomerates indicative of much less vigorous wave action are found. These contain numerous pebbles of the underlying gneisses, often of large size and showing great variation in size, and quartz pebbles are much less conspicuous or lacking. These seem to be purely local deposits laid down in sheltered hollows in the pre-Cambric floor, whose presence is likely due to uneven depth of weathering of the floor rocks. It is in rocks such as these that the pebbles of diabase and syenite porphyry which demonstrate the pre-Potsdam age of these dikes are found. Such conglomerates are much less resistant rocks than the commoner quartz-pebble conglomerates, and present exposures usually show them in much disintegrated condition.

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Very abundant also in the basal portion of the formation are beds of rapidly disintegrating, very red coarse arkose sandstones, made up mainly of quartz and feldspar grains and the whole much permeated with red hematite.

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Well-indurated red sandstones, such as those from the type locality at Potsdam, are not infrequent in the basal portion of the formation and are numerously exposed at various localities on the north border of the Adirondacks in such situation as to indicate clearly their horizon. At Potsdam itself the section is complicated by faulting, and the horizon of the red sandstone there can not be demonstrated, though inferentially it is low in the formation. Along with the red there is much hard glassy brown sandstone, also containing fresh feldspars but lacking the hematite coloration of the red beds. Above, the reds become striped and mottled with white, forming a species of passage beds to the middle division.

Van Ingen is the only observer who has undertaken to differentiate between the middle and upper portions of the Potsdam. He says:

"The middle portion of the sandstone is made up of well-sorted materials, of finer grain, compactly cemented, and of white, steel-gray, or yellowish color, with very little or no feldspathic content. The grains of sand are both angular and rounded, with the former predominating. The layers are more regular, though their surfaces are ripple-marked, and in section they are seen to be almost universally cross-bedded. Pebbles are found on the surfaces of some layers of the middle portion, but unlike those of the upper portion they seem to have been of soft mud derived by erosion of contemporaneous sediments, cast on the beach at times of rough water and flattened and squeezed out by the subsequent pressure and consolidation of the superimposed sand deposits.

"The upper portion of the formation has frequent beds of irregular laminated sandstone, with partings of greenish arenaceous shale. The shale surfaces are covered with fucoids and worm trails. Pebbles of shale and dolomite, which were hardened before the time of their entombment, are found embedded in the sandstone layers, and their disintegration causes cavities to form in the layers containing them. The dolomite pebbles become more abundant toward the upper horizons. In the upper levels frequent beds are composed of nicely rounded grains of clear quartz with a little cement that crumble to a sugary powder under the hammer. Rounded grains of quartz of a slightly larger size occasionally cover the upper surface of a layer of finer-grained sandstone, and, being without cement, they stand out in relief above the surface with an appearance of having been sprinkled from a pepper pot."

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The thickness of the Potsdam in Clinton County is unknown. The thickest measured section is that in the Ausable Chasm, but the section there is complicated by faulting and is by no means complete, all the basal portion being lacking. Walcott's measurement gives 350 feet, and Van Ingen's "at least 455 feet" as the thickness here. In the Morrisonville well, with the drill resting at 1,250 feet in the Potsdam sandstone, at least 750 feet of the formation had been drilled through, and the bottom samples were of clear, glassy quartz sand, with no trace of the feldspars which characterize the basal portion, indicating that it had not been reached. From this record alone it seems perfectly safe to say that the formation has a thickness considerably in excess of that amount in Clinton County. The writer's estimate, based on the broad belt of outcrop in the northern part of the county, assigns a minimum thickness of at least 1,000 feet to the formation, with a likelihood that it is considerably in excess of that amount.

* * * * * * * * *

The paleontologic and stratigraphic work of Walcott and Van Ingen has shown that the upper portion of the formation, through a thickness of some 350 feet, carries a sparse Upper Cambric fauna. With the exception of a few supposed tracks, of uncertain nature, no fossils have so far been found in all the remainder of the formation, and there is therefore an utter lack of paleontologic evidence as to its age, and the possibility that the lower portion may be older than the Upper Cambric must be conceded. But it seems to the writer that, fossil evidence being lacking, the formation as it occurs in New York is not susceptible of subdivision. The basal rocks grade into those of the middle division, as do those into the upper, and there is no marked structural break at any horizon which would warrant the assumption of any great difference in age between base and summit, or any marked pause in sedimentation. Prof. N. H. Winchell has long held and has recently reiterated the view that the typical Potsdam at Potsdam is much older than the upper, white, less-indurated beds, and he classes it in the middle Cambric and correlates it with a portion of the Keweenawan of the upper lake region. As above indicated, the writer's judgment is that any present attempt to divide the formation on the basis of age is premature and has but slender basis of fact, considering the lack of all evidence from fossils.

As has been shown by many observers, the transition from Potsdam to Beekmantown sedimentation is not a sharp one but through a series of passage beds. Near the summit of the former, thin beds of gray dolomite make their appearance, interbanded with the soft white sandstones which prevail there, increase in frequency till they constitute half the mass of the rock, and finally prevail and cut out the sandstones altogether. The sandstone layers are characteristically Potsdam in appearance, and the dolomites as characteristically Beekmantown. There is no mixing of materials but rather a rapid alternation of two contrasted sets of deposition conditions. Walcott has measured a thickness of 25 feet of such passage beds along the Chateaugay River and 70 feet near Whitehall. In the writer's judgment, the latter is much nearer the usual figure than the former. These beds are exposed at many localities along the northern border of the region, but seldom suitably for measurement of thickness. They seem usually of considerable bulk.

Cushing's account of the Potsdam is followed in the report cited by a description of the overlying Beekmantown. In his latest studies, however, he distinguishes under the name "Theresa dolomite" the dolomitic beds which immediately succeed the Potsdam west of the Adirondacks and which he no longer regards as equivalent to the Beekmantown. Cushing [204b] says:

Theresa dolomite.—The Potsdam grades upward into a formation which consists of sandy dolomite layers and beds of weak brown sandstone which are mostly near the base and are quite like the upper beds of the Potsdam. The line between the two formations is drawn at the base of the first dolomite layer, but in all probability this is not a constant horizon over the district. The name given to the formation is mainly intended for local use and the necessity for its introduction arises from present doubt as to the exact equivalent of the formation elsewhere in the region.

When fresh the dolomite is a hard and tough bluish-gray rock, which, however, quickly weathers to iron-stained sandy crusts. All the beds are somewhat sandy. The most characteristic lithologic feature of the rock is the glittering calcite cleavages which appear on the freshly fractured surface. These cleavages run up to an inch in length, have a somewhat satiny luster, owing to the included sand grains, and are produced by the deposit of the calcite cement around the sand grains with similar crystallographic orientation—in other words, producing true sand crystals on a small scale. This same lithologic peculiarity is a feature of the so-called Potsdam-Beekmantown passage beds farther to the eastward, and, so far as my observation goes, is confined to that horizon, not appearing in the Beekmantown above.

In the lower portion of the formation the large Lingula previously mentioned is abundant, a gastropod which has not yet been determined occurs at all horizons, occasional cystid plates and traces of other fossils are found, and fucoidal markings are frequent on the surfaces of some layers.

The general thickness of the formation over the quadrangle is from 60 to 70 feet. Like the Potsdam beneath, it thins to the west and apparently also to the south, though widespread sand deposits hide the decisive proof of the latter. In addition to this thinning because of overlap, it has also suffered erosion at its summit, owing to uplift (apparently slight) and wear during a lengthy time interval. For instance, it has a thickness of but 20 feet near the north end of Perch Lake, though recovering its normal thickness of 60 feet within a mile on each side, and the diminution in thickness is by the wearing away of the upper beds. Coincidently with this local thinning, the overlying formation thickens, showing basal beds which are lacking on each side and plainly owing their existence to the surface depression.

For the description of the overlying Pamelia and higher formations, see Chapter IV (p. 185).

The Potsdam sandstone and possibly the "Theresa dolomite" belong to the Saratogan or Upper Cambrian, formerly called the "Potsdam series." Walcott introduced the term "Potsdam series" in the large sense in 1891, but in 1903 he withdrew it in order to avoid confusion, and introduced Saratogan instead. After giving the reasons for the change he says: [858]

The type locality of the Saratogian is north and west of Saratoga Springs, N. Y. The section has, at the base, about 200 feet of evenly bedded, compact grayish to yellowish colored sandstone, that rests unconformably against or upon spurs or ridges of pre-Cambrian gneiss. At a locality 3 miles north of Saratoga Springs the sandstone is about 40 feet in thickness; it is overlain by an oolitic limestone, 30 feet, and a dark-gray, evenly bedded limestone 50 feet in thickness. In this latter limestone the following fauna occurs:

Cryptozoa proliferum.
Obolus (Lingulepis) acuminatus.
Platyceras minutissimum.
Platyceras hoyti.
Metoptoma cornutiforme.
Metoptoma simplex.
Billingsia saratogensis.
Matthevia variabilis.
Dikelocephalus hartii.
Dikelocephalus speciosus.
Ptychoparia calcifera.
(A.) saratogensis.

The Calciferous formation of the New York section rests conformably on the Upper Cambrian limestone.

The formations now referred to the Saratogian are as follows:

Type.—Sandstones and limestones of the south side of the Adirondacks, Saratoga County, N. Y., containing the Upper Cambrian fauna.

Correlated.—Upper part of Cambrian limestones of Dutchess County, N. Y., and an unknown portion of the limestones of the "marble belt" of western Vermont.

Upper part of shales of Tennessee (Knox), State of Georgia, and Alabama (Conasauga), and the lower part of the Knox dolomite.

Upper part of the sandstones of the upper Mississippi Valley (St. Croix), Upper Cambrian limestones of South Dakota, Wyoming, Montana, and Colorado.

Upper calcareous beds of the Cambrian of northern Arizona (Tonto) and central Texas (Katemcy).

Upper Cambrian limestones and shales of Nevada (Hamburg), Idaho, and Montana (Gallatin).

Black shales of the upper portion of the New Brunswick and Cape Breton Island Cambrian sections.

Upper Cambrian shales and sandstones of Conception Bay, Newfoundland (Belle Isle).

Recent contributions to the classification and interpretation of the Cambrian and Lower Ordovician of the New York province have been made by Grabau,[383] and also by Ulrich and Cushing.[822] (See p. 184.)

The general relations of the Cambrian of the Adirondacks in eastern New York and Vermont, and thence southward, were thus stated by Walcott:[854]

The strata referred to the Cambrian, on the western side of the Sutton Mountain anticlinal or the belt extending southwesterly from Quebec to the Vermont boundary, consist of more or less of the Sillery series, as found in the vicinity of Quebec, and, according to Drs. Selwyn and Ells, of a subjacent series of hard quartzite rocks interstratified with mica schist and black slate. The volcanic series, referred to the Cambrian in this region, indicates that during earlier Cambrian time the volcanic products were deposited contemporaneously with the included sandstones and slates, thus giving a phase of sedimentation not known elsewhere in the Cambrian of the Appalachian province. For this reason and from the fact that there is not any paleontologic evidence of the age of this volcanic series, I am inclined to think that it may belong to some pre-Cambrian terrane.

Entering the northern end of the valley, between the Green Mountains and the Adirondacks, a sudden change occurs in the sedimentation. At the base the Olenellus fauna ranges through 1,000 feet of magnesian limestone, and for 250 feet higher up in arenaceo-argillaceous shales. More or less arenaceous matter is associated with the limestones, and, about 2,000 feet above, a great lenticular mass of limestone occurs in the argillaceous shales, in which a fauna of Upper Cambrian aspect is found. At other localities this fauna occurs in the shales themselves and in a brecciated limestone at the same relative horizon. As far as known the upper portion of the Cambrian is formed of the shales. Proceeding southward and nearer the old coast line in Addison County, Vt., the limestone series is found to graduate into the Granular quartzite or the beach sand. From this point this shore deposit is traced without interruption to the Massachusetts boundary; and then, with more or less interruption, to the Hudson River below

Poughkeepsie, N. Y. It is taken up again in New Jersey, and thence may be followed, with some interruption, across Pennsylvania to Maryland, whence it extends as an almost continuous formation across Virginia into eastern Tennessee and thence, with some interruption, into Georgia and Alabama. On all this long line it forms the basal member of the Cambrian; and wherever fossils have been found in it they belong to the Olenellus or Lower Cambrian fauna.

The offshore or deeper-water deposits are represented by finer-grained sandstones, shales, slates, and limestones. In southern Vermont they form the roofing-slate belt that passes into New York, where the section comprises some 12,000 feet of shales, slates, and interbedded sandstones, with more or less calcareous matter, either as brecciated conglomerate or as thin-bedded, intercalated limestones. These extend, with some change in their character and regularity of exposure, to the Hudson River in Dutchess County. Near Stissingville, in this county, the basal sandstone rests upon the pre-Cambrian and contains the Olenellus fauna. A few remains of the latter have also been found in the immediate superjacent limestone. The Middle Cambrian and Upper Cambrian faunas occur in bedded limestones. As the quartzite exposed on the eastern side of the limestones of the "marble belt" represents but a very small portion of the great series of shales, slates, etc., of the Cambrian on the western side of the "marble belt," it is probable that the lower portion of the limestone is of Cambrian age, the same as in Dutchess County. This observation also applies to the basal limestone in New Jersey and Pennsylvania, where there is very little thickness of shales between the basal quartzites and the limestone.

The Beekmantown ("Calciferous") of the Champlain district was studied in detail by Brainard and Seely,[95] whose paper contains maps and local structure sections. They say:

The term Calciferous was used by the older geologists of New York and Vermont to designate the strata between the Potsdam sandstone and the Chazy limestone. The lower boundary is well defined, as the Potsdam sandstone has been long recognized and carries a peculiar fauna. The upper boundary, the base of the Chazy, is less definite; but we consider it to be certain strata of sandstone, from 30 to 40 feet in thickness, described in the "Geology of Canada," 1863 (p. 123), and found in the Champlain region in several localities below all other beds containing characteristic Chazy fossils.

In our study of the rocks of the Champlain Valley we have been surprised at the development of the Calciferous formation—at its vast thickness, its variety of rock, and its abundant fauna. That the earlier geologists, who made explorations on this ground, Profs. Emmons, Adams, and Hitchcock, should have made such brief mention of this grand subdivision must be attributed to the fact that they had wide areas to examine and but brief time allotted them. The Calciferous is, moreover, a most difficult formation to decipher, because of its great thickness, the absence of fossils in most exposures, and the resemblance to each other of its various beds of magnesian limestone.

In our study of these rocks every important exposure has been visited on the Vermont side of Lake Champlain from Philipsburgh to Benson, and most of those on the New York side. Instead of a thickness of 300 feet for the Calciferous, as estimated in the Vermont report, we find a thickness of 1,800 feet; instead of the four or five species of fossils there mentioned we find over a hundred species, many of which are as yet undescribed.

There are two localities in which the entire sequence of Calciferous strata can be seen. One of these is in eastern Shoreham, and was first discovered by Rev. Augustus Wing and referred to by him as "the Bascom ledge." (See Am. Jour. Sci., 3d ser., vol. 13, p. 343.) It is a great monocline 2 miles in width and 3 to 5 miles in length, in which all the Lower Silurian rocks are seen overlying at least 200 feet of Potsdam sandstone. The strike is somewhat sinuous and the dip varies from 9° E. to 38° E., but there are no abrupt changes in either except at the northern or western borders. Much of the rock is covered with soil, but exposures on hillsides, along watercourses, and in escarpments of cliffs are sufficient to reveal the character and thickness of all the members of the Calciferous formation. * * *

The strata of the Calciferous seen at various exposures in this monocline are as follows, in ascending order:

Division A.

	Feet.
Dark iron-gray magnesian limestone, usually in beds 1 or 2 feet in thickness, more or less siliceous, in some beds even approaching a sandstone. Nodules of white quartz are frequently seen in the upper layers, and near the top large irregular masses of impure black chert, which, when the calcareous matter is dissolved out by long exposure, often appears fibrous or scoriaceous. Thickness	310

Division B.

Dove-colored limestone, intermingled with light-gray dolomite, in massive beds; sometimes for a thickness of 12 or 15 feet no planes of stratification are discernible. In the lower beds and in those just above the middle the dolomite predominates; the middle and upper beds are nearly pure limestone; other beds show on their weathered surfaces raised reticulating lines of gray dolomite. Thickness	295

Division C.

1. Gray, thin-bedded, fine-grained calciferous sandstone, on the edges often weathering in fine lines, 40 or 50 to the inch, and resembling close-grained wood. Weathered fragments are frequently riddled with small holes, called *Scolithus minutus* by Mr. Wing	60
2. Magnesian limestone in thick beds, weathering drab	100
3. Sandstones, sometimes pure and firm, but usually calciferous or dolomitic	70
4. Magnesian limestone like No. 2, frequently containing patches of black chert	120
Thickness of C	350

Division C is followed in ascending order by division D, which Whitfield assigned to the Chazy. (See p. 187, Chapter IV.) Ulrich, however, regards division D as the most typical part of the Beekmantown. As observed by Brainard and Seely, whose section Cushing[203b] reprints with approval, division D is made up as follows:

	Feet.
Blue limestone in beds 1 or 2 feet thick, breaking with a flinty fracture, often with considerable dolomitic matter intermixed, giving the weathered surface a rough curdled appearance; becoming more and more interstratified with calciferous sandstone in thin layers, which frequently weathers to a friable, ocherous rotten stone	80
Drab and brown magnesian limestone, containing also toward the middle several beds of tough sandstone	75
Sandy limestone in thin beds, weathering on the edges in horizontal ridges 1 or 2 inches apart, giving to the escarpments a peculiar banded appearance. A few thin beds of pure limestone are interstratified with the siliceous limestone	120
Blue limestone in thin beds, separated from each other by very thin rough slaty layers, which protrude on the weathered edges in undulating lines. The limestone often appears to be a conglomerate, the small inclosed pebbles being somewhat angular and arenaceous	100
Thickness of D	375
E. Fine-grained magnesian limestone in beds 1 to 2 feet in thickness, weathering drab, yellowish, or brown. Occasionally pure limestone layers occur, which are fossiliferous, and rarely thin layers of slate. Thickness	470

Cushing continues:

Cassin formation.—In the upper part of division D and in division E are numerous fossiliferous horizons carrying a rather abundant fauna. These beds are confined to the Champlain Valley, so far as the immediate region is concerned, and have therefore the same restricted distribution as the following Chazy. In discussing Brainard and Seely's paper, Prof. Whitfield recognizes and emphasizes this point and the considerable differences between these upper beds and the ordinary sparingly fossiliferous character of the normal Beekmantown. He urges the similarity of the fauna to that of the Quebec group of Canada, argues that these beds have more natural affinity with the Chazy than with the Beekmantown, and that they should either be placed with that formation or else considered as distinct from either and given a separate name, "as Fort Cassin, or Philipsburg formation, or any other appropriate name."[a] This seems to the writer not only as eminently proper but really a necessary procedure. The thickness and importance of this group, consisting of the upper 220 feet of division D and the whole of E, is such as definitely to warrant its separate mapping in the Champlain region, and the writer proposes the name "Cassin formation" for it, to make Whitfield's suggestion more precise and definite.

L 12. SOUTHWESTERN MONTANA.

Peale originally described the Cambrian of the Gallatin section in southern Montana and furnished details to Walcott,[854a] who writes as follows:

The Gallatin section of the Cambrian includes 1,250 feet of strata, of which 835 feet are limestone, resting upon 415 feet of sandstone. Conformably subjacent to the latter, there are 5,000 feet of alternations of conglomeratic micaceous sandstones, with bands of siliceous limestones and indurated clay shales, referred to the Algonkian by Dr. A. C. Peale.[b]

A more detailed manuscript section, that Dr. Peale kindly prepared at my request, is as follows:

Gallatin limestones, 835 feet:
- Pebbly limestones, 145 feet. Fossils, Leptæna melita, Ophileta sp.?, Triplesia calcifera, Ptychoparia sp.?, Ptychoparia (E.) affinis.
- Dry Creek shales, 30 feet.
- Mottled limestones, 160 feet. Fossils, Ptychoparia sp.?, Hyolithes sp.?
- Obolella shales, 280 feet. Fossils, Obolella sp.?
- Trilobite limestones, 120 feet. Fossils, Lingulella sp., Acrotreta gemma, Kutorgina sculptilis, Agnostus bidens, Hyolithes gregaria, Olenoides serratus, Ptychoparia gallatinenses, Bathyuriscus? haydeni.

Gallatin sandstones, 415 feet:
- Gallatin shales, 290 feet. Fossils, Lingulella sp.?, Hyolithes sp.?, Ptychoparia sp.?
- Gallatin quartzite, 125 feet.

In the report just quoted Walcott expressed the view that the 5,000 feet of strata beneath the "Gallatin sandstones," which Peale assigned to the Algonkian, might be Cambrian and equivalent to the Bow River group of Canada. But in 1909 he found that only the upper part of the Bow River is Cambrian, and it is separated from the major part by an unconformity. Most of the Bow River is therefore pre-Cambrian, and the equivalent in Montana is the same.

The Gallatin sandstones of Peale in the above section were later called by him Flathead formation, but the name Flathead is now restricted to the basal quartzite, and the overlying shales have been named Wolsey shale. The latter two formations and the overlying limestone were measured in detail on Crowfoot Ridge in the Yellowstone Park by Iddings and Weed[393] and the result is given in their monograph on the park.

In the same volume Walcott[393b] describes the Cambrian faunas from these formations. He finds that—

The Cambrian fauna of the park includes 10 species that are referred to the upper division and 21 that are referred to the middle and lower divisions of the Middle Cambrian fauna.

The Middle Cambrian fauna * * * is more intimately related to that of the Black Hills and the upper Mississippi Valley in Wisconsin and Minnesota than to the Middle Cambrian fauna of Nevada or British Columbia. There are no indications of the Lower Cambrian or Olenellus fauna. The upper-division fauna is also strongly related in its Brachiopoda to the Mississippi Basin fauna.

[a] Whitfield, R. P., Observations on the fauna of the rocks at Fort Cassin, Vt., with descriptions of a few new species: Bull. Am. Mus. Nat. Hist., vol. 3, 1890, pp. 27–28.

[b] Tenth Ann. Rept. U. S. Geol. Survey, pt. 1, 1890, p. 131.

The Middle Cambrian series is well developed and somewhat diversified around the Little Belt Mountains. Weed [869] distinguished the following:

	Feet.
Middle Cambrian:	
Yogo limestone	70
Dry Creek shale	40
Pilgrim limestone	80
Park shale	800
Meagher limestone	60
Wolsey shale	150
Flathead sandstone	60

With reference to the above statements, Ulrich comments (personal note):

The series of rocks in Montana and Wyoming from the base of the Flathead quartzite to the top of the Gallatin limestone seems essentially equivalent to the Cambrian sections in central Texas, Oklahoma, Missouri, and Iowa. In each case we have a good Upper Cambrian sandstone followed, except in the far Northwest, by younger sandstone and dolomites. As to the base of the Cambrian, it is a question if at any of these localities any Middle Cambrian (like that in the Great Basin or like the Acadian of the East) is present.

The following description of the Cambrian formations in the Philipsburg quadrangle, Montana, and the discussion of their correlation are condensed from the description in an unpublished paper on the geology and ore deposits of that quadrangle, by F. C. Calkins, and from the unpublished folio on the quadrangle, by the same author.

The Flathead quartzite is composed of more or less vitreous quartzite with an average thickness of about 200 feet. It lies unconformably upon pre-Cambrian red shales and sandstones equivalent to the Spokane shale of the typical Belt section. The evidence of this unconformity, whose importance was long ago established by Walcott, is especially clear in the Philipsburg district. Near the head of Rock Creek, in the Anaconda Range, a cliff exposure shows the base of the Flathead resting on the Spokane with an angular discordance of about 30°. On a branch of Lost Creek, about 8 miles northwest of Anaconda, a slighter discordance is displayed, and here the base of the Flathead is locally a coarse conglomerate of well-rounded pebbles of a quartzitic sandstone identical with that which forms the immediately underlying Spokane beds. Due probably to beveling in the erosion interval preceding the deposition of the Flathead are the great and rapid variations in the thickness of the Spokane formation. This is at least 5,000 feet thick in the gorge north of Georgetown Lake, while at the head of Mill Creek, 13 miles southeast, the Flathead is separated from the Newland limestone by only a few scores of feet of the Spokane formation. There is likewise a great diminution in the thickness of the Spokane between the northwest corner of the quadrangle and the center of its northern margin. The uplift that initiated the beveling seems therefore to have been relatively greater to the eastward.

There is some evidence that a shore line of the Flathead sea traversed the southeast part of the quadrangle. In the locality near the head of Mill Creek where the Spokane is thinnest, the Flathead quartzite is irregular in thickness, much thinner on the whole than in most other places, and at one point was seen to taper to a knife-edge, leaving the superjacent Silver Hill formation in direct contact with the Spokane. The locality is, however, one of complex folding and thrust faulting, and the possibility of the thinning out of the quartzite by faulting nearly parallel to stratification planes is not absolutely excluded.

The Silver Hill formation is here on the average about 400 feet thick. A maximum thickness of 700 feet was observed near the head of Rock Creek, in the Anaconda Range, but this dwindles to about 150 feet within 10 miles eastward. Its lower part consists mainly of dark-greenish, rather siliceous shales, the upper part of calcareous shales and thin-bedded limestones. It shows rapid gradation into the Flathead quartzite below and the dolomites above.

In the vicinity of Silver Hill, about 12 miles west of Anaconda, where the best exposures occur, a threefold subdivision of the formation can be made; it here comprises in descending order:

	Feet.
Shales, calcareous, strongly banded in brown, white, and green, interbedded with laminated limestone	90
Limestone with thin brown siliceous laminæ about 1 inch apart	120
Shale, dark green, not noticeably calcareous, with a 3-foot intrusive sheet of dark igneous rock near the base	120
	330

In places, as near Princeton, these rocks are very poorly exposed and here not even a twofold subdivision can be actually made on the ground. The middle and uppermost divisions can rarely be separated. The thin-bedded rocks between the Flathead and the Hasmark therefore constitute a convenient stratigraphic unit.

The Paleozoic rocks above the Silver Hill formation consist preponderantly of thick limestone strata, which are separated by relatively thin shales. The first two of the calcareous strata, with the shale that parts them, are mapped as the Hasmark formation. It comprises a basal member chiefly of blue-gray dolomite, a medial member of dark shales, and a top member of white fine-grained dolomite. The highly magnesian character of the highest and lowest members is apparently not shared by the supposedly equivalent Pilgrim limestone. The lower dolomite is about 600 feet thick; the upper about 350 feet. The thickness of the medial shale member varies widely. Its maximum, attained in the southern part of the quadrangle, is about 150 feet; at Philipsburg it is virtually absent, although a few fragments of shaly rock are locally found at the horizon separating the gray from the white dolomite. On Boulder Creek, also, near the northern boundary of the quadrangle, this horizon is marked by only a few feet of shaly limestone. The shale has yielded a few imperfect shells like Obolus.

The upper and main part of the Red Lion formation has a very peculiar lithologic character, not shown by the corresponding beds farther east. It consists of gray, drab, and white, rather thickly stratified limestones, whose bedding is marked by closely spaced laminæ of siliceous or argillaceous material, about one-fourth of an inch in average thickness, which project in relief on the weathered surface. These are invariably wavy or crinkly, and locally, where they constitute the greater part of the rock, they anastomose so that the limestone forms little isolated lenses flattened parallel to the bedding planes.[a]

The lowest part of this peculiar limestone is the most siliceous and shaly, and it may roughly be said to grade downward into the lower member, consisting of black shale and thin-bedded magnesian limestone, without the cherty banding. This member has a thickness of only about 15 feet on the west side of Cable Mountain, but although it is rarely well exposed, it is apparently two or three times as thick in some other sections.

Fossils were collected from the upper part of the Red Lion formation by Mr. Kindle in 1907 and submitted to Secretary Walcott, of the Smithsonian Institution. In a lot from Rock Creek, in the western part of the Anaconda Range, he found *Billingsella coloradoensis* Shumard and Anomocare sp.; in a lot from the vicinity of Princeton, the same forms together with Cyrtolites sp. and Agraulos sp. All the specimens, according to Dr. Walcott,[b] "are of Upper Cambrian age and therefore correspond to the Yogo limestone."

Correlation of Cambrian formations.—The ascription of the series above described as a whole to the Cambrian depends on (1) the unconformity at the base of the lowest quartzitic member which can reasonably be correlated only with the widespread unconformity at the base of the Flathead, the lowest Cambrian formation of the known Montana sections, and (2) the presence of Upper Cambrian fossils in the limestone of the Red Lion formation. Thus

[a] The structure of this rock is very similar to that of the Abrigo limestone, illustrated in "Geology and ore deposits of the Bisbee quadrangle," by F. L. Ransome (Prof. Paper U. S. Geol. Survey No. 21, 1904, Pl. VI, *B*).

[b] Letter to F. C. Calkins, June 3, 1908.

the identity of the Flathead is clear, and the limestone of the Red Lion is probably equivalent to the Yogo, the highest Cambrian formation of the central Montana sections.

The age of the intermediate members of the series is more obscure, but tentative correlation may be based on the following considerations: There is in the Philipsburg Cambrian and in that of the Little Belt Mountains and the Livingston region a basal sandstone or quartzite, overlain by alternating shales and limestones that constitute more or less definite stratigraphic units. It is a reasonable supposition that considering only relatively thick and homogeneous strata, the lowest shale in the Philipsburg section corresponds to the lowest shale in the Livingston section, the lowest limestone in the one to the lowest limestone in the other, and so on. On this assumption, the most probable correlation seems to be the following:

Tentative correlation of Cambrian formations.

Philipsburg quadrangle.	Little Belt Mountains.	
Red Lion formation	Upper member	Yogo limestone.
	Lower member	Dry Creek shale.
Hasmark formation		Pilgrim limestone.
Silver Hill formation	Shale and laminated limestone	Park shale.
	Laminated limestone	Meagher limestone.
	Green shale	Wolsey shale.
Flathead quartzite		Flathead quartzite.

There is not, however, a sufficiently detailed resemblance between the Philipsburg section and those farther east to make a correlation so largely lithologic wholly safe. The Pilgrim limestone, for example, has not been described as magnesian and had it been as obviously so as the Hasmark, the fact would hardly have escaped notice; the few specimens in the National Museum do not appear magnesian. The peculiar laminated limestone of the Red Lion formation, again, does not seem to resemble the Yogo. A real correlation between the Philipsburg and other sections is hardly possible before more Cambrian fossils have been found about Philipsburg, and strata actually traced from one region to another. There is reason to believe that when both these things have been accomplished, formations equivalent in the usual senses may prove to be not quite contemporaneous. The highest limestone in the Philipsburg quadrangle has a fauna of younger facies than that in the Little Belt Mountains, and the Flathead quartzite contains older fossils in the more easterly parts of Montana than in the more westerly parts. It may be that for each or for several of the epochs of the Cambrian period the controlling conditions of deposition were initiated at the east and gradually invaded more and more westerly areas—that there were, in fact, successive westward transgressions.

L 18–19. ST. LAWRENCE VALLEY.

In the valley of the St. Lawrence it is necessary to distinguish the formations of the Ottawa Basin and its northeastern extension to Quebec from those of the region lying farther southeast. The two are separated by the St. Lawrence-Champlain thrust and the stratigraphic sequences are unlike, as are the facies of the formations and faunas. (See Chapter IV, pp. 196–206.)

In the Ottawa Basin and thence past Montreal the Cambrian is represented only by the overlapping littoral deposit of the Potsdam (Upper Cambrian) sandstone. The Lower Ordovician Beekmantown or "Calciferous" succeeds. The characteristics of these formations and the enumeration of their fossils are given according to Ami in the tables quoted in Chapter IV (pp. 200 and 201).

Logan's original descriptions[544] remain the most satisfactory concerning the details of character and occurrence in Canada. In so far as they relate to the stratigraphy of the formations in New York, they are replaced by Cushing's recent work. (See pp. 120–123.)

The later reports of the Canadian Survey, particularly those by Ells, contain many statements and descriptions relating to the Potsdam and "Calciferous."[618a]

The Cambrian terranes of the region southeast of the St. Lawrence-Champlain fault were described by Logan as part of the "Quebec group." They are now comprised under the terms Levis and Sillery. Their typical character in the vicinity of Quebec is summarized by Ami in the table quoted on pages 202–203.

The "Quebec group" was established by Logan,[544g] who described the strata in the vicinity of Quebec and gave a detailed section, which is here included as an account of the rocks, though no longer accepted as a correct interpretation of the succession:

At the upper end of the island of Orleans, on the northwest side, between high and low water marks, there are exposed about 500 feet of black graptolitic shales, such as belong to the Utica and Hudson River formations, dipping southeast 50°; resting upon which is a series of different strata, dipping in the same direction, and at the same angle with them; the contact between the two being visible. After a short distance across the measures, undulations occur. The effect of these on the distribution of the beds has been partially ascertained, round the upper end, to the southeast front of the island, and for several miles along it. The following is the sequence of the strata; the beds are, however, in some places so corrugated and broken that the measurements here given can only be taken as rude approximations to the truth.

	Feet.
1. Green calcareo-magnesian shale, weathering to a yellowish or reddish brown, interstratified with thin bands of purplish-gray argillaceous shale. Some of the magnesian shales are nearly grass-green, and the surfaces of most of the green beds are marked with fucoid-like forms of purplish gray; the green shales hold about 20 per cent of dolomite. The mass is strong and offers considerable resistance to weathering influences	100
2. Gray argillaceous shale, much softer than the magnesian shale	100
3. Gray limestone conglomerate; the rounded masses are chiefly of gray limestone; the matrix in many parts weathers to a brownish color and is probably dolomitic. Fossils occur, some of them replaced by silica, but those as yet obtained in this locality are too obscure to be determined; the band in some parts appears to break into lenticular patches	10
4. Green yellow-weathering calcareo-magnesian shale with gray argillaceous bands of the same character as No. 1	100
5. Gray soft argillaceous shale	200
6. Yellowish-gray dolomite, weathering orange-brown. It holds occasional masses of ash-gray limestone and in some parts of its thickness a multitude of pebbles of quartz as large as peas, and becomes toward the top a dolomitic sandstone	70
7. Gray fine soft argillaceous shale, with compound graptolites (*Phyllograptus typus*) about 30 feet from the summit	170
8. Gray limestone conglomerate; the matrix in some parts weathers to a reddish brown, being dolomitic, and contains large concretions of carbonate of lime in concentric fibrous layers like travertine. The band holds fossils in some places	35
9. Gray fine soft shale, with occasional bands of sandstone weathering brownish, none of them over 6 inches; the bands of sandstone increase in number toward the top	500
10. Olive-green argillaceous shale, striped with purplish-gray bands	700
11. Olive-green arenaceous shale, with disseminated soft grains of a green mineral, resembling glauconite and approaching it in composition. In the upper part of the deposit the shale contains so much grit as to become almost a sandstone; and within about 100 feet of the top it assumes a red color, in one or two bands	400
12. Yellowish-white limestone conglomerate; the matrix assumes a dolomitic aspect in some parts; the rounded masses or bowlders are occasionally 1 or 2 feet in diameter, and some parts of the bed hold fossils	10
13. Gray, drab-weathering sandstones, in general slightly calcareous, interstratified with gray argillaceous shales; some of the sandstone beds toward the bottom are 3 or 4 feet thick and hold occasional calcareous pebbles. The sandstones become thinner ascending, and then the shales prevail; but these become by degrees more and more arenaceous, and a band or two about 200 feet from the top assumes a red color	400

14. Gray limestone conglomerate; the matrix, weathering to a brown in some parts, is probably dolomitic	30
15. Gray, drab-weathering sandstones and shales, the sandstones slightly calcareous	300
16. Dark-gray and green shales, with thin bands of gray quartzite and occasional thicker beds of drab-weathering sandstone, some of them being lenticular masses; the dark shales appear in some parts to pass into black	900
17. Red and green shales, the red prevailing, interstratified with occasional thin layers of gray hard sandstone or quartzite, and a few of gray hard limestone; some of the bands of shale are of a deeper red than the general mass, approaching a maroon color. Toward the top of the equivalents of these shales, at Cape Rouge, there occur a small Lingula and *Obolella pretiosa;* the thickness of the deposit is from 1,500 feet to	1,000
	5,025

The strata from 1 to 17 are in ascending order, provided they are not inverted, of which we have no evidence unless it be the occurrence of an Obolella [not Obolella Walcott] in the red shales. Several species of this genus occur in the Potsdam group, and one in what is considered the equivalent of the Calciferous portion of the Quebec group, at Troy, in New York. The genus being only recently established, it is not yet certain of what value it may be in determining the horizon. For the purposes of generalization, in describing the Quebec group, the series will be considered an ascending one; not so much, however, with the view of asserting the order of the strata as to render more intelligible the facts connected with their geographical distribution.

It has since been shown that the sequence is inverted and also that errors in correlation arose from the failure to distinguish between fossils collected from the pebbles of the limestone conglomerates and those from the matrix. The extension of the term "Quebec group" to strata of widely differing ages led to its abandonment. The long controversy which led to this result and the detailed facts as finally ascertained are given in the report by Ells.[311] Walcott[850] reviewed the evidence with Ells in the field and discussed Ells's report, adding thereto his own observations. He says:

When first reading the description of the Point Levis rocks in 1874, I was puzzled by the mixing of the faunas in the lists published by Mr. Billings and the statement made by Sir William E. Logan, that the fossils were from the matrix. On reaching Quebec, in August, 1889, I took the first opportunity to examine the lowest bed of limestone conglomerate back of St. Joseph de Levis and northwest of the Catholic Cemetery. Dr. Ells accompanied me. As we crossed the ridge I picked up a loose bowlder full of Potsdam or Upper Cambrian fossils. A second bowlder was found embedded in the matrix and then several more, some of which were 3 feet in diameter. The matrix is a hard gray impure limestone that occurs at this point in a solid band, that we traced 500 feet or more. In the matrix I found the Calciferous fauna was represented by Obolella sp.?, Orthis sp.?, *Camerella calcifera* Billings, *Ecculiomphalus canadensis* Billings, *Ecculiomphalus intortus* Billings, *Ophileta complanata* Vanuxem, *Pleurotomaria canadensis* Billings, Pleurotomaria sp.?, Orthoceras, 4 sp. undet., *Ceraurus? apollo* Billings, *Ceraurus eryx* Billings, *Bathyurus bituberculatus* Billings, *Bathyurus quadratus* Billings.

In a bed of limestone 50 feet higher in the section I found, in addition to the preceding, the following: *Bathyurus cordia* Billings, *Bathyurus oblongus* Billings, *Amphion caleyi* Billings. In the succeeding band of limestone conglomerate *Orthis porambonites* Pander occurs.

A large number of specimens were obtained from the bowlders embedded in the limestone containing the fossils of Calciferous age, among which I have identified *Camerella calcifera* Billings(?), *Agnostus americanus* Billings, *Dicelocephalus magnificus* Billings, *D. oweni* Billings, *D. belli* Billings, *Arionellus subclavatus* Billings, *Menocephalus? sedgwicki* Billings, and *Illænurus illænoides* Billings (sp.). Other species occur, but the preceding list is sufficient to indicate the fauna of the Upper Cambrian or Potsdam zone.

Dr. Ells accepted the view that the Calciferous fauna occurred in situ in the matrix of the conglomerate, and that the bowlders containing the Potsdam fauna were derived from pre-existing strata. In the next band of conglomerate, above that which forms the ridge on the north side of the cemetery, the matrix also carries Calciferous fossils, and they are also abundant in the bowlders. In a search of two days I failed to find a Potsdam fossil at this horizon. From Dr. Ells I learned that nearly all the fossils described by Mr. Billings came from the lower zone, and we found traces of extensive collecting. With these exact data I was enabled, at once, to correlate the lower belt of limestone and conglomerate with the central band of the Phillipsburgh section, where an identical fauna occurs 1,000 to 1,100 feet above the recognized Potsdam sandstone.

This zone is 600 feet beneath the zone of "*Maclurea ponderosa*," where Mr. Billings placed the Levis conglomerates. The long period of uncertainty regarding the true mode of occurrence of the faunas in the Levis calcareous rocks is now terminated, and a fixed datum point secured for comparison with the known section on the shores of Lake Champlain.

Dr. Ells quotes the greater part of the conclusions contained in Prof. Charles Lapworth's instructive paper on the graptolites of the "Quebec group." [a] In this the graptolitic zone of the Levis shales is correlated with the typical Arenig of Great Britain and the Phyllograptus beds of Scandinavia. The graptolites of the Citadel Hill or Quebec City strata are correlated with the middle Llandeilo zone of Great Britain.

The stratigraphic succession, as determined by Dr. Ells, is as follows:

1. Black, green, and gray shales, with thick bands of grayish and sometimes yellowish-white quartzose sandstone and occasional thin bands of limestone conglomerate.
2. Greenish, grayish, and blackish and occasional bands of reddish or purple shales, with thin layers of gray sandstone. Annelid trails (fucoidal markings of Ells) are numerous on the greenish shales. On the south shore of the St. Lawrence below Levis, and also on the south shore of the Island of Orleans, beds of conglomerate occur at about this horizon, in which the Lower Cambrian fauna occurs.
3. Bright-red shales, with thin bands of greenish and gray shale.
4. Red, greenish-gray, and black shales, with interstratified Sillery sandstones. *Obolella pretiosa* in the upper part, near Sillery, and on the south side of the river *Obolella pretiosa*, *Protospongia fenestrata*, *Phyllograptus typus*, *Tetragraptus serra*, and *Lingula quebecensis*.
5. Levis shales and conglomerates of Point Levis.
6. Black and grayish-striped or banded shales, with the black and graphitic shales and limestone of the Arthabaska and Somerset synclinal, the latter not appearing in the Quebec and Point Levis sections.
7. The black or brownish bituminous shales and limestones of the city of Quebec and northwest side of the Island of Orleans. The contained fauna is of Trenton-Utica age.

From the Cape Rouge section and the strata on the south side of the St. Lawrence, Dr. Ells concludes that the evidence afforded by the stratigraphy and the graptolites, determined by Prof. Lapworth, is sufficient to refer the Sillery rocks of 1, 2, 3, and 4 of the section to the Cambrian system, and the Levis beds (5) to the Lower Ordovician.

The thicknesses of the Sillery and Levis rocks are not given; but Dr. Ells told me that the measurements given by Logan were as nearly correct as could be determined. These were 2,000 feet for the Levis shales and 5,000 to 6,000 feet for the Sillery series as now known. [b]

The *Obolella pretiosa* ranges through from 1,500 to 2,000 feet of the Upper Sillery, and the lower conglomerate, of 2, occurs in the lower portion of this series. The Cape Rosier *Dictyonema sociale* zone is regarded as the lowest of the graptolitic zones, and to indicate the horizon of the Tremadoc terrane of Great Britain. The Cape Rosier beds are referred to the Upper Cambrian by Prof. Lapworth and Dr. Ells, but with our present knowledge of the Cambrian in America, I would refer them to the Lower Ordovician or to the Lower Calciferous. The occurrence of the typical Calciferous fauna within 100 feet of the base of the Levis series, at St. Joseph de Levis, points very strongly to considering the graptolitic fauna of the Upper Sillery to be of Calciferous age, if a comparison is made with the Phillipsburgh section.

[a] Lapworth, Charles, Report on some graptolites from lower Paleozoic rocks: Trans. Roy. Soc. Canada, 1886, pp. 167-184.

[b] This transfers to the Sillery a considerable portion of the strata originally referred to the Levis.

Dr. Ells refers the Sillery series to the Cambrian and in this I mainly agree with him, except that the upper portion is evidently a passage series between the Cambrian and Ordovician. On lithologic and stratigraphic evidence the line would be drawn at the summit of the red shales. On paleontologic evidence, as furnished by the graptolites, I would include the upper portion of the Sillery red and green beds in the Ordovician, as I think they are above the typical Potsdam zone of America.

It will be recalled that Dr. Ells stated that the Sillery beds rested unconformably upon the slates, quartzites, etc., which he refers to the Lower Cambrian. He mentions that, in this lower series, beds of gray subcrystalline limestone occur. It may be that we here have the source from which the limestone conglomerate of the Sillery was derived, which contains the Olenellus fauna. This would be in accordance with the mode of occurrence of the Olenellus or Lower Cambrian fauna to the southward, in Vermont and eastern New York.

In this quotation Walcott states that he would refer the Cape Rosier beds to the "Calciferous" (Beekmantown) rather than to the Upper Cambrian as was done by Lapworth and Ells.[47, 311c]

The limestones near Phillipsburg, which in the preceding quotation are assigned to the "Calciferous" (Beekmantown), were thus described by Logan:[544w]

A.

	Feet.
1. Dark-gray and yellowish-white dolomites, weathering gray and yellowish brown	400
2. White and dove-gray pure compact limestones	100
3. Reddish-gray, brown-weathering dolomites and black dolomites with some thin-bedded black limestones	200
	700

B.

1. White and dove-gray pure limestones, with some yellow-weathering magnesian bands	120
2. Dark-gray and black limestones, some of the beds magnesian	120
3. Dark bluish-gray thin-bedded nodular limestones, with thin layers of bluish-gray slate, probably magnesian; the surfaces of some of the beds weathering into a red or yellow ocherous arenaceous earth	150
4. Black slaty thin-bedded nodular limestones, with two or three thick beds of purer limestone toward the base	300
5. Black limestones, some of them massive, weathering bluish gray; interstratified toward the bottom with black and dark-gray, yellow-weathering magnesian beds	350
	1,040

The remainder of this section comprising divisions C and D is given on pages 845–846 of Logan's report.

The faunas of the Potsdam and "Calciferous" of the Eastern Townships of Quebec and of the Phillipsburg formation are listed by Ami.[14a]

L 19. MAINE.

Certain shaly, calcareous, and quartzitic strata, which are highly altered, occur on the shores and islands of Penobscot Bay, where they have been studied in detail and provisionally assigned to the Cambrian by Smith, Bastin, and Brown,[760a] who say:

The oldest rock of the Penobscot Bay region is the Ellsworth schist, which represents sediments probably of Cambrian or even pre-Cambrian age. The deposition of these arenaceous sediments was followed by dynamic action sufficient at least to inaugurate the changes of impure sand into a crystalline schist. This metamorphism is believed to have begun before the deposition of the next younger formation, inasmuch as the Ellsworth schist exhibits a much greater degree of alteration than any other rock in the quadrangle.

The next epoch probably began in Cambrian time with the deposition upon the ocean bottom of muds and impure sands that are now represented by the Islesboro slate, with which the Calderwood slate is possibly to be correlated. This deposition presumably took place in moderately shallow water and not far from shore, but the position of the land masses which furnished the sediments is wholly conjectural. Gradually conditions became favorable for the deposition of the beds now represented by the Coombs limestone. The considerable amount of argillaceous material associated with the limestone, as well as the great variations in the purity of the limestone from place to place, may be taken as indicating shallow water and somewhat shifting currents.

The changes which closed the period of limestone deposition were more rapid and of greater magnitude than those at its beginning and resulted in the deposition above the limestone of sands and gravels of considerable purity which are now consolidated to form the Battie quartzite. The conglomerate beds of this quartzite show a somewhat impure quartzitic matrix in which are embedded pebbles of very pure quartzite. The fact that most of these pebbles are well rounded indicates that the rock from which they were derived was itself a well-indurated sandstone or possibly a quartzite. The massive quartzites have a composition about like that of the matrix in the conglomerates. Presumably these rocks represent shallow water or beach deposits which were subject to the sorting action of waves and currents. No quartzite beds which could have served as the source for such deposits are known in this part of the State, though they may occur buried beneath later formations.

The parent formation need not have been wholly or even largely of quartzite, for the assorting and disintegrating action of waves and currents would suffice to separate more resistant quartzitic portions from less resistant shaly or calcareous materials. Certain beds, however, must have been very pure quartzite in order to furnish the clean, pure pebbles characteristic of the conglomerate.

After the deposition of the Battie sands and gravels conditions for the deposition of muds were again restored and very extensive deposits were laid down, which are now represented by the Penobscot slate, the most widely outcropping and the thickest formation of the region. The change is probably indicative of slight but long-continued subsidence. Within the adjoining Rockland quadrangle these muds were succeeded conformably by thick deposits of limestone, which is now thoroughly crystalline and of great economic importance in the production of lime. The presence of beds of limestone conglomerate at various horizons within this limestone formation indicates a shallow-water origin.

Detailed descriptions of the formations are given in the Penobscot Bay folio.

L 19. CARLETON AND YORK COUNTIES, NEW BRUNSWICK.

The "slate belt" of southwestern New Brunswick comprises "Cambro-Silurian" (that is, Cambrian and Ordovician) and Silurian ("Upper Silurian") strata, which are separated by a marked unconformity and are intruded by granite. Bailey [44a] states the conditions and exact localities of the observations made in 1900 and concludes in part as follows:

The general tendency of these observations has been to confirm the view * * * that while a Silurian age must be assigned to certain tracts, such as that in which fossils were found by Mr. Wilson, of the Geological Survey staff, 6 miles north of Canterbury, and that discovered by the writer in the settlement of Waterville, in the parish of Southampton, yet the great bulk of the strata in the counties under consideration is, as previously supposed, of greater antiquity, being at least Cambro-Silurian or Ordovician (the age to which they had previously been assigned), if not even older. In seeking for evidence on this question a careful resurvey was made along the line where the supposed Cambro-Silurian or older rocks are met and overlapped by the fossiliferous Silurian rocks to the north, with the result that incontestible evidence of discordance is found along the whole length of that line. A new and well-marked instance of this was seen near the head of Eel River, in South Richmond, Carleton County, where heavy beds of bright-red slates, associated with amygdaloidal diorites, have afforded large fragments to the overlying Silurian beds.

An effort was then made to determine the limits of the fossiliferous Silurian rocks previously discovered by Mr. Wilson. Fossils similar to those obtained by that gentleman, but occurring very sparsely, were collected at several points on Eel River, and strata exhibiting similar associations were followed for 6 or 8 miles in the direction of the St. John River. Here, however, approaching the great granite belt, they not only failed to yield fossils but became so greatly altered as to be recognizable only with difficulty. In connection with this work the fossiliferous slates were found to be associated throughout with heavy beds of slaty conglomerates, the composition of which, though somewhat different from that of the South Richmond conglomerates, equally indicates their derivation from the supposed Cambro-Silurian and Cambrian strata. The course of these conglomerates is therefore provisionally regarded as marking, upon one side at least, the line of separation of the two systems in the parish of Canterbury. The southern side, owing to progressive metamorphism, can not be definitely assigned.

So far, the conclusions reached * * * were based upon stratigraphical and lithological grounds only. But near the end of the season * * * new and most important evidence, tending to confirm the views already reached, was brought to light. This consisted in the discovery near the village of Benton, in Carleton County, of a band of very black, more or less graphitic slates, associated with gray and white quartzites and containing a few layers charged with large numbers of graptolites of the genus Dictyonema. Among these were some of large size ($2\frac{1}{2}$ by 3 inches), showing both in their outlines and in the dimensions and structure of the polypary a very close resemblance to the form *D. sociale* or *D. flabelliforme* Eichwald, occurring in rocks of Cambrian age on Navy Island, in the harbor of St. John, as well as at Matane, in the Province of Quebec. They are regarded as identical by Dr. H. M. Ami, after careful studies and comparisons, and Dr. G. F. Matthew (by whom the Navy Island form has been figured and described) is also disposed to adopt the same view. It would seem, therefore, that although the occurrence of a single fossil species is in itself very insufficient evidence upon which to determine and represent the horizon of a great group of strata, yet, when this is taken in connection with the stratigraphy of the region, pointing as it does in the same direction, a strong presumption is established in favor of the Cambrian age of the beds yielding these forms.[a]

L 20-22. NEW BRUNSWICK, CAPE BRETON, AND NEWFOUNDLAND.

In 1900 Matthew contributed to a paper by Ami [16] the following statement of the succession of formations within a radius of 20 miles of St. John, New Brunswick:

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[a] For further details see Repts. Geol. Survey Canada, new ser., vol. 16, 1904, pp. 279–282A.

Pre-Silurian rocks within 20 miles of St. John, New Brunswick.

System.	Terrane.		Condition.	Characteristic strata.	Characteristic fossils.	Thickness (feet).	Locality.
Lower Ordovician.	St. John group.	Division 3, "Bretonian."	Mud rocks with slaty cleavage and plant remains, nonbituminous.	Gray sandstone. Fine black shales.	5? Leptobolus grandis. 4. Tetragraptus 4-brachiatus. 3. Dictyonema flabelliforme. 2. Peltura scarabeoides.	700	"Falls" at St. John. Navy Island, St. John. King Street, St. John.
Cambrian.		Division 2, Johannian.		Dark-gray shale. Gray slates and flags. Gray flags and sandstones. Gray flags and slates.	1. Parabolina spinulosa. 3. Lingulella radula. 2. ——— starri. 1. Worm burrows, etc.	750	Germain Street, St. John. King Street E, St. John. Wright Street, St. John.
		Division 1, "Acadian."		Black shale and conglomerate. Fine black shale. Dark-gray shale. Olive-gray shale and sandstone. White quartzite.	6. Dolichometopus acadicus. 5. Paradoxides abenacus. 4. P. eteminicus. 3. P. lamellosus. 2. Protolenus elegans. 1. No fossils.	200	Hasting's Cove, St. John County. Lockhomard, St John County. Seely Street, St. John. Kennebecasis River. Seely Street, St. John.
Pre-Cambrian.	Etcheminian.			Purplish and green shale. Purplish-red sandstone. Coarse reddish conglomerate.	Orthotheca, echinoderms. Arenicolites, worm trails. No fossils.	1, 200	Caton's Island, King's County. Loch Lomond, St. John County.
Huronian ?	Coldbrook group, etc.		Partly crystalline.	Ash rocks, felsites. Diabase, diorite.	No fossils.	10, 000?	Carleton Heights. Loch Lomond Hills.
Grenvillian.	Upper series of the Laurentian area. (Part of "Portland group.")			Clay slates and diorites. Limestones and quartzites. Mica schist, etc.	Eozoonal fragments. Archæozoon, sponges. No fossils.	1, 200?	Howe's Road. Green Head. Douglas Avenue. Green Head.
Laurentian.	Crystalline schist. (Part of "Portland group.")		Crystalline.	Feldspathic gneiss. Chloritic gneiss. Quartz diorite (intrusive).	No fossils.	(?)	Indiantown. Fairville, etc.

N. B.—A double transverse line indicates a marked discordance of stratification; a single transverse line indicates a discordance that is not so obvious. (This remark does not apply to the lines separating the *subdivisions* of the groups in the second column.) It will be seen that the terranes or formations do not always agree with those of Europe—that is, the physical and paleontological breaks are not synchronous.

Laurentian.—In the column of geological systems, beginning with the oldest or Laurentian, Dr. Matthew has assigned certain crystalline schists of Indiantown and Fairville to this horizon. These form a part of the Portland group (lower) of the reports bearing upon the geology, whereas the upper part of this group he classifies as Grenvillian, consisting of clay slates, norites, limestones, quartzites, underlain by mica schists.

Huronian.—The Laurentian Archean rocks are succeeded upwards, as Dr. Matthew points out, by rocks of doubtful Huronian age, consisting of ash-rocks, felsites, diabase, diorite, such as are met with at Carleton Heights and Loch Lomond Hills, all grouped under the designation "Coldbrook group." Both above and below this Coldbrook group, as well as between the Laurentian of Indiantown and the Grenvillian limestones, slates, etc., of Green Head, Douglas Avenue, etc., a marked discordance of stratification occurs, which apparently indicates long lapses or intervals of time between them.

Cambrian.—Above the Coldbrook group, and beneath the Cambrian or St. John group, Dr. Matthew describes and classifies certain purplish and green shales, purplish-red sandstones, and coarse red conglomerates, which are exposed on Caton's Island, in King's County, and at Loch Lomond, St. John County, under the term "Etcheminian."

Between this Etcheminian and the St. John group the discordance of stratification is not as obvious as in the case of the preceding system with the Etcheminian. The fauna of the Etcheminian, however, is essentially a Cambrian fauna according to the writer.

The Acadian, Johannian, and Bretonian constitute the three divisions which Dr. Matthew has established in the St. John group. The strata which they represent are 1,650 feet in thickness and consist of mudstones, with slaty cleavage, also sandstones and flags with conglomerate. The uppermost or Bretonian division of the St. John group, which is to be seen in the black graptolitic shales and sandstones of Navy Island and at the falls on the St. John River, near the suspension bridge, are by him referred to the Lower Ordovician. Many of the species which occur here are eminently characteristic of the Levis division of the Québec group, in the St. Lawrence Valley. These strata correspond to the Skiddaw and Arenig formations of England and Wales and to similar horizons in Scandinavia, France, and elsewhere.

It is from the Cambrian or lower and most important portion of the St. John group of rocks that Dr. Matthew has obtained material from which he described and illustrated the very extensive extinct fauna and flora of these old Paleozoic sediments.

In 1904 Matthew [582] described the Cambrian as follows:

Confining our attention to the areas where Cambrian fossils have actually been found, we note throughout this North Atlantic region the prevalence of volcanic deposits, or of red and green mud beds, in the initial period of Cambrian time. If the former are not actual lava flows, or the cores of old volcanic cones and ridges, they are the compacted ashes, mud, and stones from such a source.

Resting on these volcanic deposits, though sometimes intercalated with them, are beds of sand and mud that easily show their relation to such a source as the volcano, by the fact that this sand consists largely of feldspathic particles, while the mud beds are pale-green or red accumulations of volcanic dust that have fallen into or been swept into the sea. Hence it would appear that while the first volcanic eruptions occurred over land surfaces, the land soon sank, and the later ones were thrown into the sea. It is in the levigated material thus thrown into the sea, or swept into it by rivers, that we meet with the earliest organic remains of the Cambrian time. These levigated deposits are chiefly in the Etcheminian terrane and contain a very ancient group of Cambrian organisms. They also exhibit a cycle of deposits corresponding to that of the St. John terrane above them, for they have in the middle coarse sandy sediments, that separate two groups consisting largely of mud beds; of these the lower has conglomerates and sandstones intercalated, while the upper are found to contain flaggy sandstones.

The principal sandstones, however, are in the middle member, which is comparatively barren of fossils but contains much diffused hematite, giving the rock a markedly red color. These beds also, like those of the corresponding stage of the St. John terrane, frequently show ripple-marked layers replete with worm burrows, worm trails, and other marks of a shallow-water origin. * * *

In the outer areas of the Cambrian rocks of the Atlantic coast the Etcheminian terrane is easily traced by the prevailing red color, as well as by its fossils. In this outer zone fine slates prevail and there are beds of limestone, as may be seen in the Massachusetts and Newfoundland areas. In the inner zone (New Brunswick and Cape Breton) the sediments are coarser and limestones are wanting; it is in this inner zone that a middle member of sandstones and flags is most distinctly marked.

The organic remains of this middle member are similar to those of the lower sediments, so that the Etcheminian rocks have only two faunas, an upper and a lower. The volcanic rocks beneath them have yielded a scanty fauna, which may not be more than a subfauna of the Lower Etcheminian. More material is required to determine the importance of this fauna.

So far as the St. John terrane is concerned, it is clear that the basins we have now are but fragments of deposits that have been spread over large areas of the Atlantic coast, and there may be extensive tracts occupied by slates and flags so far metamorphosed that Cambrian fossils can not be recognized. The materials which make up the flags and slates of the Johannian division glisten with water-borne particles of mica, the sands are of uniform texture, and there are no traces of shore lines, though shallow-water beds abound.

Also the Bretonian division, with its fine-grained dark-gray mud beds holding graptolites and the perfect preservation of its delicate organisms, indicates the presence of a water cushion of considerable depth above its muds, when these were being deposited, a cushion which we can hardly think less than 1,000 feet deep. But a sea of this depth would have covered a wide area along the Atlantic coast, and we therefore infer that the known basins of Cambrian rock are but small fragments of the widespread mantle of sediments that covered this region at the beginning of Ordovician time.

The group of organic remains of the outer zone of the Etcheminian rocks appears to differ widely from that of the inner. This may be because they do not come from the same time horizon; but it seems more likely to be due to some physical cause, either difference in the depth of the sea in the two zones, or paucity or abundance of sediment in the waters, or difference of temperature of the sea water in the two zones. Whatever the cause, olenelloid trilobites have not been recognized in the strata of the inner zone, while they are characteristic of the faunas of the outer zone.

The Etcheminian, St. John, and Bretonian terranes are divided by Matthew into "assises" or faunal zones, and the faunas comprising 380 species are listed accordingly in the paper cited above.

In earlier papers relating to the Cambrian and pre-Cambrian, Matthew had included the Etcheminian in the latter, as a formation underlying the "Lower Cambrian" (Olenellus zone).

Walcott[857b] studied the sections both in New Brunswick and Newfoundland and reached conclusions differing from those of Matthew, which the latter subsequently accepted, namely:

(*a*) The "Etcheminian" terrane of Matthew is of Lower Cambrian age.

(*b*) The Olenellus fauna is older than the Paradoxides and Protolenus faunas of the Middle Cambrian.

(*c*) The Cambrian section of the Atlantic province of North America includes the Lower, Middle, and Upper Cambrian divisions as defined by me in 1891.

Walcott's conclusions are based on the following sections in part, and others to be found in his paper:[857a]

Smith Sound section.—On the northern shore of Smith Sound, east and west of Smith Point, the Cambrian rocks are well exposed along the shore. At Broad Cove, west of the point, the transition beds between the Upper Cambrian (Olenian) and the Middle Cambrian (Paradoxidian) are concealed by the drift at the head of the cove. West of the cove the fissile and arenaceous shales of the Upper Cambrian are well exposed and contain Olenus. On the eastern side of Broad Cove the Middle Cambrian is exposed. The measured section begins with the dark argillaceous shales and is as follows:

	Feet.
Middle Cambrian, downward:	
1a. Dark argillaceous shales, with fragments of Paradoxides in the upper portion. At 45 feet down the Paradoxides are abundant; also Acrothele, *Obolus (L.) ferrugineus*, Ptychoparia, etc. At 110 feet down a 4-inch band of pinkish limestone carrying fragments of trilobites occurs. A roll in the strata comes in at this point and continues for a considerable distance along the shore. It starts between the two east wharves at Broad Cove and extends some distance east of the eastern point of Broad Cove	110
1b. Below the limestone greenish shale extends downward to a layer of reddish argillaceous shale 20 feet in thickness. No recognizable fossils were found in this bed	80
1c. Pinkish nodular limestone in several layers, interbedded in reddish shale. Fossils: Paradoxides (undet.), Ptychoparia	4
1d. Reddish-purple argillaceous shales with interbedded greenish-colored bands	135

This band of shales corresponds stratigraphically to the Protolenus zone of the Hanford Brook section of New Brunswick. A basalt dike cuts through the shales a few feet above their base. On the weathered surface it has the appearance of a massive sandstone. It is 3 feet 4 inches in thickness, is vertical, and the dip of its cleavage planes is almost coincident with the dip of the shales.

	Feet.
1e. Nodular limestones. A pinkish layer 4 inches thick contains at base numerous fragments of trilobites and appears to be made up of a conglomerate formed of fragments of pinkish-colored limestone and purple shale, and dark iron- or manganese-stained nodules resembling a stromatoporoid-like growth, and a few small quartz pebbles	3

The entire stratum is as follows:

	Inches.
Dark nodular limestone	25
Purplish-colored shale	2
Pinkish limestone	2
Brick-red shale	3
Pinkish conglomerate (?) limestone	4

At the point of exposure on the shore this band is faulted down 15 feet to the west. It is exposed near the top of the bank on the eastern side of the fault, where its dip is lower than on the western side.

The stratum 1e is taken as the base of the Middle Cambrian (Paradoxidian). It is the horizon indicated by Mr. Matthew in his diagrammatic section as the base of the Cambrian, and corresponds in stratigraphic position to the St. John quartzite of the New Brunswick Cambrian.

One observes no difference, in either strike or dip, between the shales beneath this band of nodular limestone and conglomerate and the shales above it until one passes to the east of the fault line that cuts through and breaks the band a few feet above the water's edge.

	Feet.
Lower Cambrian (Etcheminian of Matthew):	
2a. Reddish-purple argillaceous shale with greenish shales in bands at irregular intervals and a massive band of greenish shale near the base. Dip near base 20° to 23° W	284

At 110 feet from the summit fragments of a large undetermined trilobite were noted. On the south side of Smith Sound, at Britannia Cove, *Olenellus (H.) bröggeri* occurs at a horizon corresponding to 140 feet below the summit of the stratum.

Near the base of 2a the following fossils were found:

Obolella atlantica.
Hyolithes sp.
Orthotheca sp.
Microdiscus sp. undet.
Olenellus (Holmia) bröggeri.
Solenopleura? bombifrons?.

	Feet.
2b. Greenish-colored arenaceous limestone, passing into an intraformational conglomerate formed of nodules of pinkish limestone mixed with fine sand and carrying numbers of fragments of trilobites	$1\frac{1}{3}$
Pinkish-colored nodular limestones	$\frac{2}{3}$

Fossils: Fragments of trilobites and a small brachiopod.

Lower Cambrian (Etcheminian of Matthew)—Continued. Feet.

2c. Reddish-purple to brick-red argillaceous shale 56

The following fossils occur in the central and lower portions of this band:

Obolella atlantica.
Microdiscus bellimarginatus S. & F.
Microdiscus n. sp.
Olenellus (Holmia) bröggeri.
Zacanthoides sp. undet.
Agraulos sp.
Micmacca walcotti.

2d. Brick-red and pinkish nodular limestone in layers varying from 3 feet to 6 inches in thickness 27

This is one of the most important horizons in the Lower Cambrian of Newfoundland (Smith Point limestone). It is very persistent about Trinity Bay, and it occurs, although much thinner, at various exposures in Conception, St. Marys, and Placentia bays. The upper 24 feet at Smith Point is practically solid limestone layers. The lower layer of limestone, 1 foot in thickness, is separated by 2 feet of reddish shale in which 3 inches of limestone occurs.

Fossils: In the upper 6 inches of the top layer of limestone numerous fragments of *Olenellus (H.) bröggeri* and Solenopleura? occur. About 3 feet below this, in the next bed of limestone, immense numbers of *Hyolithes princeps* are found in association with the fauna that marks this limestone band wherever it is found. The following species were collected in a few hours:

Iphidea labradorica (Kutorgina granulata M.).
Fordilla troyensis.
Scenella reticulata?
Randomia auroræ.
Helenia bella.
Orthotheca pugeo.
Hyolithes princeps.
Coleoloides typicalis.
Hyolithellus micans?

2e. Green argillaceous shale 23

2f. Massive stratum of nodular limestone, divided into 18 inches of a pinkish limestone and 3 feet of purple to a pink mixed with purple argillaceous shale. Fossils: *Coleoloides typicalis* 4½

2g. Green argillaceous shale in massive bands, with numerous small pinkish limestone nodules scattered irregularly on the line of bedding. At 51 feet from the base the limestone nodules increase in number and size and form the greater part of a layer 2 feet in thickness. Above this the reddish-purple and green shales occur in bands varying in thickness 62

Fossils:

Hyolithes rugosus Matt.?
Coleoloides.
Urotheca pervetus Matt.
Crustacean, n. g., n. sp.

2h. Reddish-purple argillaceous shales, with irregularly distributed bands of nodular limestone of varying thickness. A layer of nodular limestone 42 feet from the summit has 12 inches of pinkish and reddish-purple limestone above, with 10 inches of greenish limestone below. In both layers numerous tubes of Coleolides occur. At 66 feet below the summit a second band of nodular limestone 20 inches in thickness occurs. Thin layers of nodular limestone occur both above and below the two thicker bands mentioned 136

2i. Green argillaceous shale, with a few thin layers of purple shale, also scattered layers of pinkish-colored nodular limestone. Fossils: Annelid trails are abundant in some portions of the greenish-colored shales 30½

2j. Reddish-purple shale, with layers of greenish and pinkish-colored limestone nodules scattered irregularly on the line of bedding. The nodular limestones are usually from 2 to 4 inches in thickness, but at 60 feet from the top a layer 12 inches thick occurs 185

The section is here cut off by the drift coming down to the water's edge.

The nodular limestones of the Smith Point section are one of the most noticeable features of the lower portion of the section. * * * The only fossils found in the lower part of the section except annelid trails occur in the nodules. The bedding planes of the shale in the slate quarries on Smith Sound are clearly indicated, at nearly right angles to the cleavage, by the lines of scars left by the nodules.

Base of Cambrian in Smith and Random sounds.—The base of the Cambrian is exposed at the slate quarries east of Tilton Head, on the north side of Smith Sound, in the synclinal basin formed of the Avalon and subjacent Cambrian rocks. The section, however, is not here complete. On the south side of Smith Sound, near Britannia Cove, the Smith Point limestone, carrying Hyolithes, etc., is well exposed, and 220 feet above it, in the green shales, *Olenellus* (*H.*) *bröggeri* was found. Below, the limestone beds are much broken. Crossing Random Island from Britannia Cove to the north shore of Random Sound, one finds a much more complete section, east of Hickmans Harbor Point. At Hickmans Harbor Point the Signal Hill conglomerate of the Avalon series is well exposed, and above, to the eastward, the Random terrane. The summit of the latter is very beautifully shown at the slate quarries about half a mile east of Hickmans Point, where the strike of the upper bed of the Random sandstone is N. 50° E., dip 70° SE. Immediately on this band of reddish-tinted sandstone there is a thin layer of conglomeratic limestone that forms the basal bed of the Cambrian.

Random Sound section, upward:	Ft.	in.
1a. Conglomerate formed of small pebbles of the subjacent Random rocks, and small quartz grains and pebbles, all cemented together by a fine calcareous sandy matrix. Often there is scarcely a trace of calcareous matter		6
Fossils: Slender tubes of Coleoloides and fragments suggest Archæocyathus.		
1b. Reddish-purple sandstones capped by coarse-grained grayish-purple sandstone 6 inches thick	3	
1c. Pinkish-colored limestone with Coleoloides		6
1d. Reddish-purple argillaceous shale	10	
1e. Purple to pink, hard, irregular arenaceous limestone	1½	
Fossils: Coleoloides and sections of what appears to be a small Obolella-like shell.		
1f. Green and reddish-purple argillaceous shale in broad bands. At 140 feet up nodular limestone appears, and at 170 feet a band of pinkish-colored limestone 6 inches thick with Coleoloides	171	
A change of dip and overturn occurs here, which breaks the section and cuts out probably 100 feet or more of the shales. Estimated	100	
1g. Green argillaceous shale	42	
1h. Reddish-purple argillaceous shale	98	
1i. Greenish argillaceous shale	84	
1j. Pinkish-colored, massive-bedded nodular limestone	6	
Fossils: *Hyolithes princeps*, *Coleoloides typicalis*, also numerous fragments of small Hyolithes, of which, owing to the cleavage of the limestone, it was impossible to get good specimens.		
1k. Reddish-purple and green argillaceous slates, cleaned so as to make a good roofing slate at Bryant's quarries, about 1 mile east of Hickmans Point. The estimated thickness of this slate in the syncline is over 200 feet	200+	

The total thickness of the section up to the Hyolithes limestone is over 500 feet, which, with the 369 feet above the limestone at Smith Point, gives a total thickness of fully 900 feet for the Lower Cambrian on the western side of Trinity Bay.

In the city of St. John [New Brunswick] the examination of the outcrops led me to the conclusion (*a*) that the Lower Cambrian strata beneath the St. John quartzite had been deposited on and against an irregular, uneven shore line; (*b*) that the sands of the St. John quartzite had been spread conformably over the beds of the Lower Cambrian ("Etcheminian"); (*c*) that where the pre-Cambrian (Algonkian) rocks projected above the Cambrian beds, or formed the shore lines, the St. John quartzite conformably overlapped the reddish-purple and greenish-colored arenaceo-micaceous shales and thin-bedded sandstones of the Lower Cambrian ("Etcheminian") and came in unconformable contact with the Algonkian rocks. * * *

Seely Street section.—The section exposed at the head of Seely Street, beside the Park Road, is as follows. The pre-Cambrian Algonkian rocks have an uneven surface where the basal beds of the Cambrian rest against them.

Lower Cambrian, upward:	Feet.
1a. Dark reddish-brown fine conglomerate and sandstone, with reddish and green, hard arenaceous shale. The conglomerate contains small quartz pebbles and bits of the subjacent Algonkian siliceous beds. Strike N. 40° [E.] mag., dip 70° SE	12
1b. Space concealed. From the abundant débris in the soil as exposed in a cutting beside the road the section here is formed of reddish-purple and green sandy shales	85
1c. Reddish-purple and greenish arenaceo-micaceous shales and thin-bedded sandstone	52
Middle Cambrian:	
2a. Light-gray fine-grained quartzitic sandstone in thick layers. The grains of sand become coarser in the upper part of section and a layer of white quartz-pebble conglomerate occurs near the summit. Strike at base N. 55° E. mag., dip 70° SE	40–45
2b. Arenaceous and argillaceous greenish-colored shales and thin-bedded sandstones, passing above into dark argillaceous shales. About 25 feet above the base the Paradoxides fauna appears in great abundance. For further details of the section of the St. John Cambrian rocks see Mr. Matthew's papers.	

It will be noted that the strike of the basal Lower Cambrian bed 1a is N. 40°, while that of the St. John quartzite is N. 55° E. This does not indicate an unconformity as the change of strike occurs in the beds below; the shales just beneath the quartzite are conformable to the quartzite.

Hanford Brook section, St. John County, New Brunswick.—The Middle Cambrian portion of the Hanford Brook section as exposed at McAfee's sawmill on the south bank of the brook below the mill is as follows:

Middle Cambrian downward:	Feet.
1a. Greenish-colored argillaceous shales with abundant remains of Paradoxides and other forms of the Paradoxides fauna	30+
1b. Massive calcareo-argillaceous layer carrying the *Parodoxides lamellatus* fauna. Strike E. and W., dip 45° N	3
2a. Gray sandstone and greenish arenaceous and argillaceous shale	34
Very few traces of fossils were found in this bed. It is the horizon of fauna b4 and b5 of Matthew.	
2b. Greenish argillaceous shale with a layer of sandstone 8 inches thick, and a little below, another layer of sandstone 4 feet in thickness. The sandstones are very hard, fine grained, and with fossiliferous phosphatic nodules near the bottom	10
Fossils: This horizon carries the Protolenus fauna, fauna b3 of Matthew.	
2c. Fine-grained dark-gray arenaceous argillites in layers 10 to 20 inches in thickness, that break up on exposure into irregular shaly layers. Strike E. and W., dip 25° N	16
Fossils: *Protolenus* fauna, b2 of Matthew. About midway of the subdivision there is a layer of greenish-gray fine-grained sandstone 14 inches in thickness, in which numerous small phosphatic nodules occur in the lower 3 inches, with many fragments of fossils.	
2d. Dark-green to grayish-green fine-grained compact, hard sandstone	18
Fossils: Fauna b1 of Matthew.	
3. Light-gray to white quartzitic sandstone in massive layers, the upper portion passing into greenish-tinted quartzitic sandstone	30+

The section from the quartzite downward for a distance of nearly 300 feet on the surface is entirely concealed. The highest beds of the subjacent Lower Cambrian are exposed at the upper end of the mill pond, where they have a strike of N. 60° E., dip 20° NW.

Lower Cambrian downward:	Feet.
1a. Estimated thickness concealed beneath the "St. John quartzite"	136
1b. Massive-bedded dark purplish-colored arenaceous shales and sandstones. Toward the lower portion a few calcareous nodules appear in the shales	320
Strike in upper beds, N. 60° E., dip 20° NW. In beds 215 feet below summit, strike N. 70° E., dip averaging 20°–25° NW.	

Lower Cambrian downward—Continued. Feet.

1c. Reddish and greenish arenaceous and argillaceous shales and thin-bedded sandstones, with a few thin interbedded calcareous sandstones. Strike N. 65° E., dip 35° to 40° NW 30

Fossils: In a thin reddish-brown, slightly calcareous sandstone occur great numbers of a slender species of Hyolithes that resemble *H. communis*. Just below it I noted, in a hard, very fine grained, compact sandstone, specimens of Coleoloides like *C. typicalis* and a large *Iphidea labradorica?* This appears to be the horizon of the Hyolithes limestone fauna of the Smith Sound section of Newfoundland. Unfortunately the sediments are of a type in which fossils are rarely found well preserved.

2. Reddish-purple conglomerate in fine sandstone matrix. White quartz and reddish and greenish siliceous pebbles occur, some of which are from 2 to 6 inches in diameter. Strike N. 65° E., dip 40° NW 31

3. Reddish-purple to grayish-purple fine-grained sandstones, passing into flaggy gray and greenish-gray micaceous sandstone, interbedded with thick layers of sandstone 395

About 120 feet down a few layers of white quartz pebbles appear in the dark sandstone, and at 175 feet down broad annelid trails were seen on the smooth surface of a thick layer of sandstone.

The dip decreases from 40° at the top to 30°, and then 25° at the base, where the strike is N. 55° E.

At this point the upper beds of the basal conglomerate outcrop on the south side of the brook, but they are cut off a few feet down by a fault that brings up some of the beds of No. 3 of the section, and possibly No. 1c. On the north side of the brook a syncline and fault expose a considerable portion of No. 3 of the section. Up the brook the basal quartzite appears again beneath the sandstone of No. 3, from which it extends nearly to the contact with dark pyroclastic andesitic rocks of the Algonkian.

4. Rather coarse siliceous, massive-bedded conglomerate, formed of white quartz, jaspery reddish and greenish-colored pebbles. The upper 8 feet has a light-gray color that passes below to a purplish tint 128

Total of Lower Cambrian 1,040

The contact with the Algonkian rocks is not seen, the base of the conglomerate being considered as near the last angular bowlders of the conglomerate seen in the bank, a little distance below the outcrop of Algonkian rocks.

In connection with the discussion of the Etcheminian, Walcott[857] published the following general classification of Cambrian formations:

Classification of the Cambrian formations.

		Lower Calciferous.	Lower portion of the Calciferous sandrock of New York and Canada; Lower Magnesian limestone of Wisconsin, Missouri, etc.
Cambrian.	Upper Cambrian.	"Potsdam" [Saratogan].	*Type.* Sandstones of the north and east sides of the Adirondack Mountains of New York and adjoining parts of Canada. *Correlated.* Limestones of the south side of the Adirondacks and Dutchess County, New York, and an unknown portion of the limestones of the "marble belt" of western Vermont. Shales of Tennessee (Knox), Georgia, and Alabama (Conasauga). Sandstones of the upper Mississippi Valley (St. Croix), South Dakota, Wyoming, Montana, and Colorado. Sandstones and calcareous beds of northern Arizona (Tonto) and central Texas (Katemcy). Limestones and shales of Nevada (Hamburg), Idaho, and Montana (Gallatin). Black shales of the upper portion of the New Brunswick and Cape Breton Island sections. Shales and sandstones of Conception Bay, Newfoundland (Belleisle).
	Middle Cambrian.	Acadian.	*Type.* Shales and slates of eastern Massachusetts (Braintree), New Brunswick (St. John), and eastern Newfoundland (Avalon). *Correlated.* Limestones of Dutchess County, N. Y. (Stissing), and central portions of Tennessee and Alabama sections (Coosa). Limestones of central Nevada and British Columbia (Mount Stephen).
	Lower Cambrian.	Georgian.	*Type.* Shales and limestones of western Vermont (Georgia) and Red sandrock. *Correlated.* Quartzite of western slope of Green Mountains ("Granular quartz") and Appalachian Range of Pennsylvania, Virginia, Tennessee (Chilhowee), Georgia, and Alabama. Shales with interbedded limestones and roofing slates of southern Vermont, New York, and south to Alabama. Limestone, sandstone, and shales of Straits of Belleisle (Labrador), northwest coast of Newfoundland, and peninsula of Avalon (Placentia). Basal series of Hanford Brook section, Caton's Island, etc., New Brunswick (Hanford). Shales and limestones of eastern and southeastern Massachusetts (Attleboro). Lower portion of Eureka and Highland ranges, Nevada (Prospect). Portion of Wasatch Cambrian section (Cottonwood). Base of Castle Mountain limestone, British Columbia (Castle Mountain).

In 1904 Matthew[581] published the results of his studies of the Cambrian of Cape Breton. He gives detailed sections and diagrams and presents a revised classification with the following comments:

In consequence of the finding of trilobites, brachiopods, etc., of Cambrian genera in the Etcheminian strata, and for reasons given below, the writer proposes to revert to the classification of 1889, wherein these deposits are called the Basal series (of the Cambrian system).

It has been found that slates with fossils of Cambrian genera are included in the important group of volcanic rocks which lie at the base of the Etcheminian, and that where the dip of the volcanics can be found, as is not infrequently the case, it agrees with that of the Etcheminian. It is thought therefore that those volcanics (the Coldbrook group) should be included in the Basal Cambrian.

Both in New Brunswick and in Cape Breton the Coldbrook group begins with lavas showing deposition free of pressure, as they are amygdaloidal; or with agglomerates devoid of evidence of marked aqueous wear. The deposition therefore did not begin in deep water, or on exposed sea coasts, or under heavy pressure. The foundation upon which the volcanics rest shows in several places marks of deep subaerial decay at the line of contact. Calcareous bands are dissolved, leaving the siliceous portion of the strata. The feldspar of the granitic rocks is kaolinized and the magnesian silicates are hydrated, impure graphite beds are changed to a black amorphous crumbling shale, and a depression or narrow valley is usually found at the contact of the two terranes. These conditions appear to indicate that the pre-Cambrian complex had long been above the sea level in these districts when the first Cambrian effusives were thrown out upon it.

Another point worthy of note in this connection is the large amount of feldspathic material in the Etcheminian beds; the very sands are often composed of feldspathic grains, and these largely of nonkaolinized feldspar, as though they had not been exposed to subaerial decay. Feldspar in this condition is found in two kinds of deposits, those that are the result of glacial wear and those found around volcanic vents, where particles of rock have been torn from the walls and blown out upon the surface of the earth. These if dropped into the sea would soon be covered up by fine mud and preserved in their original crystalline condition. The Etcheminian appears to represent largely the submarine condition of such effusive rocks. On the other hand, the Coldbrook series, as has been intimated above, represents the preceding subaerial phase of the eruptives. It is true that we find in many places conglomerates at the contact of these two series of rocks, thus diverse in appearance; but elsewhere there are no beds of rolled fragments at the contact, and the passage is direct from ash beds or diabases to the slates and sandstones. In reports of the Canadian Geological Survey of 1870–71, pages 57–59, etc., relating to the province of New Brunswick, both these groups of rocks have been included in the Huronian system. They may be equivalent in age to the upper part of that series, but unfortunately the absence of fossils in the original Huronian leaves this matter in doubt.

As we contemplate the physical conditions of the initial epochs of Cambrian time in the Maritime Provinces, we seem to see a region long elevated above the sea, now subjected to depression nearly to the sea level, the depression being accompanied with extrusion of lavas and volcanic mud and the ejection of stones and ashes. These at first were cast upon a land surface, but, as the crust of the earth continued to sink, it was covered by the sounds and bays of a shallow sea, diversified with pre-Cambrian ridges and islands, of greater or less extent.

For the above reasons, as well as because the stratified rocks of the underlying complex are markedly unconformable to the Cambrian, the volcanics are thought to belong to the latter, and to give the natural base of this system.

The accompanying table will then show the classification of the Cambrian system, as seen in the Maritime Provinces of Canada.

Base of the Paleozoic rocks in the Maritime Provinces of Canada.

Groups and kind of rocks in Cape Breton.	Canadian reports.	European writers.		Maritime Provinces.		Leading genera of the several groups.	English equivalent.
3. Dark-gray and black carbonaceous shales, often changed to slates; a few thin seams and lentils of dark limestone, and some thin flags.	St. John group of Canadian geological reports.	Lower Silurian.	Ordovician.	3. Bretonian division.		*e*. Harpes, Trinucleus, in northwestern New Brunswick.	Llandeilo.
						d. Cyclognathus, Parabolinella, Tetragraptus, Didymograptus, in southern New Brunswick.	Arenig.
		Primordial (Cambrian).	Cambrian.			*c*[2]. Asaphellus, Parabolinella, Triarthrus, Bellerophon.	Tremadoc.
						c. Dictyonema, Monobolina, Schizambon, Acrotreta. *b*. Peltura, Sphærophthalmus, Leptoplastus, Ctenopyge. *a*. Parabolina, Agnostus, Anomocare, Orthis, in southern New Brunswick.	Dolgelly.
2. Micaceous gray slates, flagstones, and quartzites. Iron bearing in Mira Valley, Cape Breton.				2. Johannian.		*c*. Agnostus, Lingulella. (Place of Olenus.)	Ffestiniog and Maentwrog.
						b. Paradoxides, Beyrichia, Lingulepis. *a*. Obolus, Lingulella, Lingulepis.	Menevian.
1. Dark-gray slates or shales with calcareous lentils. Gray sandstones. Interraned conglomerates at and near base.				1. Acadian.		*d, e*. Paradoxides, Solenopleura; Ptychoparia, Microdiscus. *c*. Paradoxides, Conocoryphe, Liostracus, Agnostus.	Menevian.
						a–b. Protolenus, Ellipsocephalus, Beyrichona, Trematobolus, in southern New Brunswick.	Solva.
3. Fine greenish-gray argillites, some reddish gray. Horizon of roofing slates in Cape Breton and Newfoundland.	Huronian of New Brunswick in part.	Sparagmite formation, Norway.	Basal Cambrian (mihi).	Etcheminian.	3. Upper.	Solenopleura?, Ostracoda, 4 genera. Acrothele, Lingulella, Obolus, Acrothyra, Hyolithes.	Caerfai.
2. Red sandstone and red and gray argillite. Lower iron-bearing horizon of Cape Breton Cambrian.					2 and 1. Lower.	Holasaphus, paradoxidoid trilobite, Ostracoda, Billingsella, Lingulella, Acrothyra, Obolus, Hyolithes. Lingulepis, Leptobolus, Obolus, Lingulella, Acrothyra, Acrotreta, Hyolithes.	
1. Gray shale or slate with some quartzite and conglomerate, the latter especially at the base.							
Co. Dolerites, breccias, and amygdaloidal ash rocks. Some gray shales about middle.				Coldbrookian.		Obolus, Lingulella, Linguledsis. Acrothyra, Acrotreta, Leptobolus. 2 Ostracoda.	Pebidian.

L–Q 10–21. CANADIAN SHIELD.

Throughout the region covered by the Canadian Survey there occur areas of unfossiliferous clastic, usually sandy formations (the Athabaska-Nastopoka series), which rest unconformably on the metamorphosed or disturbed pre-Cambrian rocks and are themselves but little disturbed. They have been described as "Cambrian" by the Canadian Survey, but are now believed to be older than the Olenellus fauna, and consequently to belong to the late pre-Cambrian, according to the classification in this paper.

M 19–20. GASPE PENINSULA.

The Cambrian ("Quebec group") is poorly exposed on the Gaspe Peninsula but is described by Logan [544k] as follows:

Below the Magdalen, the breadth of the formation has been ascertained by transverse sections in two places only; one of them being at the Great Pond River, where it is about 2 miles, and the other at Griffin Cove, where it is less. Approaching Cape Rosier the breadth gradually diminishes; and the Hudson River strata finally disappear under the waters of the Gulf, at Anse a la Tierce. The remainder of the distance to Cape Rosier is occupied by the gray calcareous sandstones, red shales, and limestone conglomerates of the Quebec group.

In the Great Pond section also the rocks which succeed to the Hudson River strata belong to the Quebec group, and they prevail for a breadth of about 11 miles, before becoming covered up by the Upper Silurian limestones. Two miles in the middle of this section are occupied by sandstones of the Sillery series, with the red shales which usually accompany them. The dips on both sides of the area occupied by these sandstones are to the southward; the inclination on the north side being 51° and that on the south side 64°. It is probable, however, that the strata are arranged in a synclinal form, and that those on the south side are inverted; the general synclinal probably contains several subordinate undulations of a similar character. The rocks on each side of the sandstone appear to belong to the Levis formation; some of the masses on the south side resemble the magnesian conglomerate bands of Point Levis. * * *

On the section from Griffin Cove, at the distance of 2 miles southwestward from the coast, about one-eighth of a mile is covered with large angular fragments of greenish sandstone, some of which are fine conglomerates, with quartz pebbles as large as peas. None of this rock has been seen in place; but the abundance and angularity of the fragments leave little doubt that the beds can not be far removed. The position of the fragments may therefore be assumed as that of the Sillery sandstones, particularly as they occur in what would be a continuation of the axis of the Sillery synclinal on the Great Pond section. Between the position of these sandstones and the Hudson River strata on the coast there would be room for the rocks of the Levis formation, but none of them have been there observed. * * *

Between Cape Rosier and the base of the Gaspe limestones a sudden turn in the coast gives a natural section, nearly at right angles to the strike, of 2¼ miles in length. The coast is low and shelving, and the violence of southeastern storms has heaped upon it a great mass of gray limestone shingle, which covers nearly the whole of it, with the exception of three points. One of these is Cape Rosier itself, where a breadth of 450 yards of the strata, including what are seen between high and low water marks, is exposed. The strata consist of gray limestones, in beds varying from 6 inches to a foot in thickness, with two thicker conglomerate beds, made up of gray limestone pebbles in a calcareous matrix, very much resembling the conglomerates of Ste. Anne des Monts, the whole interstratified with black and gray shales. Separated from the strata of the cape by an interval of 1,000 yards, covered by limestone shingle, there occur, at the next point exposed, gray, yellow-weathering limestones, probably magnesian, interstratified with jet-black and gray shales, with a band of conglomerate or brecciated limestone on the northeast side. The distance across the strata is about 800 yards; but there are intervals of concealment in it, making up 300 yards of the amount, and, though the dip is pretty uniform in direction to the southwest, there are variations in the inclination, which ranges from 44° to 60°. Another interval of concealment occurs, of about 1,000 yards across the measures; but a partial exposure at the end of the distance shows a continuation of the same alternation of shales, limestones, and sandstones. Red, purple, black, and olive-green shales succeed, associated with gray sandstones; some beds fine grained and close in texture and others coarse, with transparent quartz, silvery mica, white feldspar, and very minute bright green grains, probably of glauconite. A few thin layers of black bituminous limestone are interstratified among the shales. Several corrugations are visible in a low cliff, in which these beds are exposed; but the measurement across the shales is about 350 yards, and the dip, which is southwestward, varies in inclination from 26° to 90°.

Between these beds and the base of the Gaspe limestones there is a distance of about 800 yards across the shales, but the strata are only obscurely seen at intervals at the beginning and end of the measurement. The strike appears to be uniform, being N. 62° W.; but only the extreme edges of the beds are anywhere seen, and the dip is sometimes to the one side and sometimes to the other, at inclinations varying from 50° to 90°. The strata consist of black shales and thin limestones, which become somewhat arenaceous toward the south side; and the last beds, seen immediately in contact with the overlying Gaspe limestones, are of jet-black shale, yielding a black powder.

M 21. NORTHERN NEWFOUNDLAND.

Logan [544y] described the lower Paleozoic strata of northern Newfoundland under the headings "Potsdam group" and "Quebec group." He first recognized sixteen divisions and later reclassified them under letters. He says:

In the ascending section of the Labrador and Newfoundland rocks the divisions were arranged under the numerals 1 to 16. Some of these divisions have since been remeasured in greater detail than before; while with respect to others, the examination of their equivalents in other localities has shown that these divisions include additional strata. In giving these farther results, it will be convenient to designate the divisions by letters, and to indicate the subordinate parts of each by numerals. To facilitate a comparison of the present results with those stated in the previous chapter, a summary of the section already referred to is here given, with the former numerals, but having the letters now to be used, prefixed. The thickness formerly assigned to these divisions, and the localities in which they were observed, are also appended.

Potsdam group [Cambrian].

				Feet.
A.	1.	Red and gray sandstones	Anse au Loup	231
B.	2.	Gray, reddish, and green limestones	do	143
C.	3.	White sandstones, concealed	Strait of Belleisle	250
				624

Quebec group.

D.	4.	Gray and reddish magnesian limestones	St. Barbe Bay	150
E.	5.	Dark-gray limestones	do	400
F.	6.	Dark-gray geodiferous limestones	Port au Choix	400
G.	7.	Dark-gray limestones	do	130
H.	8.	Grayish-blue limestones	do	340
I.	9.	Light yellowish-gray magnesian limestones	do	150
K.	10.	Gray and whitish magnesian limestones	Point Rich	130
L.	11.	Light bluish-gray limestones	do	130
M.	12.	Light bluish-gray limestones	Table Head	550
N.	13.	Black bituminous limestones	do	200
				2,580
O.	14.	Gray calcareous sandstones and black shales	Cow Head	700
P.	15.	Gray and white limestone conglomerates	do	700
				1,400
Q.	16.	Greenish sandstones and red shales	Bonne Bay	2,000
				6,604

The preceding summary represents Logan's conclusions in assembling the results of his observations. The measured sections are given by him in detail and may be abstracted as follows:

Between 1 and 2 miles inland from the northeast side of the East Arm of Bonne Bay [northern Newfoundland] there arises a range of hills of Laurentian gneiss, 2,000 or 3,000 feet in height, on the flank of which is exposed the following measured section:

A.

	Feet.
1. Blackish-blue fine-grained slate. Of this slate only 105 feet of the upper part are seen; the lower part is concealed in the space between the upper portion and the gneiss and may comprise a thickness of about 230 feet	335
2. Blackish-blue slate interstratified with gray quartzites, in beds of from 6 inches to 3 and 4 feet. In the 80 feet at the bottom the quartzites greatly predominate, and they constitute 15 feet at the top, while the intermediate 175 feet consist chiefly of slate	270
	605

B.

1. Light-gray, yellow-weathering limestone, in beds of from 1 to 3 inches thick, interstratified with blackish-blue, slightly calcareous slate, both containing small specks of silver-white mica, which are more abundant in the limestone than in the slate. The limestones hold in abundance fragments of trilobites, chiefly belonging to three or four species. Among them is *Paradoxides* (*Olenellus*) *vermontana*, a new species of Bathyurus, and the pygidium of a species so closely resembling *B. extans* of the Birdseye and Black River formation that it can scarcely be distinguished from it and may possibly be the same	80
2. Grayish-green micaceo-arenaceous shale, interstratified with a few beds of grayish quartzite weathering slightly yellow	80
3. Strata concealed	30
4. Reddish granular quartzite in thick beds	105
5. Gray and grayish-green micaceo-arenaceous shale in beds from a quarter of an inch to an inch thick, interstratified with a few beds of gray, very ferruginous sandy dolomite and fewer of gray quartzite	127
6. Reddish quartzite, in beds of from 1 to 2 feet thick	34
7. Gray arenaceous dolomite, weathering yellowish brown, interstratified with reddish quartzite, in beds of from 1 inch to 1 foot thick, and with reddish and grayish micaceo-arenaceous shale, predominating toward the top. The beds of dolomite and shale contain fossils, among which are *Obolella chromatica?*, *Obolus labradoricus*, *Paradoxides vermontana*, *Conocephalites*, a new species of Bathyurus, and one or more undetermined species of Salterella	27
	483

C.

1. Whitish quartzite in beds of from 6 inches to 2 feet, interstratified with light-gray micaceo-arenaceous shale, in layers of from 6 inches to 1 foot, which occur at intervals of from 5 to 10 feet	150
2. White and reddish quartzite, in beds of from 1 to 3 feet thick, interstratified toward the bottom with a gray arenaceous dolomite, weathering yellowish brown	160
3. White and reddish quartzite, in beds of from 1 to 3 feet thick, interstratified with greenish micaceo-arenaceous shale, constituting about one-half the amount	90
4. Gray pure limestone, in beds of from 1 to 3 feet thick, marked with a few reticulating strings of yellowish-weathering dolomite. The rock is a mass of comminuted organic remains, among which are *Paradoxides vermontana* and undetermined species of Bathyurus and Salterella, as before	20
5. Blackish-blue soft shale, interstratified with gray, yellow-weathering limestone, probably magnesian, in beds of 1 or 2 inches thick. The quantities of shale and limestone are about equal, and the whole is intersected by reticulating strings of calc spar	35

	Feet.
6. Gray pure limestone, composed of comminuted organic remains, belonging to Paradoxides, Bathyurus, and Salterella, as before	27
7. Bluish-black soft shale, interstratified with gray, yellow-weathering dolomitic bands, as before	60
8. Gray pure limestone, probably composed of comminuted organic remains as before; underlaid by bluish-black shale inclosing nodules of blue compact limestone; some of which weather yellowish-brown, and are probably magnesian	13
9. Bluish-black soft shale of the same character as before, interstratified with a few beds of quartzite	68
	623
	1,711

The summit of the above section occurs on the east side of Deer Brook Bay, on the East Arm of Bonne Bay, and its base about 6 or 7 miles up the East Arm from the mouth of Deer Brook. All of the beds can be seen coming to the coast in succession, with a westward dip, and an inclination of from 20° to 60°. Where the beds of the base were observed, the measures appear to fold over an anticlinal axis, and for about 100 yards they dip to the eastward. For 2 miles beyond this, along the east side of East Bay, the greatest confusion prevails, and nothing reliable in regard to the sequence can be obtained from the exposures. East Bay and West Bay are two deep southward parallel indentations of the coast, which form the extremity of the East Arm. The area between them is from 1 to 2 miles wide, and the strata in it appear to lie in the form of a synclinal. The axis of this synclinal would run about north and south, and in the former direction it would strike to the eastward of the anticlinal just mentioned as occurring on the north side of the East Arm, while the axis of this anticlinal would strike into West Bay. The distance across the East Arm, on the axis of the synclinal, from the position where the lowest beds of the section above given would come upon it to the position where it would be crossed by the lowest beds between East and West bays would be about the same as that occupied by the whole section between the Laurentian gneiss and the coast of Deer Brook Bay. On the west side of this bay there occur some limestones of a peculiar color and character, whose stratigraphical place would be a few hundred feet above the highest beds in the section just given. About the same distance above the base of the strata between East and West bays similar limestones occur; and there is therefore not much doubt that the strata between these bays come in immediate or proximate sequence to those already given in section C. These additional strata are as follows:

C—Continued.

	Feet.
10. White quartzite, in beds of from 2 to 3 feet thick, interstratified with striped olive-drab and black compact arenaceous magnesian brown-weathering limestone, which constitutes one-fourth of the mass and holds small disseminated masses of iron pyrites	58
11. Strata concealed	150
12. Blackish-gray limestone; it is divided into beds of from 2 to 8 inches, and under the influence of the weather breaks up into thin scales	54
13. Smoke-gray compact pure limestone, striped with ocher-yellow arenaceo-ferruginous limestone, passing into brick-red. The gray and yellow alternate in lenticular layers, varying in thickness from a quarter to half an inch, and the rock presents a very peculiar and striking aspect. The yellow and red colors may be the effect of weathering, but in breaking up the rock the same alternation of these with the gray limestone was apparent in the interior. Rock of the same character occurs on the west side of Deer Brook Bay	30
14. Olive-gray, brown-weathering ferruginous sandy dolomite, containing thin lenticular patches and thin beds of pure smoke-gray limestone, with disseminated cubes and small masses of iron pyrites	17
	309

D.

	Feet.
1. Greenish-white and yellowish-white magnesian limestone, in massive beds, some of which are ferruginous and weather buff, while others remain unchanged in color. They are interstratified with beds of ash-gray limestone, weathering yellowish, and near the middle with two bands of gray calcareo-arenaceous shale, one of 2 and the other of 3 feet thick. These massive limestones terminate in a 4-foot bed of smoke-gray pure limestone in thin layers, interstratified with thin layers of probably magnesian limestone, weathering ocher-yellow. The bed, for the thickness of a foot, is arranged on the strike in a series of curves or arches, which span from 2 to 3 feet, separated by straight intervals, varying from 1 to 2 feet. The curved portions appear to hold a greater number of the yellow-weathering layers than the straight parts, and these layers have in general a lenticular form. The top and bottom of the bed are arranged in even layers, which fill up the inequalities of the intermediate part	174
	483

The surface between East and West bays rises into a mountain of 500 or 600 feet in height, in which the strata dip in directions conforming to their synclinal arrangement, at angles varying from 12° to 25°. Proceeding southward along the east side of West Bay, they are seen to accumulate above one another to the amount of 1,400 feet, in addition to the preceding section. These higher strata consist almost entirely of limestone of various shades of gray, with two or three bands of black, the latter usually thin bedded. Of the lowest 200 feet, about two-fifths weather to various shades of yellow and brown; of the succeeding 300 feet the proportion of yellow-weathering beds is about one-sixth, and in the remaining 900 feet they are but few. If these yellow-weathering beds are, like the similar ones in the detailed section just given, magnesian, it would appear that the proportion of magnesia gradually diminishes in ascending this portion of the series. In the whole of these 1,400 feet, which are supposed to represent the divisions E, F, G, the only strata in which fossils were observed occur at about 400 feet from the top; where the surfaces of various beds, in a thickness of between 10 and 20 feet, are marked by the weathered-out forms of silicified fossils, consisting of undetermined species of Pleurotomaria and Ophileta.

From West Bay the strata strike, in a general way, along the coast to the westward; they are much contorted and it is difficult to make out any true continuous succession of the beds. At the west horn of the bay, however, the whitish massive magnesian limestones of division D occur; and in the contorted strata for a couple of miles beyond the peculiarly striped smoke-gray and ocher-yellow thin-bedded limestones of C 13 are occasionally seen. At the promontory which faces the west horn of Deer Brook Bay the strata become vertical, or nearly so, but somewhat more regular; and the absence of any beds weathering yellow or brown appears to indicate a proximity to the horizon of the silicified fossils above mentioned. About 800 feet of dark-gray limestones are here exposed, at the summit of which there occurs a bed holding Maclurea, *Orthoceras piscator*, and Leperditia. Of the genus Maclurea the opercula were the only parts observed and these are silicified; but the bed is supposed to be higher in the series than the band with silicified fossils between East and West bays, inasmuch as it is immediately followed, not by the dark-gray limestones, but by about 200 feet of light-gray limestone; a good deal of which, although it does not weather yellow, is magnesian. The summit of these 200 feet is fossiliferous and contains undetermined or undescribed species of Orthis, Ophileta, Maclurea, Nautilus, Amphion, Asaphus, and Leperditia. The 800 feet are probably comprised in the divisions F and G, while the 200 feet may constitute a part of H.

The divisions M and N of the Newfoundland rocks have been, in a general way, described from exposures occurring at Table Head. The total thickness was here estimated from measurements by pacing, but few details were ascertained; and the fossils collected having been lost, from the necessity of abandoning them on the coast through stress of weather, it was considered expedient to reexamine the locality. The following detailed ascending section is the result. It commences between 600 and 700 feet lower than the strata comprised in the division M, or 12, as previously given, and the lowest part of these additional strata are considered equivalent to some of those at Point Rich.

H.

	Feet.
1. Bluish-gray limestone in beds of from 1 to 2 inches, interstratified with gray subcrystalline yellow-weathering magnesian limestone in beds of from 3 to 6 inches thick. The beds are fossiliferous, containing the genera Orthis, Ophileta, Maclurea, Pleurotomaria, Murchisonia, Orthoceras, and Bathyurus. The described species are *Orthis electra?*, *Maclurea matutina?*, and *Orthoceras piscator*	100
2. Strata concealed	165
	265

Division I of Logan's classification was placed by Billings in the Chazy, with some doubt, and is described in Chapter IV, together with divisions K to P inclusive. (See pp. 211–217.)

Billings [81] classified the faunas and arranged them in a catalogue. Commenting on their distribution and relations, he states:

POTSDAM GROUP.

In this group consisting of divisions A, B, and C, we have 19 species, none of which are found in the Potsdam sandstone in Canada. But in that part of the group, which is usually known, in the State of Vermont, under the designations of the Red sandrock and the Georgia slates, the following occur: *Scolithus linearis, Palæophycus incipiens, Obolus labradoricus, Obolella* (*Kutorgina*) *cingulata, Olenellus thompsoni, O. vermontana, Conocephalites adamsi*, and *C. teucer*. As these are the most abundant species in the formation, both in Vermont and Newfoundland, there can be little doubt but that the rocks in which they occur, in these two widely separated localities, are of the same age. * * * In the next overlying strata, division D, *Lingula acuminata* was found at Bay St. Barbes. I have compared the specimens from this locality with those that occur so abundantly in the upper part of the Potsdam in the township of Beverly, in Canada West, and believe them to be perfectly identical.

CALCIFEROUS FORMATION.

The Calciferous formation is represented in Newfoundland by all the divisions from D to H inclusive. In this series of strata there are 63 species, of which the following 14 are found in Canada and New York: *Stenopora fibrosa, Stromatopora rugosa?, Lingula acuminata, Euchasma blumenbachia, Pleurotomaria calphurnia, P. calcifera, P. laurentina, Murchisonia anna, Ecculiomphalus atlanticus, Orthoceras lamarcki, Piloceras canadensis, Bathyurus cordai, Asaphus canalis*, and *Leperditia turgida*. Excepting *S. fibrosa* and *B. cordai*, all of these occur in the true Calciferous in Canada. *B. cordai* abounds in the same formation in New York. *S. rugosa* is doubtfully determined and is probably distinct from the Black River species of that name. The beds in which *L. acuminata* occurs in Canada are placed in the top of the Potsdam; but as *Pleurotomaria canadensis* and an orthoceratite are associated with it, perhaps these particular strata should be more properly referred to the base of the Calciferous, and they would then correspond to division D. Most of the species are found in divisions G and H, the upper part of the formation in Newfoundland. Two of the species (*S. fibrosa* and *A. canalis*) range upward into the Chazy, the former continuing to the Upper Silurian. The general aspect of the fauna is peculiarly that of the Calciferous, the most striking features being the great numbers of small Maclurea and species of Piloceras, the latter a genus which seems to have culminated in this particular period.

M-N 11. ROCKY MOUNTAINS OF CANADA.

The stratigraphy of the Canadian Rockies was originally described by McConnell,[559e] who distinguished the Bow River and Castle Mountain groups. Walcott [859] has recently studied these rocks and divided them into several formations. He says:

Mr. McConnell proposed the name "Castle Mountain group" for the great series of limestones and shales between the quartzitic sandstones and siliceous shales of the "Bow River group" below and the superjacent Ordovician graptolitic shales on the west and Banff limestone on the east. This includes the upper portion of the Lower Cambrian fauna at the base and the lower portion of the Ordovician fauna at the summit. The term "Castle Mountain" is useful for the series, but I think that local names can be applied with advantage to several of the formations of the "Castle Mountain group" as originally defined. The following table [a] gives the relative positions and thicknesses of the new formation names herein proposed and defined for the Canadian Rocky Mountain section:

Cambrian formations of the Canadian Rocky Mountains.

Formation.	Character.	Thickness (feet).		
		Mount Stephen.	Mount Bosworth.	Castle Mountain.
Upper Cambrian.				
Sherbrooke formation	Bluish-gray arenaceous, dolomitic, massive, and thin-bedded to shaly limestones, with a few oolitic layers and cherty inclusions.	0	1,360	0
Paget formation	Bluish-gray oolitic limestones, usually thin-bedded.	0	360	0
Bosworth formation	Arenaceous dolomitic limestones, massive, thin bedded, and shaly, with bands of purple and gray siliceous shales.	Not measured	1,855	0
Middle Cambrian.				
Eldon formation	Massive arenaceous, dolomitic limestones, with a few bands of purer bluish-gray limestone.	Not measured	2,733	2,195
Stephen formation	Limestones and shales, calcareous and siliceous.	562	640	366
Cathedral formation	Massive arenaceous and dolomitic limestone	1, 600–1, 800	1,595	987
Lower Cambrian.				
Mount Whyte formation [a]	Alternating bands of limestone and siliceous and calcareous shale.	315	390	248
St. Piran formation [b]	Mainly gray quartzitic sandstones, with a few bands of siliceous shale.	300	300+	500+
Lake Louise formation	Siliceous shales			
Fairview formation	Gray quartzitic sandstones			

[[a] In the book cited, through a typographical error, the Mount Whyte formation was placed in the Middle Cambrian in the table on page 2, but the fauna was recognized by Walcott as Lower Cambrian, and is so termed on page 4.]

[[b] The St. Piran and the two underlying formations compose the upper part of the Bow River group. In 1910 Walcott found a conglomerate at the base of the "Fairview formation," recently renamed by him the Fort Mountain sandstone (Mon. U. S. Geol. Survey, vol. 51, 1912, p. 131), that marks an unconformity between it and the underlying part of the Bow River group, which is very much the thicker portion. He therefore regards the Bow River group as chiefly pre-Cambrian. (Personal communication.)]

[a] The table as here printed is not an exact quotation but is made up from Walcott's paper.—B. W.

Q 3. SEWARD PENINSULA.

(See O–R 2–8, Alaska, Chapter VII, pp. 353–354.)

Q 5–6. ENDICOTT RANGE, NORTHERN ALASKA.

(See O–R 2–8, Alaska, Chapter VII, pp. 353–354.)

S 27. EASTERN COAST OF GREENLAND.

(See Chapter IV, p. 224, description by Nathorst.)

T 17–18. ELLESMERE LAND.

The following notes on the occurrence of Cambrian and Ordovician strata are quoted from Schei:[550c]

At Cape Camperdown, on Bache Peninsula, is found granite overlain by an arkose-like conglomerate sandstone, in flat strata, the dip being north-northwest. Its thickness here probably does not exceed 500 feet, though the contour swells to considerably greater magnitude by reason of intrusions of diabase, occasioning an additional thickness of perhaps 300 feet. At its upper part this sandstone merges gradually, by interstratification, into a series of gray sandy and marl-like schists and limestone conglomerates. From a few inches up to a couple of yards in thickness these conglomerates and schists, continuously interstratified, build up a series 600 to 900 feet in thickness, interrupted by two compact beds of yellowish-gray dolomitic limestone about 150 feet in thickness. These again are overlain by a series similar to the underlying one, excepting that here the limestone conglomerates exceed the schists.

In a detached block, in all probability originating from one of the two 150-foot beds, were traces of fossils, of which one, Leptoplastus sp., can be identified. In another detached block, whose mother rock is not known, was found Anomocare sp. It may be said with certainty after the finding of these fossils that this series contains deposits of the Cambrian age.

The second series of conglomerates is overlain by a light grayish-white limestone in a bed some 300 feet in thickness, observed in the midst of the section of Cape Victoria Head. Indistinct Orthoceras, Lichas, and Symphysurus assign this limestone to the Lower Silurian period.

Above the Orthoceras-bearing light-colored limestone bed are some less extensive strata of alternating limestone and quartz sandstone, and finally a 100-foot bed of close brown limestone of which certain layers are fossiliferous and gave an Asaphus, traces of other trilobites, and some gastropods.

Following the direction of the dip to the north side of Princess Marie Bay we find it again, though seemingly somewhat abrupter, in the limestone beds of Norman Lockyer Island. A fauna with Halysites sp., Zaphrentis sp., Orthisina sp., Rhynchonella sp., Leperditia sp., Illænus sp., etc., assigns this limestone to Lower Silurian. It is again found with its fauna at the base of Cape Harrison; in this case with a thick superincumbent bed of marly sandstone, quartz sandstone, and finally extensive limestone conglomerate.

CHAPTER IV.

MIDDLE AND UPPER ORDOVICIAN.

Color, light bluish purple.

Symbol, 17.

Distribution: General throughout the continent. In the Arctic mapped with the Silurian; in the Rocky Mountains of the United States included in narrow bands of Cambrian and lower Ordovician.

Content: Early to uppermost Ordovician (Chazy to Richmond, inclusive).

Middle and upper Ordovician areas.

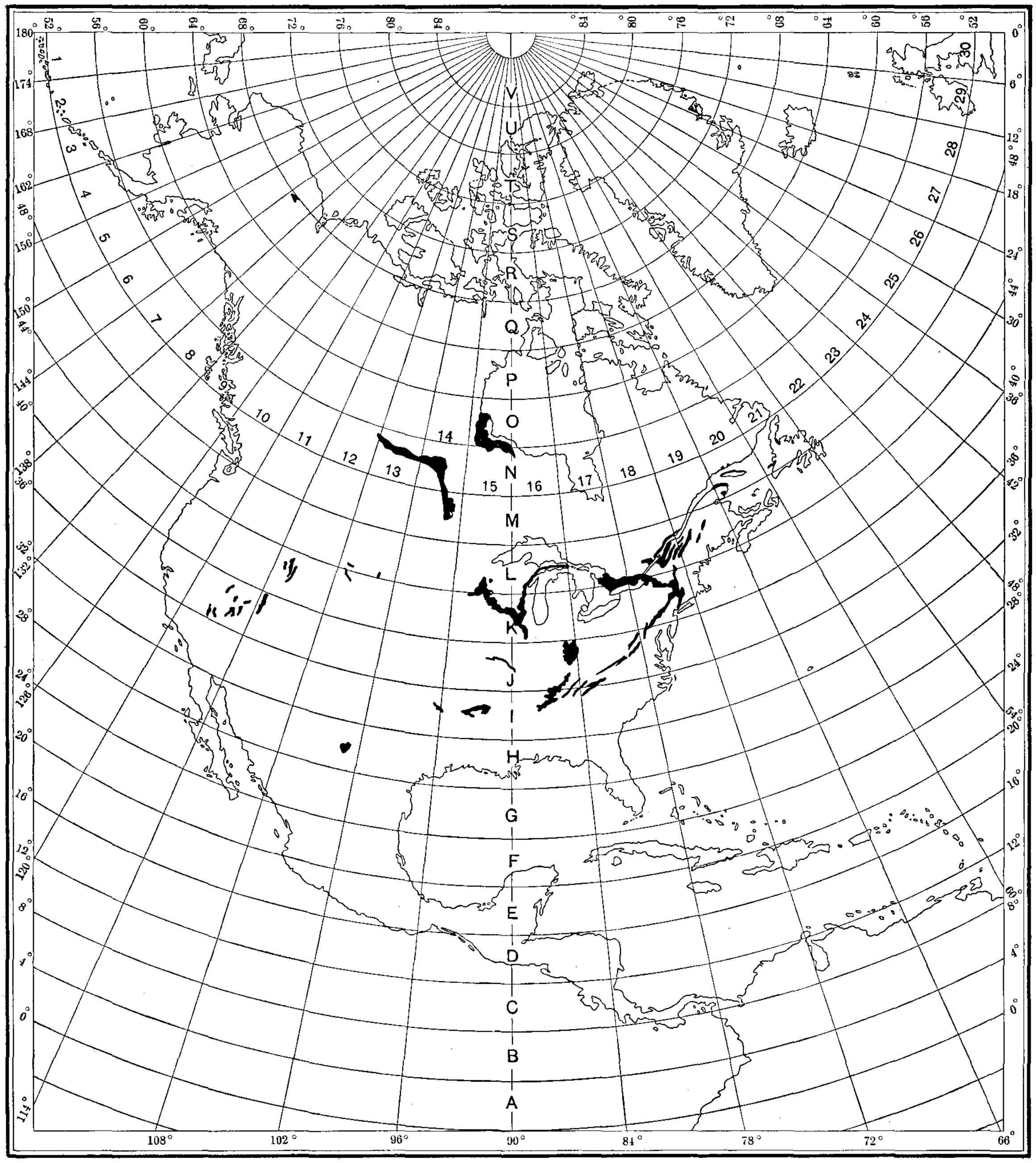

FIGURE 6.—Sketch map showing the distribution of middle and upper Ordovician rocks represented on the geologic map of North America and the key to references in the text.

H 13. TEXAS.

In the Caballos Mountains, southern Texas, is exposed an area of Paleozoic rocks from which Udden [819] procured Ordovician fossils. Other Paleozoic formations are probably represented.

With reference to the Upper and Middle Ordovician in the district north and east of El Paso, Richardson [668a] states:

> The Montoya limestone also has been recognized by its stratigraphic position and fossils in both of the quadrangles [El Paso and Van Horn]. This limestone contains two distinct Ordovician faunas, the Richmond and Galena, and on paleontologic grounds it is desirable to separate the two, but the small thickness of the formation, only about 250 feet, and the scale of the maps will not admit of it.
>
> Fossils characteristic of the Galena occur in the lower part of the Montoya linestone, the zone being commonly marked in the El Paso quadrangle by massive dark-colored limestone containing little or no chert. The upper part of the limestone is prevailingly gray, but some of the beds are almost white while others are dark, and the two parts of the formation can not always be distinguished lithologically. The zone which carries the most abundant Richmond fossils in places is seamed with conspicuous bands of chert a few inches in thickness. In the Van Horn quadrangle the base of the Montoya limestone is commonly marked by the presence of thin-bedded earthy yellow and reddish limestone, but otherwise in both quadrangles the contact is apparently conformable. Like the El Paso limestone, the Montoya is characteristically magnesian. Mr. Ulrich has identified the following fossils from the Montoya limestone:

Fossils from the Galena beds.

Receptaculites oweni.
Maclurina manitobensis.
Maclurina acuminata.
Hormotoma major.
Ormoceras sp. undet.

Fossils from the Richmond beds.

Streptelasma rusticum.
Hemiphragma imperfectum
Monotryprella quadrata.
Strophomena flexuosa.
Leptæna unicostata.
Dinorthis subquadrata.
Dinorthis proavita.
Platistrophia acutilerata.
Rhynchotrema capax.
Orthis whitfieldi.
Parastrophia divergens.

In southwestern United States outside of the areas here considered few Ordovician rocks are known. The system apparently is not represented by sediments in either the Grand Canyon or Bisbee districts. The Longfellow formation in the Clifton quadrangle, Arizona, probably should be correlated with the El Paso limestone as well as a part of the Ordovician limestone in the central Texas region. Recently several small areas of Ordovician rocks have been reported in central New Mexico by Gordon and Graton.[a] Mr. Ulrich reports that the Beekmantown fauna of the El Paso limestone is of the type prevailing in the Wichita Mountains, Oklahoma, in the upper 1,000 feet or so of the Arbuckle limestone; and that the Galena and Richmond faunas of trans-Pecos Texas are similar to those in the Mississippi Valley, Oklahoma, the Black Hills, the Bighorn Mountains, and elsewhere.

2–13. ARIZONA AND NEW MEXICO.

The interval corresponding to the Ordovician appears to be represented throughout most of Arizona only by a parting between two limestones containing Middle Cambrian fossils.[657, 658a] These relations resemble those of the Grand Canyon section.

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[a] Am. Jour. Sci., 4th ser., vol. 21, 1906, p. 190.

Near the eastern boundary of Arizona, in the Clifton district,[541a] the Longfellow limestone represents the early Ordovician ("Calciferous," Ulrich) and possibly some Upper Cambrian, but the later Ordovician is lacking.

The Ordovician of New Mexico is described by Gordon and Graton [372] as comprising the equivalent of the lower Ordovician and also limestones which carry a distinct Richmond (uppermost Ordovician) fauna. Fuller descriptions are given by Lindgren.[542]

I 14. OKLAHOMA.

In the Arbuckle Mountains of Oklahoma Ordovician strata are represented by the Arbuckle limestone (Upper Cambrian and early Ordovician; see pp. 82–83, Chapter III), the Simpson formation (of Chazy or Stones River age), and the Viola limestone (of Black River to Richmond age). Taff and Ulrich [808a] give the following account of the stratigraphy and correlation:

> After the Arbuckle limestone was deposited there was a general change in the nature of the sediments. The top of the limestone seems to have been slightly eroded locally and upon the surface were deposited beds of pure sand. At other places the Arbuckle limestone is overlain by shaly and impure lime—the basal beds of the Simpson formation. On these local sandy beds at the base there were deposited greenish shales and thin crystalline and shelly limestones interstratified with a number of beds of sandstone, making a total thickness ranging from about 1,200 to 2,000 feet.

A generalized section measured on the south side of the Arbuckle uplift gives the following beds:

	Feet.
Thin limestone and shale	890
Sandstone	100–200
Thin-bedded limestone and shale, with some sandstone	1,250

The sandstone separates the formation into two divisions, regarding which Taff and Ulrich say:

> The fauna of the lower division of the Simpson formation is decidedly similar to that of the Chazy of New York and Canada and of the Pogonip formation of Nevada. Considering these east and west connections, it is surprising to note that the lower Simpson fauna, so far as known, contains none of the prolific fauna of the lower division (Murfreesboro limestone) of the Stones River group in middle Tennessee, which is believed to be of equivalent age. As a whole, the fauna of the upper part of the Simpson is closely related to the upper division of the Stones River group in Tennessee and Kentucky and the equivalent beds in the upper part of the Mississippi Valley.

The description of the Viola limestone follows and comprises the items quoted below:

> There is a gradual transition from the top of the Simpson formation up into the basal part of the Viola formation. The top layers of the Simpson are usually argillaceous, are thinner, darker, and more evenly stratified than those at the base of the Viola, and in places contain partings and beds of clay. The rocks at the contact on each side, however, vary somewhat in different parts of the field.
>
> The Viola formation is a continuous but slightly variable deposit of limestone 500 to 700 feet thick, which usually appears massive on very fresh exposures. Upon weathering, however, the bedding is pronounced, showing layers rarely more than a foot in thickness. In the lower and middle parts especially there are occasional bands and nodular masses of chert.
>
> The Viola limestone is divisible into three members, distinguished by variations in bedding, in texture, and to a less extent in the color of the limestone. The upper and middle members

are approximately 300 feet thick. The lowest member is somewhat thinner and more variable than the others. The lowest member consists of light-colored, coarse-textured, and usually roughly bedded limestone. It probably will not exceed 100 feet in thickness anywhere, and in places is much less.

The middle member consists of white to light-blue and generally even- and thin-bedded limestone. On account of the abundance of fossil trilobites of the genus Trinucleus in certain layers it might be known as the Trinucleus member. It is characterized by white surface where weathered and even bedding. * * *

An investigation of the fossils by Mr. Ulrich, who collected and studied the rock section, shows that there are three faunal divisions, which correspond to the three lithologic members above described. The most fossiliferous development of the basal member was noted at the extreme northern occurrence, in the region at the base of Double Mound, 6 miles northeast of Roff. A preliminary study of the fossils collected shows [a large number of species, nearly all of which] occur in Phylloporina and Clitambonites beds of the Ordovician section in Minnesota. These beds are correlated with latest Black River and earliest Trenton. Many of the species occupy these horizons in New York and Canada and what are regarded as equivalent positions in middle Tennessee and Kentucky.

As a whole the middle member or Trinucleus bed of the Viola limestone is not abundantly fossiliferous. The organic remains occur chiefly in three horizons, one near the base, another above the middle, and the third near the top. The first and second contain an abundance of graptolites. Next to the Trinucleus the graptolites are the most characteristic and commonest fossils of the middle member. The fossils indicate that the Trinucleus beds were deposited during the latter half of the Trenton age.

The upper member of the Viola limestone is approximately 300 feet in thickness, but only in the upper 25 feet is it abundantly fossiliferous. The lower 50 feet yielded no fossils. In the middle portion the fossils are not only rare but poorly preserved. The fossils are all species characterizing the upper divisions of the Richmond age in Minnesota, Wisconsin, Illinois, Indiana, and Ohio. In northern Arkansas the same fauna occurs in the Polk Bayou limestone and in middle Tennessee in the Fernvale formation.

I 15. ARKANSAS.

Purdue[655] has recently published the results of studies of the stratigraphy of the Ouachita Mountains, in Arkansas, as worked out by himself and Ulrich:

	Feet.
Carboniferous: Stanley shale	6,000
Unconformity.	
Age unknown:	
Fork Mountain slate	100
Arkansas novaculite	800
Missouri Mountain slate	300
Probable unconformity.	
Ordovician:	
Blaylock sandstone	1,500
Polk Creek shale	100
Bigfork chert	700
Stringtown shale	100
Unconformity.	
Ouachita shale	900
Crystal Mountain sandstone	700
Probable unconformity.	
Age unknown: Collier shale (observed thickness)	200
	11,400

The Collier shale was considered by the Geological Survey of Arkansas as of Lower Silurian (Ordovician) age.[a] Some of the older rocks above this shale are certainly of Ordovician age, as

[a] Geol. Survey Arkansas, vol. 3, 1890.

is shown by the fossils they contain; and the Crystal Mountain sandstone, the formation immediately above, is considered Ordovician on lithologic grounds. But careful search has failed to reveal any fossils in the Collier shale, nor has it any lithologic characters that would give it claim to an age classification with the overlying rocks. On the other hand, it is quite different from the rocks above, and at its top there is at least locally a conglomerate which future study may determine to be widespread. For these reasons, it is thought best not to even provisionally place this with the Ordovician. It may be Cambrian. If so, these are the oldest outcropping rocks in the State. * * *

It is a dark, soft, graphitic clay shale, containing widely separated thin beds of dense black and intensely fractured chert. As a result of the severe squeezing and shearing it has undergone practically all traces of bedding have disappeared. It is intensely crumpled and is full of glossy, slickensided surfaces. In places slaty cleavage may be observed. The upper 100 feet or more is quite calcareous, limestone occurring in dark-colored crystalline lenses and layers one-half inch or more in thickness, distributed through the shale. In other parts the limestone is several feet in thickness and occurs in much contorted layers from a few inches to more than 2 feet thick, interbedded with thin seams of graphitic shale. In such cases the limestone is dark and compact, is much jointed, and on long exposure weathers in very uneven surfaces. * * *

The rocks of known Ordovician age within the Ouachita Range include five formations, which are here known as the Crystal Mountain sandstone, the Ouachita shale, the Stringtown shale, the Bigfork chert, the Polk Creek shale, and the Blaylock sandstone.

The Crystal Mountain sandstone consists of two parts—a lower massive one composed wholly of sandstone, 300 feet thick, and an upper part consisting of rather massive layers of sandstone interbedded with black to gray shale, 400 feet thick. The shale is in places altered to ribboned slate, like the lower part of the Ouachita shale. The lower part is the main rock of the Crystal Mountains, which owe their existence to this massive, slow-weathering formation. It is a coarse-grained white sandstone, composed of well-rounded grains, and commonly weathers to the color of brown sugar. In many parts it is thickly set with a network of quartz veins from the thickness of a knife blade to several inches. In other parts there are fissures from several inches to several feet in width, the walls of which are lined with magnificent clusters of quartz crystals. * * *

This formation has not to the present time produced any fossils, and it is considered of Ordovician age wholly on lithologic grounds. The sandstone passes gradually into the Ouachita shale above, and the close resemblance of the included shale beds to the Ouachita shale seems to the observer in the field conclusive evidence that the two are of the same age.

The Ouachita shale is the next formation above the Crystal Mountain sandstone, into which it passes by gradual increase of sandy layers. * * * The formation is intensely crumpled, and for that reason its thickness has not definitely been made out, but it probably is not less than 900 feet.

For the most part this is a dark-colored clay shale, but not uncommonly the dark layers alternate with green ones. In many places slaty cleavage is developed, when the alternating layers of dark and green produce ribboned slate. Somewhere in the lower portion there are thin layers of limestone, interbedded with the shale. Quartz veins and thin layers of hard flinty material are common, and fragments of quartz frequently occur on the ground where this is the surface rock. The shale is frequently dissected by straight, well-defined joints. Graptolites, while not so common as in the shales above, are frequently to be found.

The Stringtown shale in Arkansas rests unconformably upon the Ouachita shale and is from 75 to 150 feet thick. It consists of two parts, a lower calcareous part and an upper shaly part. The lower part of the formation contains lenses of bluish compact brittle limestone, usually thickly set with calcite veins. The basal portion of this is sometimes conglomeratic, the pebbles ranging from the size of peas to 2 inches in diameter and subangular. They consist of shale, very fine grained brown sandstone, and limestone. * * *

The maximum observed thickness of the limestone lenses is about 75 feet. They are made up of layers from a few inches to 2 feet in thickness and they may thin down to a few feet or entirely disappear, within very short distances. The rapid thickening and thinning of the limestone, its sporadic occurrence, the conglomerate it contains, and the lithologic difference between the shale of the formation and that beneath led to the conclusion in the field that there is an unconformity between the two formations, which afterward was confirmed on paleontologic evidence by Mr. E. O. Ulrich. The irregular occurrence of the limestone is due to its having been put down in the valleys of the old land surface, and the pebbles of the conglomerate at the base of the limestone doubtless were carried in by the streams flowing over that surface.

The upper or shale portion of the formation usually is from 50 to 75 feet thick. It is a very black shale and is soft enough to soil the fingers in handling, qualities due to the presence of a large per cent of finely disseminated graphite. In places the graphite is conspicuous and occurs in thin, wavy sheets. While most of this part of the formation is shale, there sometimes occur in it, especially near the top, thin beds of dark-colored chert, very similar to the Bigfork chert, next to be described, as well as thin layers of limestone. Some of the shale layers are quite calcareous, and when the lime is dissolved out from these, there remains a gray to pink colored porous, spongy shale, fragments of which are frequent on the slopes. Fossil graptolites abound in the shale of this formation and occur sparingly in the limestone.

The Bigfork chert is a very close textured, even-bedded siliceous rock, in layers from 1 to 18 inches thick, but the most common thickness is from 3 to 6 inches. * * * The color varies from a slate to a dark gray, the former being most common. It is very brittle and under the blows of the hammer flies into small pieces. The fracture is angular, in some of the layers approaching conchoidal. In places it is thickly set with a network of fine quartz veins. It is along these veins that the stone breaks when struck with a hammer, and so numerous are they that it often is difficult to secure a hand specimen with fresh surfaces. Straight joints several inches in length with remarkably smooth surfaces are common. Weathered portions have the appearance of fine-grained gray weathered sandstone. Usually the layers are crumpled to an astonishing degree, and it probably was the strain accompanying this intense folding that caused the network of thin joints, which subsequently were filled with quartz, forming the veins above described. Its thickness is about 700 feet.

This formation is mapped by the Geological Survey of Arkansas [a] as novaculite, but it differs materially from the true novaculite of the area in being of a coarser texture, darker color, thinner bedded, not translucent, older, and in having a much more complex structure.

The Polk Creek shale overlies the Bigfork chert, with which it is conformable, and outcrops along the bases of many of the ridges in the Ouachita Range. In color, hardness, and texture this shale is much like the Ouachita shale. It resembles that also in containing a large number of quartz veins and locally in having slaty cleavage well developed. In this, as in the Ouachita shale, graptolites abound. It differs from that shale in containing no sandy or calcareous layers and in being only about 100 feet thick. In places it appears to be absent.

The Blaylock sandstone is well exposed at the eastern end of the mountain, where the Little Missouri River cuts across the exposed edges. Like the other formations described, it is extremely crumpled. The repetition of beds resulting from the crumpling renders its thickness difficult to determine, but this is thought to be about 1,500 feet in the thickest part. Apparently it is conformable with the Polk Creek shale beneath. In parts, through a hundred feet or more, it consists almost wholly of sandstone, while in other parts it is made up of alternating beds of sandstone and shale. The sandstone is in layers that usually are from 1 to 6 inches thick, and the bedding is very even. Some of the layers are quite quartzitic and contain numerous thin quartz veins. Others of the thin layers closely resemble chert. It is fine grained to medium grained, and varies from dove-colored to dark gray or green. Graptolites occur in it rather sparingly. The interbedded shale is dark colored, often black, and fissile. In places it contains large numbers of graptolites.

[a] Geol. Survey Arkansas, vol. 3, 1890.

The exact stratigraphic relations of this formation are not at present understood. The only area in which it has been carefully studied is in the southern part of Montgomery and Polk counties, where it outcrops over an east-west belt about 3 miles wide, and from which it thins northward until it is only a few inches to a few feet thick where it outcrops on the north slope of Caddo Mountain. That the formation is absent north of Caddo Mountain is known, for the horizon at which it occurs is widely exposed. Whether the sudden appearance and rapid thickening as we pass southward is due to its having been put down in a trough, or to an erosion interval during which that part to the north was removed, will require further field work to determine; but its much contorted condition and its relations to the overlying formation, later to be described, impress one with the strong conviction that probably it is due to an erosion interval. * * *

From recent work it appears that the age of the Missouri Mountain slate, the Arkansas novaculite, and the Fork Mountain slate can not yet be determined, for no fossils have been found in them[a] by recent workers in the area. They may be of Ordovician age, they may be Silurian, and they may be Carboniferous. Their lithologic character is so very different from the nearest rocks of Devonian age (coarse-grained sandstones and black shales), which occur in northern Arkansas, that the possibility of their being of that age is scarcely entertained. On the other hand, their siliceous character might easily permit them to be considered contemporaneous with either the Ordovician limestones of the Ozark region, which contain a great deal of chert, or with the Boone formation (Mississippian) of that region, which is largely and in parts entirely chert. The representative of the Silurian in northern Arkansas is the St. Clair limestone, which contains no chert. * * *

The Missouri Mountain slate, where the Blaylock sandstone is present, rests upon that formation; where that is absent, it rests upon the Polk Creek shale at all points where contacts were observed. While it partakes of the large and comparatively gentle folds of the area, it appears not to enter into the minute crumpling of the Blaylock sandstone and lower formations, but on the contrary to rest upon their upturned and what seem to be eroded edges. Whether it does or not has thus far eluded all efforts to determine, on account of the great amount of débris nearly always present on the slopes where the contact between the two formations would otherwise be exposed.

This formation varies from 50 feet and less to 300 feet in thickness, the thinnest part being, so far as observed, along the southern border of the Ouachita Range. The formation is a clay slate. A few feet of the basal portion usually is green. Locally this lower portion is somewhat sandy and such parts contain small crystals of iron sulphide. The remainder, above the basal portion, varies from a blood-red to a dark red, containing patches and streaks of green. The green at the base may be the original color, but that above is secondary. * * *

The Arkansas novaculite is the principal formation of the Ouachita Range. Owing to an unconformity at the top, its thickness is quite variable, but the maximum observed is about 800 feet. The character of the formation varies from the base to the top, as well as in different parts of the same horizon. In a general way it may be described as consisting of a lower, heavy-bedded siliceous part that is wholly novaculite and an upper, thin-bedded part of the same material, interpolated with thin layers of black soft shale. In places there is an intervening portion containing sandstone.

The lower portion is about 300 feet thick and consists of massive beds from 2 to 10 feet thick, with large ripple marks showing along the bedding planes. This part of the formation furnishes the abrasives that are known in the markets as the Ouachita and Arkansas stone. It is a very close textured rock, the grains being of microscopic size. The common color is a very light gray, but bluish tints and pink, black, and dove-colored spots are quite common in the lower 50 to 75 feet. The fracture is uneven to conchoidal, and it is very brittle. In

[a] Prof. L. S. Griswold, in the report of the Geological Survey of Arkansas, vol. 3, 1890, pp. 404–407, names several localities in which graptolites were supposedly obtained from above the novaculites. Several of these localities were visited by Mr. H. D. Miser, who reports that in each case the graptolites occur above the Bigfork chert instead of above the novaculite.

luster it is often waxy, and thin edges frequently are translucent. The bedding is quite irregular, small lenses between the beds being very common. * * *

The upper portion, in those parts where it is all present, is much thicker than the lower. It consists of layers of novaculite the most common thickness of which is from 1 to 6 inches, interpolated by layers of shale that is very black and soft when unaltered. When weathered, this shale is brown to green in color, producing a banded effect. The novaculite layers usually are dark to black but lithologically are not otherwise very different from the massive novaculite beds of the lower part of the formation. This part of the formation is frequently and sometimes wholly removed, as a result of an unconformity between it and the Carboniferous rocks that rest upon it.

The Fork Mountain slate, when present, lies at the top of the Arkansas novaculite, and is about 125 feet thick. On account of the unconformity above mentioned, it is only locally present, having in many places been removed by erosion. * * *

This formation consists of gray to greenish and chocolate-colored slates, containing thin layers of quartzite in the lower part.

I 16. ALABAMA, GEORGIA, AND SOUTHEASTERN TENNESSEE.

The classification and synonymy of the Ordovician worked out by Hayes [417] in the southern Appalachian region is:

Ordovician rocks in southern Appalachian region.

Period.	Formation names used in report.	Names hitherto applied to the same rocks.		
		Smith, Geology of valley region adjacent to Cahaba coal field, 1890.	Smith, Outline of the geology of Alabama, 1878.	Safford, Geology of Tennessee, 1869.
Silurian [Ordovician].	Rockmart slate		Cincinnati or Nashville.	Nashville.
	Chickamauga limestone.	Trenton or Pelham limestone.	Trenton, Chazy or Maclurea.	Trenton or Lebanon Maclurea limestone.
	Knox dolomite	Knox dolomite	Quebec or Knox dolomite.	Knox dolomite.

The stratigraphic relations and distribution of the formations are described in the Stevenson, Gadsden, and Chattanooga folios of the Geologic Atlas of the United States, according to the divisions which have been carefully worked out as lithologic units. Recent paleontologic studies by Ulrich and Bassler, not yet published, appear to lead to the discrimination of several paleontologic facies and to correlation with the Stones River and other established horizons of the Mississippi Valley and New York sections.

A recent study of the Birmingham district[107a] has resulted in the following lithologic distinctions:

	Feet.
Silurian: Clinton (Rockwood) formation	250–500
Unconformity.	
Ordovician: Chickamauga (Pelham) limestone	200–1,000
Unconformity.	
Cambro-Ordovician: Knox dolomite (includes at base Ketona dolomite member, 600 feet)	3,300
Cambrian:	
Conasauga (Coosa) limestone	1,000
Rome (Montevallo) formation (great thickness).	

In these systems there are included the Rome (Montevallo) formation and the Conasauga (Coosa) limestone, both of known Cambrian age; the overlying Knox dolomite, the lower part of which is regarded as Cambrian and the upper part Ordovician, though the plane of division between the Cambrian and Ordovician is unknown; and the Chickamauga (Pelham) limestone, of known Ordovician age.

The lowest Cambrian rocks exposed in this area are limestone and shale, possibly 1,000 to 1,500 feet thick, so far as can be judged from the width of outcrop in Opossum Valley. These rocks have been designated the Conasauga limestone by the United States Geological Survey and the Flatwoods or Coosa formation by the Alabama Geological Survey. They consist of thin-bedded blue limestone interbedded with shale, which in some sections, as in the vicinity of Bessemer, carries considerable chert in thin layers. This limestone is underlain by a mass of shale of great thickness, which to the east is known as the Rome formation. Locally it has been called the Montevallo shale. In this report it is called the Rome formation.

The Knox dolomite includes the rocks between the Conasauga and the Chickamauga (Pelham) limestone. In the Birmingham region and other parts of Alabama the lower part of the formation is almost free from chert, and on account of both this lithologic difference and its economic importance it has been separated out as a member from the mass of the Knox and named the Ketona dolomite member. The name Ketona is chosen because of the extensive quarry in this member at Ketona. The Ketona dolomite overlies the Conasauga (Coosa) limestone with apparent conformity and is 500 to 600 feet thick along Opossum Valley east of Birmingham. It is a nearly pure dolomite, with but little chert. It is thick bedded, crystalline in texture, and of prevailingly light gray color. From it is drawn most of the fluxing rock used in the Birmingham furnaces. * * *

The rest of the Knox dolomite, 2,700 to 2,800 feet thick, overlies the Ketona dolomite member conformably. It is composed of dolomite with chert layers, which in places reach a thickness of 10 feet or more. Possibly one-fourth of the formation is chert.

Overlying the Knox dolomite unconformably is the Chickamauga limestone, of Ordovician age. It is the same as the Trenton or Pelham limestone of the Alabama Geological Survey. In Birmingham Valley this is a thin-bedded bluish to dove-colored limestone ranging generally from 200 to 500 feet thick. It has been used for flux to some extent.

I-J 16-17. OHIO, KENTUCKY, AND TENNESSEE.

The well-known areas of Ordovician strata exposed on the Cincinnati and Nashville domes in Ohio, Kentucky, and Tennessee are mapped from the respective State geologic maps. The terranes comprise the oldest sediments exposed, namely, Middle Ordovician limestones of the Stones River group and others of Trenton age and the overlying Cincinnatian series (Upper Ordovician), consisting of strata of Utica, Lorraine, and Richmond age. They are thin limestones and shales, which are inconstant in thickness and faunal content.

In Ohio Orton [620] distinguished the following beds:

Cincinnati group of southwestern Ohio.

		Feet.
Lebanon beds		293
Cincinnati beds proper:		
Hill Quarry beds	125	
Eden shales	250	
River Quarry beds	50	
		425
Point Pleasant beds		50

The Point Pleasant formation was subsequently, by Winchell and Ulrich,[944a] shown to be of Trenton age and to be "terminated above with a heavy current-formed crinoidal layer, which includes large pebbles and disturbed masses of the underlying limestone layers and exhibits other evidences of unconformity by erosion" with the overlying shales. In the report just cited the authors state:

The strata of the Cincinnati period as exposed in Ohio, Indiana, and Kentucky are divisible into three groups, having about the same geological value as the Chazy, Stones River, Black River, and Trenton groups of the Trenton period and the Medina, Clinton and Niagara groups of the Niagara period. These three divisions correspond very nearly with the Lower, Middle, and Upper Hudson of the Kentucky geologists, and the Eden shales, Hill Quarry beds, and Lebanon beds of Prof. Edward Orton in volume 1, Geology of Ohio.

At Cincinnati we begin the period with the Utica group, which here consists of over 250 feet of grayish and blue calcareous shales and marls, in which many layers of more or less crystalline limestone, from 1 to 20 inches thick, are included. The lower 14 or 20 feet of this division are of a darker color than the succeeding shales, being greenish gray or drab rather than light blue.

It is this portion that agrees best in all respects with the Utica of New York and Canada, and it was so determined by Prof. James Hall as early as 1842. The gray shales contain more or less abundantly such widely distributed and characteristic Utica fossils as *Triarthrus becki, Primitiella unicornis, Leptobolus insignis, Lingula daphne, Dicranograptus ramosus, Diplograptus spinulosus, D. putillus, Dendrograptus simplex,* and *D. tenuiramosus.* Of these, the last three, as well as many other species, continue into the main body of the shaly strata of the group. Throughout, fossils, Bryozoa especially, occur in greater abundance, variety, and perfection than at any other known locality for the Utica. At the top the shales pass rather gradually into the "Hill Quarry beds."

The latter, for which we propose to use the name Lorraine group, are clearly equivalent to the greater part of the New York strata which Emmons included under that name.[a] At the base of the division, which at Cincinnati comprises about 200 feet of strata, there are some arenaceous layers that on weathering frequently preserve the fossils as casts. Above these there are numerous layers of crystalline limestone, 3 to 10 inches in thickness, separated by relatively thin bands of shale. In the upper 60 or 70 feet the bedding is more irregular and the limestone layers thinner and generally argillaceous, unfitting them for building purposes. Fossils are well preserved and exceedingly plentiful and among them may be recognized nearly every species that has been described from the equivalent beds in New York. Perhaps 300 species of fossils are known from the Cincinnati exposure of the Lorraine group and of these at least two-thirds are limited to the group, which is, considering the very similar lithological characters of the preceding and succeeding beds, a surprisingly large percentage.

Resting on the Lorraine there is a series of alternating thin-bedded shales and limestones and in some localities finally a sandstone, in all quite 350 feet thick in southwestern Ohio and southeastern Indiana. Almost the entire series is excellently exposed at Richmond, Ind., so that the name Richmond group which we propose to apply to the series is eminently appropriate. East and southeast of Oxford in Ohio the whole group consists of thin-bedded limestones and shales, but at Richmond the upper part shows an increase of arenaceous matter while the uppermost layers of shale have become harder and include one or two heavy beds of impure limestone. Southward from this locality in Ripley and Jefferson counties, Ind., the heavy layers are increased. In the last county their texture is very compact and the color a drab or dove, reminding one in both respects very greatly of some beds of the Trenton period. In Indiana and Ohio this upper part of the group is, as a rule, not very fossiliferous, but when the bed is traced over into Kentucky it becomes a veritable coral reef reaching from Jefferson County, Ky., to and beyond Marion County. The rock in this distance has changed some, being in the last county of a yellowish color and finely arenaceous texture, the whole giving way very readily under the weather so that the surface is sometimes thickly strewn with masses of Columnaria, Tetradium, Labechia, and Beatricea.

[a] We refer particularly to Emmons's Lorraine sandstone, the greater part, if not all, of his Lorraine shales, which Walcott in 1879 referred to the Utica, being probably equivalent to the upper part of the Utica at Cincinnati.

Foerste [339] gives the history of the classification of the Cincinnatian series and describes its representatives in the Tennessee Valley and thence south to the central basin of Tennessee. He concludes with the following list of local formations:

According to the preceding observations, the Ordovician exposures in the valleys of the Tennessee River, the Buffalo River, Swan Creek, and South Harpeth Creek suggest the following lithologic succession, in descending order:

Cincinnati group:
- Richmond:
  - Mannie shale.
  - Leipers creek limestone.
- Lorraine:
  - Warren limestone; clay rock at Newsom.
  - Swan Creek limestone. Richly fossiliferous Lorraine limestone in the eastern part of the area studied, containing *Platystrophia lynx*.
- Utica: Saltillo limestone.

The Lorraine appears to become thinner west of the Cincinnati anticline, so as to be represented by thinner sections or so as to be entirely absent along the Mississippi in Missouri and adjacent Illinois, in the Wells Creek basin in northern Tennessee, and along the Tennessee River in southern Tennessee. The Richmond also appears to become thinner west of the northern half of the Cincinnati anticline. It becomes thinner also southward along the flanks of the anticline. In some parts of Tennessee it is entirely absent along the western flank of the anticline. West of the southern half of the anticline, in Tennessee, the thickness of the Richmond appears to vary irregularly.

Details of the distribution of the Ordovician strata, with numerous graphic sections, are given by Foerste [338, 340] in subsequent articles.

The Ordovician strata of the central basin of Tennessee have been minutely mapped and described by Hayes and Ulrich,[431a] who give the following classification and correlation with Safford's nomenclature:

Generalized time scale for central North America.		Mappable lithologic equivalents in the Columbia quadrangle.	Safford and Killebrew, Elements of the geology of Tennessee, 1900. Middle Tennessee.		Safford, Geology of Tennessee, 1869. Middle Tennessee.	
Ordovician.	Richmond.	Fernvale formation.	Hudson (College Hill; Cincinnati). Includes Hudson phosphate.		Upper Nashville.	Nashville.
		(Wanting.)				
	Lorraine.	Leipers formation.				
	Frankfort.	(Wanting.)				
	Utica.				Middle Nashville.	
	Trenton.	Catheys limestone.	(f) (g) Cyrtodonta and Stromatopora beds.	Nashville (Trenton).		
		Bigby limestone.	(d) (e) Dove and Ward limestones. (c) Capital limestone or Mount Pleasant phosphate.		Lower Nashville (Orthis bed).	
		Hermitage formation.	(b) Orthis bed.			
	Black River.	(Wanting.)	(Not classified.)		Carters Creek limestone.	Trenton or Lebanon.
	Stones River.	Carters limestone.	(a) Carters limestone.			
		Lebanon limestone.	Lebanon limestone.	Stones River (Chazy).	Glade limestone.	
		(Not exposed.)	Ridley limestone.		Ridley limestone.	
			Pierce limestone.		Pierce limestone.	
			Murfreesboro limestone.		Central limestone.	

J 11-12. GREAT BASIN, NEVADA AND UTAH.

A zone containing Trenton fossils is distinguished at Eureka, Nev., in the base of the Lone Mountain limestone, which is unconformable to the Eureka quartzite below. The limestone is 1,800 feet thick and is all of Ordovician age. Fossils found in the upper part were assigned to the "Upper Silurian" by Hague,[391] but they are now regarded by Ulrich [a] as of Richmond age (uppermost Ordovician). The distribution of the Lone Mountain limestone is not well known. The limestone or its

[a] Personal note.

equivalent may occur in any of the ranges where the Cambrian and Ordovician are mapped together or where the Silurian is shown, throughout Nevada and western Utah.

Ulrich [a] regards part of the Lone Mountain limestone as much older than the Bighorn dolomite and Whitewood limestone of Wyoming or the Harding sandstone and Fremont limestone of Colorado. According to Kindle [498] the beds which have been classed as Silurian, on account of containing *Halysites catenulatus,* may in general be regarded as possibly Ordovician, and Ulrich states that Halysites occurs generally in the West in faunas which are regarded as of Richmond age but is also known in faunas which are correlated with late Black River horizons.

J 13. SOUTHERN COLORADO AND NEW MEXICO.

Throughout much of southern Colorado, New Mexico, and Arizona Ordovician rocks are generally lacking and the hiatus corresponding with the period also comprises earlier and later epochs, down to the pre-Cambrian and up to the Carboniferous, over extensive areas. Ordovician deposits along the shores of the Colorado land constitute the Harding sandstone and related formations. At Canon City, the type locality, the sandstone rests on Algonkian strata, is 86 feet thick, and is overlain by the Fremont limestone, 200 feet thick. The sandstone contains the oldest known fish remains[855a] and the limestone an invertebrate fauna containing Trenton and Richmond fossils.[a] The Fremont limestone is overlain by Carboniferous limestone, Silurian and Devonian strata being absent, yet, as stated by Crosby,[183] the line of demarcation "is not strongly defined, though it represents a long period of nondeposition and a great time break."

J 15. NORTHERN ARKANSAS.

The Ordovician section of northern Arkansas is very incomplete. There are unconformities at several horizons and the formations are irregular in thickness to the extent of being entirely lacking in some sections though present elsewhere. Ulrich [820] states that the equivalents of the upper Stones River, Black River, Trenton, and Utica are absent. The lower Stones River and the Joachim dolomite of Missouri are represented by the Izard limestone, the lower Richmond by the Polk Bayou limestone, and the upper Richmond by the Cason shale. Beneath the Izard limestone there is in many places a representative of the St. Peter sandstone.

J 15–16. MISSOURI AND SOUTHERN ILLINOIS.

The lower Ordovician of Missouri and southern Illinois comprises the later formations of the "Magnesian Limestone series" or "Ozark series." The latest published classification is given in Chapter III (p. 104), according to Ulrich.

The strata placed in middle and later Ordovician comprise the Trenton, Hudson, and Cape Girardeau of Keyes's section.[491a] More recent discussions bearing on the correlation of the "Magnesian Limestone series" and the St. Peter sandstone have been published by Hall and Sardeson [395] jointly and by Berkey.[71] The strata to which Keyes applied the name Trenton are now known as Plattin limestone (at the

[a] Ulrich, E. O., personal note.

base) and Kimmswick limestone, and Keyes's Hudson is now called Thebes formation. The formation overlying the Thebes is known as Girardeau limestone. According to Ulrich [a] the Thebes formation includes more than the Maquoketa shale, recognized farther north in Missouri and elsewhere.

Keyes described the three higher Ordovician formations as follows:

Trenton limestone.—In southeastern Missouri the Trenton limestone as now understood embraces, besides the Trenton as comprehended in earlier reports of the State, the Black River and Birdseye limestones of Shumard. The latter probably more properly represents the lower and less fossiliferous portion of the Trenton of the region and nowhere can be separated faunally or lithologically from the upper part containing the typical Trenton fauna.

The lower Trenton ("Black River" and "Birdseye" limestone) is a compact, heavily bedded limerock, often not unlike certain lithographic stones in texture.

The upper Trenton, or Trenton proper, is well exposed in all the counties along the Mississippi River from Marion to Cape Girardeau. In its northern extension it is chiefly a buff-colored or yellowish-gray limestone with occasional shale partings. Fossils are abundant in places, though often in the form of casts. Southward the limestone becomes compact, bluish-drab, with abundant fossils.

Hudson shales.—Everywhere on the eastern border of Missouri, wherever the Trenton limestone is exposed, blue calcareous shales are found to overlie it. These shales rapidly disintegrate, upon exposure to the weather, into a soft plastic clay. Numerous thin seams of impure limestone are intercalated and often form beds of considerable thickness. Fossils are abundant and well preserved. They are all very characteristic of the fauna occurring at Cincinnati, Richmond (Indiana), and in northeastern Iowa.

Upon lithological and faunal grounds, Swallow and Shumard early correlated these shales with the Hudson River shales of New York and Ohio. In 1868 Worthen called these beds the "Thebes" shales, from the village of that name in southern Illinois, on the Mississippi River below Cape Girardeau. As defined by the Illinois geologist, the Thebes shales and sandstone form the lowest member of the Cincinnati group, the upper section embracing practically the same beds as the Girardeau limestone of Shumard but placed by the last author in the Upper Silurian. In the same region Shumard had previously (though through delays not published until several years later) divided those shales into—

	Feet.
Upper Hudson shales	45
Cape Girardeau sandstone	35
Lower Hudson shales	50

At Thebes the whole formation is well exposed in a sharp anticline, bringing up centrally the Trenton limestone above the water level of the Mississippi River, and successively, on either side, all the beds of the Hudson shales.

North of the Missouri River, in Pike, Ralls, and Marion counties, the lithological characters and fossils are essentially the same as in the southern part of the State.

Girardeau limestone.—This rather well marked division of the lower Silurian in southeastern Missouri was first differentiated by Shumard in 1885 and provisionally called by him the Cape Girardeau limestone but was regarded as a member of the Upper instead of the Lower Silurian.

Lithologically the limestone is bluish, very compact, and resembles somewhat the stones used in lithographing. It is rather thinly bedded, with numerous vertical fractures or joints. Fossils of peculiar types abound. Its thickness is over 60 feet.

Worthen also recognized this formation as a distinct horizon but made it the upper member of the Cincinnati group, the superior part of the Lower Silurian of the region.

[a] Personal communication.

Ulrich states that the Upper Hudson shales, the Cape Girardeau sandstone, and the Lower Hudson shales of Keyes are now all regarded as of Richmond age.

From Missouri these Ordovician strata cross the Mississippi into southern Illinois, where they have very recently been critically studied by Savage,[703] who distinguishes "Galena-Trenton" light-colored crystalline nonmagnesian limestone, 68 to 80 feet; "Richmond-Maquoketa," 91 feet, consisting of a lower member of sandstone or sandy shale (Thebes sandstone) and an upper one of bluish shale; and Alexandrian, consisting of the Cape Girardeau limestone and certain overlying beds, 41 feet. Savage proposed the new term "Alexandrian," from Alexander County, Ill., to designate a terrane which bridges "the lost interval between the Cincinnatian and the Clinton." This terrane, previously distinguished by Ulrich in the Mississippi Valley, appears to constitute a transition from Ordovician to Silurian. Its correlation with Brazilian strata is discussed by Schuchert.[715]

J 16. INDIANA.

The strata and faunas of the Cincinnatian series in Indiana have been described in great detail by Cumings,[196] who has reclassified the sequence of limestone and shale beds according to formations and faunal zones. The divisions do not possess very distinctive lithologic characters, all being limestone, shaly limestone, or shale, and they do not maintain a uniform character over any large area, as a rule. The following is Cumings's classification,[196a] as tabulated by him in comparison with those that preceded:

Tabulation of the various classifications of the Cincinnati group.

Early authors.	Orton, Ohio Survey, 1873.	Winchell and Ulrich, 1897.	Nickles, 1902.	Nickles and Foerste, 1905.	Ulrich, 1906 (Bassler).	Present report.		
Blue limestone of Ohio, Indiana, and Kentucky. Hudson River group of many. Cincinnati group of some authors.	Lebanon.	Richmond.	Richmond. Upper. Middle. Lower.	Richmond. Saluda. Whitewater. Liberty. Waynesville.	Richmond group. Saluda. Whitewater. Liberty. Waynesville.	Richmond. Elkhorn. Whitewater. Saluda. Liberty. Waynesville.	*Platystrophia moritura* zone. *Rhynchotrema dentata* zone. *Tetradium minus* zone. *Strophomena planumbona* zone. *Dalmanella meeki* zone.	
			Lorraine. Warren.	Maysville. Arnheim.	Arnheim.	Arnheim.	*Homotrypa bassleri* zone of Nickles.	*Rafinesquina alternata* zone.
	Hill Quarry (in part).	Lorraine.	Mount Auburn. Corryville. Bellevue. Fairmont. Mount Hope.	Mount Auburn. Corryville. Bellevue. Fairmont. Mount Hope.	Covington group. McMillan. Fairview.	Maysville or Lorraine. Upper. Middle. Lower.	*Callopora rugosa* zone. Platystrophia zone.	
	Eden (in part).	Utica.	Utica. Upper. Middle. Lower.	Eden. Upper. Middle. Lower.	McMicken. Southgate. Economy. Fulton.	Eden or Utica. McMicken (upper). Southgate (middle). Economy (lower).	*Dekayia ulrichi* zone. *Callopora onealli* zone.	*Dalmanella multisecta* zone.

J 17-18. MARYLAND, VIRGINIA, AND EAST TENNESSEE.

The middle and later Ordovician of the Appalachian Valley south of Pennsylvania are represented by the strata which lie between the Knox dolomite below and the Clinton ("Rockwood") formation above. In many places, especially along the east side of the Appalachian Valley, there is a distinct unconformity between these strata and the Knox dolomite. The formations are calcareous, generally limestone in the western sections but shaly or sandy in the eastern. They have been described by Hayes,[419-426, 428] Campbell,[121, 123-125] and Keith[475-479, 481] as Chickamauga limestone, Athens shale, Tellico sandstone, Sevier shale, Holston marble, and Moccasin limestone; by Safford[689] as Lenoir limestone and Nashville or Sevier shale; and by Smith[748] as Chickamauga. Darton[221a] applied the name Shenandoah limestone to the full thickness of limestone occurring between the Lower Cambrian quartzite and the Upper Ordovician shales (Martinsburg shale), especially in Virginia.

Local descriptions follow, in order from southwest to northeast.

In central eastern Tennessee (Knoxville quadrangle) the sequence and thickness of lithologic formations of the Ordovician differ somewhat in the northwestern and southeastern areas. Keith[475a] gives the two following sections:

Generalized section northwest of Bays Mountain.

Period.	Formation name.	Thickness (feet).	Character of rocks.
Silurian [Ordovician].	Sevier shale.	1,000–1,200	Light-blue sandy and calcareous shales, with beds of limestone and argillaceous marble.
	Tellico sandstone.	250–500	Bluish-gray calcareous sandstone.
	Chickamauga limestone.	200–400 500–700	Variegated marble, red, brown, gray, and white. Blue limestones and gray argillaceous limestones.
Cambrian.	Knox dolomite.	3,500	Magnesian limestone, white, gray, light and dark blue, with nodules of chert.

Generalized section southeast of Bays Mountain.

Period.	Formation name.	Thickness (feet).	Character of rocks.
Silurian [Ordovician].	Sevier shale.	500–600 200–400 500–600 500–650 500–750	Light-blue calcareous shale. Bluish-gray and red calcareous sandstones and shales. Light-blue calcareous slates. Bluish-gray and gray calcareous sandstones and shales. Light-blue calcareous shale.
	Tellico sandstone.	800–900	Bluish-gray and gray calcareous sandstones and shales.
	Athens shale.	1,000–1,200	Light-blue calcareous shale. Black calcareous shale.
	Chickamauga limestone.	0–50	Gray argillaceous limestone.
Cambrian.	Knox dolomite.	3,500	Magnesian limestone; white, gray, light and dark blue, with nodules of chert.

In northeastern Tennessee Keith [481a] distinguishes the following formations:

Generalized section of the sedimentary rocks in the Great Valley, Greeneville quadrangle.

System.	Formation name.	Thickness (feet).	Character of rocks.
Ordovician.	Sevier shale.	1,300–1,800	Calcareous sandstones and shales. Bluish-gray and yellow calcareous shale and shaly limestone.
	Tellico sandstone.	2–200	Red and gray calcareous sandstone.
	Athens shale.	1,000±	Black and bluish-black calcareous shale.
	Moccasin limestone.	450–500	Red, blue, gray, and drab massive and shaly limestone.
	Chickamauga limestone.	0–450	Blue and gray limestone, shaly in part, and variegated marble.
—?— Cambrian.	Knox dolomite.	3,000–3,500	Magnesian limestone, light and dark blue, white, and gray, with nodules and layers of chert and a few beds of calcareous sandstone.

In southern Virginia M. R. Campbell [121a, 125a] has mapped the lithologic divisions named below:

Generalized section for portion of Bristol quadrangle north of Clinch Mountain.

Period.	Formation name.	Thickness (feet).	Character of rocks.
Silurian [Ordovician].	Sevier shale.	1,100–1,300	Sandy shale. Blue calcareous shale which generally weathers yellow upon exposure. Occasional beds of impure limestone near the base.
	Moccasin limestone.	400–500	Red argillaceous limestone.
	Chickamauga limestone.	900–1, 000	Blue limestone with occasional small lentils of red and gray marble.
Cambrian.	Knox dolomite.	2,300–2,800	Limestone conglomerate with pebbles of chert or beds of red earthy limestone. Gray or white magnesian limestone with nodular cherts occurring at intervals throughout the formation.

The Shenandoah limestone, the comprehensive series of Cambrian and Ordovician limestones of the valley of Virginia, formerly known as the "Valley limestones," is briefly described by Darton,[221] who recognized a lower division of dark magnesian limestones, grading upward into lighter-colored cherty strata, and followed by purer, more thickly bedded, highly fossiliferous limestone. Variations in the character of these formations are noted in the reports by W. B. Rogers [676a] and J. L. Campbell,[120] but the distinctions made have no systematic value. For central Virginia H. D. Campbell [119] has introduced the following classification:

Section of the Valley limestones near Lexington, Va.

	Feet.
Ordovician:	
Liberty Hall limestone	1,000±
Murat limestone	100–150
Natural Bridge limestone	3,500+

The correlation of these divisions with those recognized both north and south depends on detailed studies, in progress, from which it appears that the limestone formations present differences of sequence and facies not previously suspected. Bassler [60] states:

The name Shenandoah limestone proposed by Darton for the Valley limestone of early geologists was made to include all the limestones in the Valley of Virginia occupying the interval between the Cambrian quartzites and the Upper Ordovician shales. The lower portion of the great limestone series had been found by Mr. Walcott to include Lower, Middle, and Upper Cambrian rocks, but the Ordovician portion had been determined only to the extent that Trenton strata were supposed to occur at the top. The work of the writer in Virginia brought out the fact that the geologic succession of the Ordovician division was quite different in various parts of the valley. In northwestern Virginia a great thickness of Beekmantown is overlain by 1,000 feet of Stones River, and this in turn by 400 feet of Black River, while the strata bearing Trenton fossils form the lowest division of the overlying shales. In central western Virginia the Black River alone rests upon the Beekmantown, but in southwestern Virginia two distinct arrangements were noted. Along the western edge of the valley the Beekmantown is followed by 1,000 or more feet of Stones River but no Black River, while along the eastern side only the Black River occupies the interval between the overlying shales and the Beekmantown. In each case the Trenton does not form the upper part of the limestone, but is the basal member of the overlying shales.

The Shenandoah limestone, therefore, is a broad term, embracing strata of Cambrian and Ordovician age, the geologic succession of the latter varying in different parts of even the type area.

The classification of the Ordovician limestones of southern Pennsylvania as worked out by Stose and Ulrich is given in Chapter III (pp. 107–111). There is no reason to look for any marked difference in the section where the belt crosses Maryland, but the divisions have not been traced.

K 10. TAYLORSVILLE DISTRICT, CALIFORNIA.

The Grizzly formation, which occupies the summit of Grizzly Peak, in the Lassen Peak quadrangle, California, is an unfossiliferous formation, 400 feet thick, which underlies the Montgomery limestone. As the latter is considered by Walcott [271b; 272] to be of Niagara age, it is possible that the Grizzly formation is of Ordovician age.

K 12. WASATCH AND UINTA RANGES, UTAH.

The quartzite of the Wasatch and Uinta ranges, distinguished by the Fortieth Parallel Survey as Ogden quartzite and mapped as Devonian, is correlated by Weeks [873] and Ulrich as Ordovician. In the Wasatch section it rests upon limestone of Cambrian and Ordovician age, is 800 to 1,200 feet thick, and is overlain by Silurian limestone, at least in Cache Valley. Along the south side of the Uinta Range it lies upon the Lodore shale (Cambrian) and is immediately followed by limestone of lower Mississippian age. No equivalent is known on the north side of the Uinta Range.

Blackwelder [84c] showed that the quartzite in Ogden Canyon is a Cambrian quartzite which owes its apparent stratigraphic position to an overthrust. There is therefore no Ordovician quartzite in Ogden Canyon and the name is inappropriate. But an Ordovician quartzite does occur in Cache Valley and also south of Ogden. In green shales at the base of this quartzite have been found abundant fossils, which, on preliminary examination, E. O. Ulrich [84d] pronounces to be of the age of the Beekmantown fauna of the Eastern States.

K 13. BLACK HILLS.

In the northern Black Hills occurs a formation similar to the massive Bighorn dolomite, known as the Whitewood limestone, which is of Trenton age. It is 80 feet thick near Deadwood, but thins out toward the south.[241a, 471]

In the Front ranges of Colorado north of Colorado Springs the Ordovician, like other pre-Carboniferous Paleozoic systems, is lacking.

K 16. SOUTHEASTERN WISCONSIN AND NORTHEASTERN ILLINOIS.

The St. Peter sandstone, Trenton limestone (as defined by the Wisconsin Geological and Natural History Survey), Galena dolomite, and "Cincinnati" shale constitute the Ordovician of Wisconsin and northeastern Illinois above the "Lower Magnesian" ("Calciferous") limestone. The St. Peter [71] is a friable white or yellow sandstone, which varies in thickness from a thin edge to 212 feet and lies unconformably on the "Lower Magnesian." The overlying Trenton is in part a simple, in part a magnesian limestone with clayey partings, about 115 feet thick, in which several distinct subdivisions are recognized. Next higher is the Galena, a coarse-grained thick-bedded dolomite, about 250 feet thick, which becomes more argillaceous toward the northeast and northwest. The highest formation of the Ordovician section is the "Cincinnati" shale, bluish or greenish, with intercalated limestones, which reaches a thickness of 200 feet or more.[133c] A period of nondeposition and erosion followed in Wisconsin and elsewhere in the central western United States [885] covering late Ordovician time. This period of nondeposition corresponds to the interval between the "Cincinnati" shale and the Galena dolomite. The so-called "Cincinnati" shale is of Richmond age. In southwestern Wisconsin and northwestern Illinois the Ordovician shale outcrops and is there known as Maquoketa shale.

The formations in northern Illinois constitute the southward extension of those described by Chamberlin for Wisconsin. Bain [51] has recently described the limestones and associated strata of northwestern Illinois. Above the earlier Ordovician rocks he recognizes the St. Peter sandstone, Platteville ("Trenton") limestone, Galena limestone, and Maquoketa shale.

K 17–18. PENNSYLVANIA AND NEW JERSEY.

The limestones of southeastern Pennsylvania have been described by Stose.[801] The quotations regarding the Cambrian and early Ordovician formations given in Chapter III (pp. 107–113) are here continued for the later Ordovician.

The Stones River limestone is composed in general of three divisions—a middle band of massive pure granular limestone containing the large gastropod *Maclurea* *magna* and thin beds of black chert that weather into small rectangular blocks; an upper series of thin-bedded pure limestone; and a lower series of interbedded massive pure beds and magnesian layers. From the middle division 22 species of fossils have been obtained, among which there are eight which occur in the middle Chazy of the Champlain Valley. As a whole, the fossils as well as the lithologic character of the formation are practically the same as those of the Stones River group of Tennessee.

The Chambersburg limestone is the uppermost division of the Shenandoah limestone. It is characterized throughout the area by fossiliferous thin-bedded limestones with argillaceous partings. It varies in thickness across the strike from a maximum of 600 feet in the Chambersburg belt to about 100 feet in the McConnellsburg Cove.

Its most typical development is in the Chambersburg belt, throughout which fossils are abundant. The following section in the railroad cut 1½ miles west of Kauffman is the most complete continuous section in this belt:

Black shale (Martinsburg).	
Largely concealed, but probably chiefly shale (near the top are black carbonaceous limestone with conchoidal fracture, shaly dark crystalline limestone, thin sandstone, and 10 feet of coarse crystalline limestone containing Lingulas)	150
Calcareous shale and limestone	100
Nodular clayey limestone	50
Dark platy limestone	94
Compact dark limestone, very fossiliferous	108
Cobbly limestone containing numerous nidulites, Bryozoa, and a layer of cystid heads	105
	607

The "cobbly" character of the weathered outcrop of certain of the beds, due to a wavy lamination or clay parting that crosses the bedding at a high angle and, on weathering, gives rise to rounded lenticular masses resembling rough cobbles, is one of the noticeable features of this formation. The upper 200 feet of the formation is composed largely of shale with interbedded thin fossiliferous limestones.

* * * * * * * * *

Nearly everywhere this formation yields on careful search an abundance and great variety of fossils, and those from the Chambersburg quadrangle differ from those obtained in the Mercersburg quadrangle. In the Chambersburg belt the formation may be divided into four faunal zones.

* * * * * * * * *

In the Mercersburg quadrangle four faunal zones are also distinguished, but they do not correspond with those of the Chambersburg belt.

In southeastern Pennsylvania and Maryland the Ordovician strata are overthrust by pre-Cambrian schist and metamorphosed to phyllite and schist. The complex relations have been worked out by Bascom[57, 58] and Mathews,[579] who distinguish the established divisions of the section in adjacent fossiliferous districts.

The Cambrian and Lower Ordovician formations of the Philadelphia district (Chickies quartzite and Shenandoah limestone) are described in Chapter III (pp. 111–113). Bascom [58b] continues the description of the Ordovician formations as follows:

Further sedimentation in Ordovician time is represented by the Octoraro. This is the last known Paleozoic deposit in this region and, like the preceding Paleozoic sediments, is dynamically metamorphosed and free from igneous intrusions.

The Octoraro schist is largely confined to the South Valley Hills, pinching out to the northeast and expanding to the southwest. Outliers of the mica schist occur north of Berwyn and of

Paoli and on Henderson and Bridgeport hills. The Henderson and Bridgeport outliers, while lithologically similar to the main mass of mica schist, can not be positively correlated with the formation. Their relation to limestone of Chazy age, as seen in the Schuylkill River cut, is such as to admit interpretation either as an interbedded structure or as the overlying synclinal structure which the Octoraro schist must possess.

The mica schist is characterized by a pronounced lamination of a slaty rather than a schistose type. The laminæ exhibit lustrous silvery surfaces and a blue-gray or green-gray color, which under the action of weathering alters to reddish yellow.

The chief constituents of this mica schist are quartz, muscovite, orthoclase, and chlorite. Quartz occurs in interlocking grains which show undulatory extinction and other pressure effects in their form and arrangement. Orthoclase occurs sporadically in considerable areas, but it is not an important or characteristic constituent. Chlorite is uniformly distributed through the rock, interspersed with wavy lamellæ of muscovite. Plagioclase, biotite, magnetite, ilmenite, tourmaline, apatite, and pyrite are accessory constituents.

The constituents of the schist do not possess clearly defined outlines and the crystalline texture is neither so coarse nor so sharply defined as in the Wissahickon gneiss.

In the hand specimen quartz is completely overlain by minute plates of mica, which alone show on the cleavage surface, while eyelets of quartz may show on the edges of the laminæ. Cubes of pyrite more or less altered to limonite are characteristic. Considerable oxide of iron is present in this formation, which is evidently the source of the limonite ore that occurs sporadically in pockets between the limestone and the schist.

The analyses of the mica schist, with the relatively high alumina and low silica and absence of lime, fairly indicate a sedimentary origin for the formation.

* * * * * * * * *

The lower beds of this formation are more calcareous, more siliceous, finer, and darker colored than the upper beds. The outlying areas at Bridgeport and Henderson are of this character. In some places there appears interbedded with the mica schist a quartz schist or a quartzite similar to the Cambrian quartzite. Fragments of such a quartz schist show 1 mile north of Paoli on the northwestern boundary of the mica schist, and 2 miles north of Wayne such a siliceous member furnishes sand for local use.

The mica schist of the South Valley Hills appears to overlie the Shenandoah limestone without faulting or unconformity. This is indicated by the lithologic gradation between the limestone and schist which may be seen at the northwest base of the South Valley Hills and by the persistence of the same geodiferous quartzose beds along the contact of the two formations and is confirmed by the fact that the outcrops show that deformation was by folding and flowage and not by faulting.

The structure of the hills is evidently synclinal, though cleavage and fissility are so pronounced as to obscure the stratification. On the limbs of the syncline cleavage and bedding are approximately parallel, while cross structures prevail in the trough of the syncline.

* * * * * * * * *

The structure of the formation in the South Valley Hills indicates a thickness probably not exceeding 1,000 feet. It is not known, however, whether the full thickness of the formation is present here.

* * * * * * * * *

The formation is held to be Ordovician in age on the ground of its normal stratigraphic position on the Cambro-Ordovician limestone. It is correlated with the Berkshire schist of the New England section, the Hudson schist of New York, and doubtfully with the phyllites of Maryland. It is the Primal upper slate of the First Geological Survey of Pennsylvania, and the Cambrian phyllite of the Second Geological Survey.

Ranging southwestward from Orange County, N. Y., the Cambrian and Ordovician strata pass into New Jersey with the facies described as the Hardyston quartzite, the Kittatinny limestone, the Jacksonburg limestone, and the Martinsburg shale. The formations have been described by Kümmel,[512, 513a] from whose recent account the following notes on the Ordovician are taken. The description of the Cambrian formations has been given in Chapter III (p. 113).

In northern New Jersey, as elsewhere in the great Appalachian Valley, there is no sharp line of demarcation between the rocks of the Cambrian and those of the Ordovician system. The base of the Ordovician lies somewhere below the top of the Kittatinny limestone, as stated above, but the exact position of this division line can not readily be determined.

Above the Kittatinny limestone, and separated from it by a break in sedimentation indicated by a calcareous basal conglomerate, is a dark-blue or black fossiliferous limestone, correlated with the Lowville, Black River, and lower Trenton limestone of the New York section and hitherto classed as "Trenton," some layers of which contain as much as 95 per cent or more of calcium carbonate. Calcareous shales occur interbedded with these limestones and above them to the top of the formation. The sequence of conglomerate, limestone, and shale is a variable one, but, so far as observed, the transition to the overlying formation is always through a series of calcareous shales which become less and less limy.

The thickness of the Jacksonburg formation varies from 135 to 300 feet or more. It contains an abundant fauna, 98 forms having been described by Weller. At the type locality the lower strata for a thickness of 58 feet carry a Lowville-Black River fauna, and the higher beds have a lower Trenton fauna.

The Jacksonburg limestone passes upward through the calcareous shales mentioned above into a great thickness of shale, slate, and sandstone, which has heretofore been known as the "Hudson River slate" but which is now correlated with the Martinsburg shale of West Virginia and takes that name.

The formation ranges from the finest-grained shale and slate to fine sandstone. The former beds on the whole are black and more abundant in the lower part, whereas the sandstone beds are dark bluish gray, many of them calcareous, and occur more commonly higher in the formation. The fine-grained rocks exceed the gritty beds.

* * * The whole formation is so crumpled and cleaved that no accurate estimate of its thickness can be made, but it is probably at least 3,000 feet, and it may be more.

Four species of graptolites of the Normanskill fauna of New York have been found in the lower portion of the Martinsburg shale, so that the beds in which they occur are equivalent in age to the middle portion of the typical Trenton limestone of central New York. A few miles north of the New Jersey State line Schizocrania and graptolites characteristic of the Utica shale of the Mohawk Valley have been found in beds close to the overlying Shawangunk conglomerate.

Detailed descriptions of the fauna are given by Weller.[769, 878, 880]

K-L 12-13. WYOMING AND NORTHERN COLORADO.

The Ordovician of this region is a relatively thin deposit of limestone, attaining a maximum thickness of 300 feet, lacking in many sections, and locally underlain by a sandstone which carries remains of fish.[855] Darton[241, 244] has recently summed up the known facts in a comprehensive manner.

In the Bighorn Mountains the Ordovician strata constitute the Bighorn dolomite, which in the north averages about 300 feet in thickness, including a basal white sandstone, a massive magnesian limestone, and about 100 feet of softer thinner-bedded limestone at the top. The strata range in age from Black River at the base to late Richmond at the top and are said to be divided by a hiatus equivalent to later Trenton, Utica, Eden, and Lorraine, of which, however, the evidence is mainly paleontologic.

In the Owl Creek and Wind River mountains of central and western Wyoming the Bighorn dolomite occurs with much of the character which it has in the type locality of the northern part of the Bighorn Range.

K-L 15. MINNESOTA, NORTHEASTERN IOWA, SOUTHWESTERN WISCONSIN, AND NORTHWESTERN ILLINOIS.

The Ordovician exposed on both sides of Mississippi River comprises the following formations, in descending order:

Maquoketa shale.
Galena dolomite.
Decorah shale ("Green shales" of Minnesota reports).
Platteville limestone.
St. Peter sandstone.
Prairie du Chien group (of Beekmantown or Lower Ordovician age):
  Shakopee dolomite.
  New Richmond sandstone.
  Oneota dolomite.

The Prairie du Chien group is discussed in Chapter III (pp. 119–120). The classification of the Ordovician into the formations enumerated above is based on the work of Calvin[118] and of Grant, Burchard, and Ulrich.[386] In the folio by the three authors last cited the middle and upper Ordovician rocks are described in detail and lists of fossils are given. The following is an abstract of their description:

Unconformably upon the Prairie du Chien formation lies a comparatively thin sandstone long known as the St. Peter from the fact that it occurs along the lower course of St. Peters (now known as Minnesota) River. The thickness of this sandstone varies considerably, averaging in this district perhaps 70 feet but ranging from 35 to 175 feet. * * * The variation in the thickness of the St. Peter sandstone is due, at least in the main, to irregularities in the surface of the underlying formation—the Prairie du Chien—which suffered considerable erosion before the sandstone was deposited. The top of the sandstone likewise may have been somewhat eroded prior to the deposition of the succeeding Platteville limestone, although this is not evident from discordance of stratification.

* * * Nearly everywhere at the base of the formation there is a foot or two of bluish-green sandy clay shale. Above this basal shale the St. Peter is practically pure quartz sandstone, the percentage of silica in its composition being very high and at some places exceeding 99 per cent. * * *

The grains are well waterworn and of medium fineness, the greater part passing a sieve having 40 meshes to 1 inch.

* * * * * * * *

The transition from the St. Peter sandstone to the overlying Platteville limestone is marked by a bed of blue sandy shale which ranges in thickness from a few inches to 5 feet or more. This shale is not commonly sharply separated from the sandstone, but grades into it. On the other hand, the upper edge of the shale is sharply delimited by the overlying massive beds of the lower part of the limestone. The sand grains in the shale do not usually extend to its upper surface, and very rarely are these grains found in the lower beds of the Platteville. * * *

The St. Peter can be regarded as a practically nonfossiliferous formation, though a few casts, mainly of pelecypods or bivalve shells, have been reported from it. This scarcity of fossils seems to be due as much to the fact that in so porous a rock solution would destroy calcareous shells as to the fact that few animal remains were entombed in it originally. The St. Peter is a wide-reaching formation in the upper Mississippi Valley, and in the Ozark region it is represented by the sandstone which immediately underlies the Joachim limestone and which has frequently been termed the "First Saccharoidal" sandstone.

The Platteville limestone is noticeably different from the other calcareous members of the Paleozoic section in these quadrangles in that it is largely a pure limestone, or a magnesian limestone, rather than a dolomite. In earlier reports on this district this formation was called the Trenton limestone, but the name Platteville has recently been applied to it, as it is possible that these beds do not represent the exact equivalent of the Trenton in its type locality. * * *

The Platteville averages 55 feet in thickness and maintains this average over a considerable part of the area.

Generalized section of Platteville limestone.

	Feet.
4. Limestone, principally in thin beds, and shale	10–15
3. Thin-bedded brittle fine-grained limestone	15–25
2. Thick-bedded magnesian limestone or dolomite	15–25
1. Blue shale, at some places sandy	1–5

* * * * * * * * *

It is at some places difficult to draw the boundary between the Platteville and the Galena on purely lithologic criteria. The contact, however, is probably unconformable, despite its obscurity and the fact that it apparently occurs in the midst of a shaly unit. A close study of the fossils rarely fails to locate the contact within very narrow bounds, and then the actual physical break between the two formations may in places be determined. At many places the first few inches of the Galena consist of a shale or clay containing more or less clear evidence that it is a deposit which has been reworked by water. At some places it contains fragments of fossils, more perfect forms of which occur in the bed just below. At some localities this lowest bed of the Galena consists of a yellow to white clay, called "pipe clay," underlain by an inch or two of dark carbonaceous clay.

* * * * * * * * *

The Platteville is commonly highly fossiliferous, more so than any other formation within the area except possibly the Maquoketa shale. Although practically all the beds of the formation except the basal shale contain fossils in greater or less abundance, certain beds are literally packed with organic remains. The dolomitic second member contains relatively few fossil remains, and at some places this bed may appear almost barren. A few species range through nearly all the beds, notably *Leperditia fabulites* Conrad, which is the most characteristic fossil of the formation. Many other species, however, being more restricted in range, may occur in only one or two of the beds.

* * * * * * * * *

The Platteville is regarded as the equivalent of the Stones River group of Tennessee and Kentucky, a group that lies lower than the Black River and Lowville (Birdseye) limestones of New York.

* * * * * * * * * *

Lithologically the Galena is a dolomite—a granular, crystalline, coarse-grained porous rock, which weathers into exceedingly rough, pitted, and irregular forms. * * * The formation exhibits the same lithologic character everywhere except in its extreme upper and lower parts. As a whole it is massive in appearance; the average thickness of the beds is from 1 to 4 feet. Near the bottom and near the top, however, thinner beds occur. Chert nodules are common in the middle part. At many places very thin seams or partings of clayey material, a little darker in color than the main mass of the dolomite, separate the formation into irregular layers. * * *

The thickness of the formation within this area averages about 235 feet.

The upper portion of the Galena is thin bedded, earthy, and noncrystalline. Shale occurs as partings, and in the uppermost strata, where the Galena passes into the Maquoketa, it forms the rock and the limestone becomes nodular. Near the bottom of the Galena occurs a so-called oil rock, a finely laminated brown to black shale, which is made up largely of microscopic unicellular algæ and which contains as much as 20 per cent of heavy oil.

Some beds of the Galena contain abundant organic remains, but the main body of the dolomite carries few recognizable fossils. Locally, however, where the basal limestone and shale were deposited, as shown in the first two sections of the Platteville limestone given in the description of that formation, they are highly fossiliferous.

* * * * * * * * *

The Galena and Platteville form a thick dolomite-limestone series, which is of much importance in the upper Mississippi Valley. The lithologic features of the two formations here described are those which are common to the lead and zinc district. Outside of this district the characteristics vary somewhat, and toward the west the Galena becomes less dolomitized, especially in its lower part.

In the lead and zinc district the Platteville, commonly known as "Trenton" in the reports on this district, is essentially a nondolomitic formation, while the Galena is a dolomite. If this lithologic distinction should be used as a means of separating these formations in areas lying farther west the thickness of the Platteville would be there greatly increased. Recent work, however, has shown that the Platteville is a well-defined formation of comparatively uniform thickness, possessing distinctive faunal characteristics; that, at least locally, it is separated from the Galena by a period of nondeposition; and that in certain localities, especially at places west of the Mississippi, the Galena is in considerable part nondolomitic.

* * * * * * * * *

Upon the Galena dolomite lies a shale formation, which has been described in reports of the Iowa Geological Survey under the term Maquoketa, a name derived from Little Maquoketa River, on which it is typically exposed. The same formation is known in the Wisconsin State reports as the Cincinnati shale. * * *

The shale ranges in thickness from 160 to 200 feet and in the region south of this area is more than 200 feet thick.

* * * * * * * * *

The Maquoketa shale in this area can be arranged roughly into the three characteristic divisions described below:

General divisions of Maquoketa shale.

	Feet.
3. Argillaceous and calcareous shale, in beds becoming thicker and possibly dolomitic toward the top, about	35
2. Plastic blue and green shale and clay, with some indurated fossiliferous bands near the top, about	100
1. Drab and blue thin fissile shale, interbedded with thin layers of fossiliferous argillaceous limestone; near base is a thin, hard conglomerate of fine chert and phosphatic pebbles in a ferruginous matrix	60

* * * * * * * * *

The Maquoketa shale in general throughout the upper Mississippi Valley forms a markedly fossiliferous horizon. There is at the very base of the formation a thickness of 2 to 5 feet of shale which contains rather abundant fossils. * * * At the top of the formation there is another horizon, more frequently exposed, that affords fossils, at some places in great abundance. * * * This association of species indicates that the beds are of Richmond age.

* * * Definite evidences of stratigraphic unconformity or of an erosion interval at the base of the Maquoketa have not been observed during the survey of this area. The change from the dolomite beds of the Galena to the shale is fairly abrupt, and mention has been made of a small conglomerate that occurs locally in the basal shale, but the sedimentation planes on the two sides of the contact line are parallel, as far as seen. The evidence, so far as it goes, does not indicate any marked physical break between the formations, although the fossils would indicate a period of nondeposition.

Upon the Maquoketa lies a heavy magnesian limestone of the Niagara, whose basal layers apparently rest concordantly on the magnesian upper Maquoketa beds where these are present. Here the lithologic change is less abrupt than at the bottom of the formation; nevertheless, the evidence furnished by fossils indicates a hiatus. There is also some evidence that the topmost fossiliferous Maquoketa beds are not everywhere present, this fact suggesting that erosion has actually occurred.

The Ordovician formations which traverse northeastern Iowa range northward into Minnesota in the apparent embayment of the sea which lies between the Isle Wisconsin[133b] on the east and the Peninsula of Minnesota, which terminates in the Sioux quartzite area, on the west. The strata have been made the object of an elaborate correlative study by Ulrich.[944]

K-L 17-18. ONTARIO AND NEW YORK.

North of Lake Ontario is a wide belt of Ordovician strata which extends southeastward around the Adirondack crystalline rocks into the Mohawk and Hudson valleys, New York. In Ontario the section as described by Ami[20a] comprises limestones and shales from the Potsdam to the Lorraine inclusive. The sandstones are local basal shallow-water deposits resting unconformably on the pre-Cambrian.

The distribution and character of these strata from Kingston, on the St. Lawrence, to Georgian Bay are described by Logan[544d] with detailed local sections and lists of fossils. His general statement runs as follows:

> From the province line, where it crosses Lake Champlain in eastern Canada, the Birdseye, Black River, and Trenton formations, striking through the valley of this lake and the valleys of the Mohawk and Black rivers, reach the waters of the St. Lawrence and cross over into western Canada. On the United States side of the St. Lawrence they occupy a breadth extending from the Thousand Islands to Sandy Creek, and on the Canadian side from the neighborhood of Kingston to the outside of the Prince Edward peninsula.
>
> It has already been stated that between the Potsdam formation and the strata characterized by the fossils of the Birdseye and Black River formations, to the westward of the Laurentian ridge of the Thousand Islands, there are about 80 feet of strata the age of which is not very clear. These appear in two succeeding escarpments and are traceable for a considerable distance.

Logan then gives a minutely divided section of strata outcropping at Vanluvin's mills, Storrington, which are assigned to the Chazy by Ami. Around Kingston these basal beds are Pamelia, but near Georgian Bay they are Lowville. In either case they are lithologically nearly the same.

Logan's descriptions of the Black River and Trenton limestones are characterized by that degree of detail which marks his work and makes it a standard of reference that can not be adequately summarized.

In New York the Ordovician strata range south of the Adirondack area through Jefferson, Lewis, Oneida, Herkimer, Montgomery, Schenectady, and Saratoga counties to the Hudson. North of the Adirondacks they extend through St. Lawrence, Franklin, and Clinton counties to Lake Champlain. Their distribution as shown on the map of North America is taken from the New York State map of 1901.[592]

The district west, south, and east of the Adirondacks includes the local sections that were established as the standard New York section, which became the basis of North American correlation.

Dana [220] distinguished "Calciferous epoch, Chazy epoch, Trenton epoch, Utica and Hudson epochs" and described the strata which characterize each epoch in this and other districts. The New York State Survey publishes the following classification,[155] which shows also the distribution of the several divisions and brings out the fact that they are not uniform throughout the State.

Extent of unit formations along their strike from west to east in the State of New York. [a]

[A star (*) signifies that the unit is absent from the outcrops in the region represented by the column in which it stands.]

System.	Central.	East central.	Eastern.
	Lorraine shale.	Lorraine (Frankfort) shale.	Lorraine (Frankfort) shale.
	Pulaski shale.		
	Frankfort shale.[b]		
	Salmon River shale.		
	Utica shale.	Utica shale.	Utica shale.
			Trenton limestone.
Champlainic or Lower Siluric.	Trenton limestone.	Trenton limestone.	Normans Kill shale.
			Rysedorph conglomerate.
	Black River limestone.	Black River limestone.	Black River limestone.
	Lowville limestone.	Lowville limestone.	(*)
	(*)	(*)	Chazy limestone.
			Deepkill shale.
			Beekmantown limestone.
			Wappinger limestone.

[a] Revised in accordance with letters from John M. Clarke, Jan. 13 and 19, 1910.—B. W.
[b] The Frankfort begins well down in the Trenton and extends upward to some undetermined age. Possibly it corresponds to the Martinsburg shale.—E. O. Ulrich, comment on manuscript.

Grabau [383] published a discussion of the Ordovician in 1909 and suggested a revised classification.

It appears from the investigations of recent years that the Ordovician limestones west and south of the Adirondacks, like those of the upper St. Lawrence Valley, differ from the formations of corresponding age that occur east of the Hudson-Champlain trough. The western strata were spread over the margin of the continent in embayments that extended north and south of the Adirondack island or peninsula. They are neither uniform in distribution nor continuous in sequence.

Cushing [204a] has recently worked in Lewis and Jefferson counties west of the Adirondacks, in the original locality of the Lowville (or "Birdseye"), Black River, and Trenton limestones, to which Logan refers as quoted above (p. 183). He there determined the following section:

	Feet.
7. Trenton limestone: Thin-bedded black, somewhat shaly limestones, with lenses of gray crystalline limestone.	
6. Black River limestone: Massive black limestone, lower portion full of black chert nodules	15–20
5. Lowville limestone: Blue or dove-colored fine-grained limestone, with beds of thin shaly limestones, which constitute nearly one-third of the formation	75–85
4. Pamelia limestone: Blue and dove limestone, with intercalated magnesian limestones and, in the upper half of the formation, much whitish impure limestone and some yellow water lime. A thin basal sandstone and overlying shales	40–130
[Unconformity.]	
3. Theresa formation: Somewhat calcareous, sandy dolomites, weathering to rotten stone, with interbedded weak sandstones, especially near the base	20–60
2. Potsdam sandstone: White, yellow, and red quartzose sandstone, brown spotted and weakly cemented toward the summit	0–80
1. Pre-Cambrian.	

Referring to Chapter III (p. 123) for the description of the Potsdam and "Theresa" formations, we may quote Cushing [204c] on the Pamelia and Lowville of the Watertown district (west of the Adirondacks) as follows:

The Pamelia limestone is the most interesting formation in the section, since it represents the thinned edge of a formation which, while widespread elsewhere, has not heretofore been recognized in New York and is probably in existence in the State as a surface formation only in this immediate district. Because of its wide separation from other areas where the formation appears and because it represents only a small portion of the entire formation, the giving of a local name seems justified, and in Pamelia Township the entire thickness and both contacts are exposed.

The formation consists essentially of limestone, though the bulk of it is not pure limestone. At its base is found a thickness of from 10 to 20 feet of sandstone and greenish shale, the sandstone being coarse but weak, owing to calcareous cement, and somewhat pebbly at the base, while the overlying green shales are both sandy and calcareous. * * *

The formation has a thickness of from 125 to 150 feet along the western margin of the Theresa quadrangle and somewhat less than half that thickness on the eastern border. * * * Above the sandy base the lower portion of the formation, 50 to 60 feet in thickness, is composed of alternating beds of blue-black limestone, dove limestone, and gray magnesian limestone. The beds usually run from 1 to 3 feet in thickness, though the black limestones may reach a thickness of 10 to 15 feet. The upper half of the formation lacks the black limestone and consists of alternations of dove limestone, gray magnesian limestone, light-gray to white thin-bedded impure limestone, and yellow water lime. About midway of this upper half is a horizon where the rocks have a pronounced pink tinge through a thickness of from 10 to 20 feet. Outside of the dove limestone beds, most of the material of this upper division is thin bedded, and the abundance of light-colored layers sharply distinguishes it from the lower division. Near the summit certain layers contain abundant nodules of coarsely crystalline calcite and sometimes celestite as well. At the extreme summit are 10 to 15 feet of more massive beds of gray limestone overlain by a thickness of a few feet of white impure beds which are somewhat sandy, and these uppermost white beds are regarded as forming the base of the overlying Lowville formation. From base to summit the formation carries an abundant ostracod fauna. In addition, the black limestones of the lower division carry a considerable additional fauna of gastropods, cephalopods, corals, and trilobites. There is some evidence that, as the formation thins to the east, owing to overlap, these black fossiliferous limestones occur at higher and higher horizons, in fashion similar to the rise of the basal sandstone in the same direction.

Many of the beds of dove limestone have mud-cracked surfaces. In connection with the ostracod fauna and the presence of water limes, this seems to indicate shallow-water and closed-basin conditions, similar to those which characterized the deposition of the water lime of the Upper Silurian in the State; but the fossiliferous limestones of the lower portion of the formation indicate that a period of open water, permitting the incoming of a marine fauna, preceded the closed basin conditions.

* * * [The Lowville] is a quite pure limestone formation, with a thickness of some 75 feet. The upper 20 feet are of pure limestone of blue or dove color and are exceedingly fossiliferous. Beneath follow 10 to 15 feet of thinner, more shaly limestones, with occasional fossils, after which through 30 feet thickness appear alternations of these thin layers with thicker beds of blue or dove limestone, with a basement of 10 feet of massive blue limestone, and then the white shaly beds already noted as forming the base of the formation. * * * The lower part of the Lowville formation carries mainly an ostracod fauna, other forms being scarce, though they do appear. "But the lower Lowville Ostracoda include species of Leperditia and Isochilina of much larger size than any so far observed in the underlying Pamelia." [a]

This local section is placed by Cushing [204d] in comparison with those of the Mohawk and Champlain valleys.

[a] E. O. Ulrich, letter of March 25, 1908.

Comparison with the Champlain and Mohawk sections.

Champlain Valley.	Mohawk Valley.	Watertown district.
Black River and Lowville, 40 to 60 feet.	Black River, 0 to 15 feet. Lowville, 0 to 25 feet.	Black River, 20 feet. Lowville, 60 to 75 feet.
Chazy: Upper, 200 feet. Middle, 350 feet. Lower, 340 feet.	Absent. Absent. Absent.	Absent. Pamelia, 40 to 140 feet. Absent. Absent.
Beekmantown: Division E, 470 feet. Division D, 375 feet. Division C, 350 feet. Division B, 295 feet.	Absent.	Absent. Unconformity
Beekmantown, A, 310 feet. Passage beds, 30 to 75 feet.	Little Falls dolomite, 500 (?) feet.	Theresa, 20 to 60 feet.
Potsdam.	Absent.	Potsdam.

Cushing [204e] concludes:

It has been shown that four formations—the Lowville, Pamelia, Theresa, and Potsdam—are present underneath the Black River limestone in the Watertown region, and that there is a great unconformity, both by erosion and by overlap, between the Theresa and Pamelia formations. The Pamelia formation is of upper Stones River age, and [is] thus a formation hitherto unrecognized in the New York section. It is thought that the unconformity mentioned can be traced down the St. Lawrence Valley to the Champlain meridian and represents the expanded western representative of the break discovered by Ulrich in the Champlain Valley between divisions A and B of the Beekmantown. It is also thought that it represents the proper line of division for northern New York between the Cambrian and Lower Silurian systems, thus relegating to the Cambrian nearly 400 feet of strata which have hitherto been classed as Beekmantown.

Prior to the recognition of the "Theresa" and Pamelia formations, described above, the terms Beekmantown ("Calciferous"), Chazy, Lowville ("Birdseye"), Black River, Trenton, and Utica were used. Their general distribution and relations all about the Adirondacks have been stated by Cushing.[203]

In 1910 Ulrich and Cushing [822a] published a detailed study of the Little Falls dolomite of the Mohawk Valley, in course of which they developed the relations between the Little Falls dolomite and overlying strata. They class the dolomite as the uppermost Saratogan and separate it from the Beekmantown, with which it has hitherto been placed. They describe an unconformity at the top of the dolomite and take the plane of that unconformity as the basis of classification. They say:

Our comparative study of the region has, we think, made clear the correlation of the Calciferous of the Champlain and Mohawk valleys and seems to us also to show that the Little Falls dolomite (division A and the lower part of B) does not properly belong with the Beekmantown, either structurally or faunally, and has been heretofore classed with it simply on the basis of supposed lithologic resemblance; that it is separated from the remainder of, or rather the true

Beekmantown, by an unconformity, while it invariably grades into the Potsdam beneath through a series of passage beds; and that faunally also its association is with the Potsdam, the Hoyt limestone of the Saratogan region being merely a more calcareous and more fossiliferous phase of its lower portion, of very local character, rather than a phase of the Potsdam.

Local sections of the Ordovician in the Mohawk Valley have been described with great detail and faunal lists are given in publications by Cumings,[195] Cushing,[202] Prosser,[647, 652] Walcott,[845] and White.[908, 909, 910]

The Champlain-Hudson Valley is here mapped according to the authorities cited by Merrill [592a] for Clinton, Washington, Rensselaer, Columbia, Dutchess, Ulster, and Orange counties. The Ordovician of this region comprises, above the Beekmantown, the Chazy, Trenton, and "Hudson River." The Chazy is restricted to the northeastern section.[823] Near Albany the "Hudson River shales" are now recognized as representing, in ascending order, the Normans Kill, middle Trenton, Utica, and Lorraine. The Normans Kill shale is a clastic representative of the lower Trenton limestone of the western part of the State.

It is convenient to take up the discussion at the north in Clinton County and to proceed southward. Cushing's general statement of the relations of the several Ordovician formations around the Adirondacks is quoted on page 186. The Chazy is thus described by Cushing:[201]

Brainard and Seely have recognized three subdivisions of the Chazy rocks. * * * The lower subdivision is largely constituted of quite crystalline limestones of gray color, often full of crinoidal fragments and with *Orthis costalis* the most abundant fossil; the middle division is of blue-black fine-grained limestone and contains *Maclurea magna* at nearly all horizons; the upper division is quite variable in character but is largely composed of somewhat impure blue limestones, carrying *Rhynchonella plena* abundantly.

The aggregate thickness of the Chazy limestone at Chazy village is 740 feet, with the base not shown. On Valcour Island, Brainard and Seely give it a thickness of 890 feet, and there it seems to reach its maximum.[a]

Brainard's section at Valcour Island [94] reads, in ascending order:

Group A (Lower Chazy).

	Feet.
1. Gray or drab-colored sandstone, interstratified with thin (or sometimes thick) layers of slate, and with occasional thin layers of limestone at the base, containing *Camerella* (?) *costata* Bill	56
The slaty sandstone gradually passes into—	
2. Massive beds, made up of thin alternating layers of tough slate and of nodular limestone, containing undetermined species of Orthis and Orthoceras	82
3. Dark bluish-gray, somewhat impure limestone, in beds of variable thickness; often packed with *Orthis costalis* Hall, which occurs with more or less frequency through the whole mass. Other fossils are *Lingula huronensis* Bill., *Harpes antiquatus* Bill., *Harpes ottawaensis* Bill. (?), *Illænus arcturus* Hall (=*bayfieldii* Bill.), Lituites sp. (?)	110
4. Gray, tolerably pure limestone in beds 8 to 20 inches thick, separated by earthy seams, the bedding being uneven. Many layers consist of crinoidal fragments, largely of *Palæocystites tenuiradiatus* Hall. Near the middle of the mass, for a thickness of 10 feet, some of the fragments and small ovoid masses (*Bolboporites americanus* Bill.) are of a bright-red color, and these beds on the west side of Bluff Point are extensively quarried and furnish a fine marble for indoor use	90
Total thickness of A	338

[a] Ulrich regards this as a mistake, for in his judgment it robs the Beekmantown of its most essential part, namely, division D.—B. W.

Group B (Middle Chazy).

	Feet.
1. Impure nodular limestone, containing *Maclurea magna* Lesueur	25
2. Gray massive pure limestone, abounding in crinoidal fragments	20
3. Bluish-black thick-bedded limestone, usually weathering so as to show pure nodular masses enveloped in a somewhat impure lighter-colored matrix; everywhere characterized by *Maclurea magna*. Near the middle of this mass, for a thickness of about 30 feet, the fossils are silicified and of jet-black color. The more important, besides Maclurea, are species of Strophomena, Orthis, and Orthoceras	210
4. Dark compact fine-grained limestone, with obscure bedding, weathering to a light gray. This rock resists erosion and is the upper stratum at Bluff Point, sloping upward from the lake at an angle of 5° to a height of 170 feet. In one exposure the basal portion is densely oolitic. Fossils are infrequent, but at a single locality there were collected *Orthis perveta* Con., *Orthis platys* Bill., *Leptæna fasciata* Hall, *Asaphus canalis* Con., *Cheirurus polydorus* Bill., Harpes sp. und., *Illænus incertus* Bill., *Lichas minganensis* Bill., *Sphærexochus parvus* Bill., and several undescribed species	20
5. Bluish-black limestone like No. 3, but less pure, containing *Maclurea magna* Lesueur, *Orthis perveta* Con., *Strophomena incrassata* Hall, *Orthis borealis* Bill. (?), *Orthis disparilis* Con., or *O. porcia* Bill	75
Total thickness of B	350

Group C (Upper Chazy).

1. Dove-colored compact limestone, in massive beds, containing a large species of *Orthoceras*, *Placoparia (Calymene) multicosta* Hall, *Solenopora compacta*, and a large Bucania	60
2. Dark impure limestone, in thin beds, abounding in *Rhynchonella plena;* at the base a bed 4 or 5 feet thick is filled with various forms of Monticulipora or Stenopora	125
3. Tough arenaceous magnesian limestone, passing into fine-grained sandstone	17
Total thickness of C	202
Aggregate thickness of the Chazy on Valcour Island	890

Raymond [660, 661] gives a classification of the faunal divisions of the Chazy (*Herbertella exfoliata* division, *Maclurites magna* division, and *Camarotœchia plena* division) and distinguishes a number of faunal zones. He also discusses the distribution and correlation of the formation so far as it has been identified in Canada and the United States.

The belt east of the Hudson has been mapped by Dale [207, 208] from Lake Champlain south to the Kinderhook (latitude 42° 30′). The rocks are chiefly slate, range in age from Lower Cambrian to Lorraine, and are but sparsely fossiliferous. The areal distribution of distinct formations is not worked out and the divisions mapped by Dale are broad and indefinite.

The post-Beekmantown Ordovician is included under the term "Hudson" and the stratigraphy is summed up as follows: [208a]

Table showing the Hudson formation as exposed in Rensselaer County and the northeastern part of Columbia County, N. Y.

Description of strata.	Fauna.	Estimated thickness in feet.	Age.	Metamorphic equivalent.	
				[Description.]	Estimated thickness in feet.
Black shale with arenaceous limestone, etc.[a]	Diplograptus amplexicaulis.[b]				
Black and gray shale with interbedded grit.[c]	Normans Kill graptolite fauna.				
Similar shale with limestone and limestone conglomerate.	Trenton fauna in limestone and cement of conglomerate.[d]	1,200–2,500?	Trenton..	Sericite schist, black, green, or purple, in places with greenish quartzite up to 20 feet thick.	1,000–2,000
Black siliceous white-weathering, "cherty-looking" shale.[e]	....				
Reddish, purplish, greenish shale, with small quartzite beds.[e]	....				

[a] See Ruedemann, Rudolf, Bull. New York State Mus. No. 42, 1901, pp. 535–537, stations 24, 25, 26.
[b] See Ruedemann, op. cit., for other fossils.
[c] Rarely with small beds of quartzite.
[d] The pebbles of this conglomerate contain Trenton, Chazy, and Lower Cambrian fossils. See Ruedemann, Rudolf, Bull. New York State Mus. No 49, 1901, and Ford, S. W., Am. Jour. Sci., 3d ser., vol. 28, 1884, pp. 206–208. [Regard this zone as overlying the true Normans Kill.]
[e] The vertical relations of the colored shale and the black siliceous shale to each other and to the black and gray shale with Normans Kill graptolite fauna are not clear. They are all intimately associated. The greenish shale sometimes includes small limestone beds.

The presence of strata of Chazy, Trenton, and Lorraine age constituting the upper part of the Stockbridge dolomite in the compressed syncline near Rutland, Vt., was shown by the discovery of fossils by Wing in 1877.[216] and has been confirmed by Wolff [945] and by Dale.[205]

The faunal horizons of the "Hudson shales" in the vicinity of Albany have been worked out by Ruedemann,[678] who sums up his results as follows:

This paper purports to demonstrate the presence of four zones of shales in the "Hudson River shales" of the Hudson Valley region about Albany. These zones, which extend from north-northeast to south-southwest, consist, going from west to east, of shales containing the Lorraine, Utica, middle Trenton and Normans Kill graptolite faunas. The shales last named include lower Trenton conglomerate and rest on lower Trenton limestone. This succession of zones places the Normans Kill graptolite beds, which form the mass of the "Hudson River shales" in the Hudson River valley, between the middle and lower Trenton and determine, together with other facts, the lower Trenton age of these shales.

The beds lie conformably inverted, on account of their being the remnant of the underturned wing of an overturned fold of Appalachian type. This fold has turned into an overthrust fault, which brought the Cambric beds as the next succeeding terrane above the Normans Kill shales.

On account of the fact that the mass of beds hitherto called Hudson River shales and correlated with the Lorraine beds of central New York is composed of terranes ranging from the Lorraine to the lower Trenton, and on account of the lack of a fully representative fauna and of a complete section of the Lorraine portion of these terranes, it is proposed to drop the term "Hudson River shales" for the uppermost part of the Lower Siluric and the term "Hudson River group" for the Utica and Lorraine beds and to employ the term Normans Kill shales for the classic facies of a part of the lower Trenton which is characterized by the graptolite fauna at the Normans Kill.

The limestone conglomerate referred to in the above quotation was made the subject of refined study by Ruedemann,[679] with reference to the faunas of matrix and pebbles, origin of materials, and conditions of deposition. From this paper the following summary is taken:

1. The investigation of the lower Siluric shales of the neighborhood of Albany has led to the observation of a conglomerate bed embedded in these shales and outcropping on Rysedorph Hill near Rensselaer, on the Moordener Kill near Castleton, and at Schodack Landing.

2. The most interesting feature of this conglomerate is the fauna which the component pebbles and the matrix contain. To describe these and to obtain from them conclusive data as to the age of the inclosing Normans Kill shales is the principal purpose of this paper.

3. The conglomerate contains a great variety of pebbles. In the southern outcrops, at Schodack Landing, nonfossiliferous sandstone pebbles prevail; going northward, fossiliferous limestone pebbles increase, and on Rysedorph Hill they are the principal components.

4. The limestone pebbles are shown by their faunas to be derived, in very small number, from Cambric and Chazy rocks; more frequently from the Lowville limestone; and prevailingly from extremely fossiliferous black and gray limestone beds which are of lower or lowest Trenton age.

5. A specially interesting feature of the fauna of these Trenton pebbles was found in the considerable number of new forms, largely brachiopods, trilobites, and ostracods. Some of these belong to genera new to the American Trenton but well represented by very similar forms in equivalent north European beds. These, as well as several other forms which also occur in the Rysedorph Hill conglomerate and are restricted to the eastern Trenton, support the conclusion derived from the distribution of the Normans Kill graptolite shales, viz, that in lower Trenton time the eastern Trenton sea had attained connection with the Atlantic.

6. As the fauna of the Trenton pebbles is in marked features different from that of the beds known in the Mohawk and Hudson valleys, it is supposed that the material was derived from the regions to the east and northeast, where the Trenton beds have now become metamorphosed and the fossils obliterated.

7. The occurrence of the lower Trenton limestone pebbles in this region is taken to indicate that at the beginning of the Trenton period the quiet limestone-depositing Trenton sea extended also over this region; while the presence of Normans Kill shale of lower Trenton age proves that this favorable condition soon came to an end, and a radical change in the physical conditions took place.

8. The conglomerate itself is intraformational. It is embedded in shale of the same age, and the fauna of the matrix of the conglomerate is of lower Trenton age. The conglomerate, therefore, evidently does not mark any important change in the physical condition of the region but is probably due to a temporary elevation of a low Appalachian ridge into the sphere of wave action.

This conglomerate closely resembles the conglomerate of the Quebec formation of Citadel Hill, Quebec, in its constitution, associated shales, and faunas.

The full statement of Ruedemann's studies of the graptolites is contained in two memoirs, to which reference should be made for adequate appreciation. The first of these [680] deals chiefly with horizons discussed in Chapter II of this work; from the second [681] the following table is quoted:

Correlation table of the graptolite zones of New York.[a]

System.	Stage.	Graptolite zones in New York.	Distribution in North America.	Corresponding zones in Great Britain and Scandinavia.	Extra-American distribution.
Siluric	Clinton beds	Zone of *Monograptus clintonensis* and *Retiolites geinitzianus* var. *venosus*.	....	Zone of *Cyrtograptus murchisoni*.	Great Britain, France, Belgium, Scandinavia, Bohemia.
[Ordovician] Champlainic.	Richmond beds (?)	....	Zone of *Dicellograptus complanatus* in Indian Territory.	Zone of *Dicellograptus complanatus*.	Great Britain, Scandinavia.
	Lorraine beds	Zone of *Diplograptus peosta* and *D. foliaceus* mut. *vespertinus*.	Wisconsin, Minnesota	....	
	Frankfort shale	Zone of *Glossograptus quadrimucronatus* mut. *posterus*.	Ohio, Canada	....	
	Utica shale	Zone of *Glossograptus quadrimucronatus* and *Climacograptus typicalis*.	Canada, Vermont, Pennsylvania, Ohio, Wisconsin, and Minnesota (Maquoketa shale and part of Galena?).	Zone of *Pleurograptus linearis*.	Great Britain, Scandinavia.
		Subzone of *Climacograptus caudatus* and *Corynoides curtus* mut. *comma*.	....	....	
	Upper Trenton Middle Trenton	Zone of *Diplograptus amplexicaulis* (Upper Dicellograptus zone).	Canada (Magog, Cove Fields, etc.).	Zone of *Dicranograptus clingani*.	Great Britain, Scandinavia.
	Lower Trenton Black River limestone and Lowville limestone.	Zone of *Nemagraptus gracilis* (Normans Kill shale).	Canada, New Jersey, Alabama, Arkansas, Indian Territory, Nevada, British Columbia.	Zone of *Nemagraptus gracilis*.	Great Britain, Scandinavia, France (?), New South Wales, and Victoria.
	Chazy limestone	Zone of *Diplograptus dentatus* and *Cryptograptus antennarius* (Third Deepkill zone).	Canada (Point Levis zone), Arkansas, Nevada.	Zone of *Didymograptus geminus*.	Great Britain, Scandinavia.
		Subzone (transitional zone) with *Didymograptus forcipiformis* (Ash Hill quarry).	....	....	
	Beekmantown limestone.	Zone of *Didymograptus bifidus* and *Phyllograptus anna*.	Canada (St. Anne zone), Newfoundland.	Zone of *Didymograptus bifidus* and *Phyllograptus typus* (Upper Tetragraptus zone).	Great Britain, Scandinavia, France, Bohemia, Victoria.
		Zone of Tetragraptus .... Subzone b of Goniograptus. Subzone a of Clonograptus.	Canada (main Point Levis zone).	Zone of Tetragraptus (Lower Tetragraptus and Dichograptus zones).	Great Britain, Scandinavia, France, Victoria.
Cambric[b]	Schaghticoke shale	Zone of *Dictyonema flabelliforme*	Canada (Gaspe, St. John).	Zone of *Dictyonema flabelliforme*.	Great Britain, Scandinavia, Esthonia, Belgium.

[a] This in part replaces the correlation table in Memoir 7 (facing p. 490).

[b] It is still a mooted question whether the shale of *Dictyonema flabelliforme* constitutes the last horizon of the Cambric or the first of the Champlainic (Lower Siluric), and several authors have lately inclined to the latter view.

In the southern part of the Hudson Valley the Ordovician divides around the pre-Cambrian of the Highlands. In the eastern area the strata are more or less metamorphosed; they are described with the similar slates and schists of New England (below). The western area extends through Ulster and Orange counties to New Jersey.[225]

Ries [673] recognized in Orange County the Trenton limestone and the "Hudson River slates." Of the limestone he mentions one occurrence near Newburgh Ferry. The slates are widely distributed.

In the western part of the county the formation is represented by interbedded shales and red and brown or gray sandstones, while in the central part the slates and shales only appear. The sandstone beds again come in toward the northeast. Conglomerates are occasionally seen in the northeastern part of the county. * * * Fossils are rare but have been found at several localities. * * * They show a mixed Hudson River-Trenton fauna. * * * These rocks rest unconformably on the Cambrian limestones and gneisses and underlie younger rocks in the same manner. Their thickness in this county is probably not less than 2,000 feet.

K-L 18-19. VERMONT, NEW HAMPSHIRE, MASSACHUSETTS, AND CONNECTICUT EAST OF THE GREEN MOUNTAINS.

The presence of middle Ordovician strata in Vermont, in continuation of the Canadian occurrences, is probable, but their distribution is not known. They probably lie in synclines, overthrust by Cambrian and below remnants of the Silurian, which here, as in New Brunswick and eastern New York, is probably unconformable to the older strata. The structure is much confused by folding, thrusting, and igneous intrusions. In Canada immediately north of the international boundary Ells [312] has traced out the divisions of the "Quebec group" and distinguished the belts of graptolitic slates of the Ordovician. (See pp. 132–134.) The southward extension into New Hampshire and Vermont was described by Hitchcock [452, 453] as the Calciferous mica schist and the Coos group.

In Massachusetts and Connecticut the upper part of the Stockbridge dolomite is of Beekmantown, Chazy, and Trenton age and the Berkshire schist is assigned to the general position of the "Hudson River"—that is, to Trenton and later Ordovician, the upper limit being indeterminate.

Along the boundary between New York on the west and Vermont, Massachusetts, and Connecticut on the east extends the Taconic Range, the area of the Taconic system of Emmons. Dana published the results of his prolonged study of the structural relations and his conclusions as to the true order of the strata of the Taconic Range in a series of papers in the American Journal of Science (1872–1887).[218, 219] He also summed up the history and facts in the Quarterly Journal.[217]

The early discoveries of fossils by Wing (see p. 189) were followed by Walcott's discoveries in the central Taconic area, which proved the Cambrian and Ordovician age of the strata. Walcott [849] distinguished the rocks of certain areas as "terranes" and concluded that terrane 3, the upper part of the Stockbridge dolomite, was equivalent to the "Calciferous" (Beekmantown), Chazy, and Trenton limestones of the Champlain-Hudson Valley and terranes 4 and 6 were of "Hudson" age.

In Berkshire County, northwestern Massachusetts, lies Mount Greylock, which is composed of the Stockbridge dolomite and overlying strata. Dale [206] worked out its structure and gives the following tabulation of the stratigraphy as determined by him, in comparison with other classifications:

General lithologic character, order, and estimated thickness of the strata of Mount Greylock, East Mountain, and Stone Hill.

Formations (natural order).	Lithologic character.	Thickness (feet).	Age.			
			Emmons, 1855.	Hall, 1839–1844.	Dana, 1882–1887.	Walcott, 1888.
Greylock schist	Muscovite (sericite), chlorite, and quartz schist, with or without biotite, albite, magnetite, tabular crystals or lenticular plates of interleaved ilmenite and chlorite, ottrelite, microscopic rutile, and tourmaline. These schists are rarely calcareous or graphitic.	1,500–2,000	Pre-Potsdam. Lower Taconic No. 3. "Talcose or magnesian slate."	Trenton (Hudson River).	Lower Silurian	Trenton (Hudson River).
Bellowspipe limestone.	Limestone, more or less crystalline, generally micaceous or pyritiferous, passing into a calcareous schist, or a feldspathic quartzite, or a fine-grained gneiss with zircon and microcline, or a schist like the Berkshire schist. The more common minerals are graphite, pyrite, albite, and microscopic rutile and tourmaline. More rare, galena, zinc blende, siderite.	600–700	Pre-Potsdam. Lower Taconic No. 3. Included in "Talcose or magnesian slate."	Trenton (Hudson River).	Lower Silurian	Trenton (Hudson River).
Berkshire schist	Muscovite (sericite), chlorite, and quartz schist, with or without biotite, albite, graphite, magnetite; frequently with tabular crystals or lenticular plates of interleaved ilmenite and chlorite. Garnet, ottrelite. Microscopic rutile and tourmaline. These schists are in places calcareous, especially toward the underlying limestone, where they are often graphitic.	1,000–2,000	Pre-Potsdam. Lower Taconic No. 3. "Talcose or magnesian slate."	Trenton (Hudson River).	Lower Silurian	Trenton (Hudson River).
Stockbridge limestone.	Limestone, crystalline, coarse or fine; in places a dolomite, sometimes quartzose or micaceous, more rarely feldspathic, very rarely fossiliferous. Galena and zinc blende rare. Irregular masses of iron ore (limonite) associated sometimes with siderite, often with manganese ore (pyrolusite). Some quartzite.	1,200–1,400	Pre-Potsdam. Lower Taconic No. 2. "Stockbridge limestone."	Lower Silurian (Trenton and lower).	Lower Silurian	Trenton (Trenton); Canadian (Chazy, Calciferous).
Vermont formation	Quartzite, fine grained, alternating with a thin-bedded micaceous and feldspathic quartzite (the latter with calcite, pyrite, tourmaline). Associated with these quartzites, and probably at the base of this horizon, is a coarse-grained micaceous quartzite (tourmaline), passing in places into a conglomerate and containing blue quartz, feldspar (plagioclase, microcline), and zircon, all of clastic origin.	800–900	Pre-Potsdam. Lower Taconic No. 1. "Granular quartz."		Cambrian (Potsdam).	Lower Cambrian (Olenellus).
	Total thickness:					
	Minimum	5,000				
	Maximum	7,200				

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In the same monograph Pumpelly [654] describes the structural and stratigraphic grounds for correlating the Cambrian and Ordovician strata of Mount Greylock with the Hoosac schist on the east. The latter is mapped as Cambrian and Ordovician. (See Chapter III, p. 114.)

In southwestern Massachusetts and adjoining parts of Connecticut and New York lies the Mount Washington mass of the Taconic Range, which has been more particularly studied by Hobbs,[455] who distinguished four formations apparently equivalent to those recognized by Dale, namely:

Mount Washington, Hobbs.	Mount Greylock, Dale.
Top.	
Everett schist	Greylock schist.
Egremont limestone	Bellowspipe limestone.
Riga schist	Berkshire schist.
Canaan dolomite	Stockbridge limestone.

Ordovician strata, which, though highly metamorphosed by igneous injection, are identified as representatives of the Stockbridge dolomite and "Hudson shale," form part of Manhattan Island, New York.[593] They have been traced through eastern New York and western Connecticut to the fossiliferous area of the Taconic Range, first by Dana, and later by Gregory.[387]

L 12. SOUTHWESTERN MONTANA.

There is no recognized break in the sequence of lower Paleozoic strata which appear around the uplifts of southwestern Montana; and yet no strata which may certainly be referred to the Ordovician are known there. Apparently but slight record of marine or land conditions was made in the region during that long time.

L 16. UPPER PENINSULA OF MICHIGAN.

Rominger [677a] describes in detail the occurrence of "Chazy and Calciferous, Trenton, and Hudson River" strata in the Upper Peninsula of Michigan. The distribution of the formations as shown on the map of North America is taken from the geologic map of Michigan published by the present Survey, and the following notes are abstracted from a paper by Lane.[517]

Lane describes in ascending order St. Peter sandstone, Trenton limestone, Utica shale (Eden of Ohio), and Lorraine or Maysville shale as formations composing the Ordovician between the "Calciferous" and his "Richmond and Medina transition beds."

The St. Peter sandstone does not outcrop in Michigan but is recognized in well drilling as a quartz sand between the "Trenton" limestone above and the "Calciferous" limestone below. Its thickness is very irregular, presumably because it lies on an uneven surface.

The "Trenton" of northern Michigan, according to Lane and Grabau, comprises the equivalents of the Chazy, Black River (Lowville or "Birdseye" and Black River of present usage), and Trenton of Hall's classification in New York, or the Chazy and Mohawkian of the present New York State Survey classification. The base of this limestone is the passage into the St. Peter sandstone, or, where that is lacking, the contact with the "Calciferous" (lowermost Ordovician) or the pre-Cambrian, upon which it overlaps. The passage from the "Trenton" limestone or dolomite to the overlying shale described by Lane as the Utica is well marked lithologically. Lane states the thickness of the "Trenton" as 250 to 271 feet. It is in places dolomitic. Subdivisions in the Green Bay region are recognized by him as follows:

	Feet.
Galena limestone:	
[Limestone,] crystalline, granular	83
Limestone, fossiliferous 55 feet, white 8 feet, dark 9 feet	72
Alternating blue and brown, crystalline, granular. With the dark base compare the Wisconsin oil rock	225
Sandy limestones, "quartz" 6 feet, limestone 44 feet, quartz 1 foot, limestone 24 feet; compare quartz sandstone at Marinette at 260–275 feet	75
Wisconsin Trenton (Platteville?), blue shale and limestone (blue shale 4 feet, black limestone 141 [14?] feet, limestone 19 feet, blue shale 4 feet)	41

The formation recognized by Lane as the Utica shale is described as a black shale ranging in thickness from 50 feet at the north to about 200 feet at the south. The formation described by him as Lorraine or Maysville is an abundantly fossiliferous blue shale which he correlates with the Maquoketa of Iowa.

Lane groups certain coarser deposits and residual red clays formed from limestone as "Richmond and Medina transition beds." The former he places in the Ordovician, the latter in the Silurian, although he does not doubt that Ulrich is right in placing the Richmond of Indiana in the Silurian. He states, however, that in this region the strata to which he applies the name Richmond are so closely associated with the underlying shales, being included with them in many well drillings, that it is not convenient to separate them from the Ordovician. The strata described by Lane as Richmond and Medina consist of red and green shale, with some limy beds, and vary in thickness from little or nothing to about 142 feet at Cheboygan, thickening toward the south.

Ulrich in commenting on Lane's view states that the Utica and Lorraine do not outcrop in Michigan, but that the "Trenton" is succeeded by the Maquoketa, of Richmond age, with a hiatus between equivalent to the Eden, Utica, and Maysville of the Cincinnati section.

L 17. MANITOULIN ISLANDS.

The east end of Great Manitoulin Island, Ontario, falls within the area mapped on the French River sheet. In reporting on that area Bell [67] summarized the results of his own work and that of his colleagues in preceding years. The several formations of the later Ordovician—"Chazy?, Trenton, Utica, and Hudson"—are described in some detail. To the Chazy are doubtfully assigned the lowest beds of the Paleozoic in this region, certain chocolate-colored marls, with some fine sandstones, 100 feet thick. Bell obtained no fossils from these strata, but Ami [24] states that "Billings notes in a list of fossils from the island farthest south of the group, off Point Pallideau, Lake Huron, the occurrence of *Modiolopsis parviuscula*, *Vanuxemia inconstans*, *Pleurotomaria staminea*, and *Lingula huronensis*, species known to occur in the Chazy of different portions of Ontario, notably in the Montreal-Ottawa-Champlain basin."

The "Trenton group" is represented by gray limestones with shaly and marly beds, approximately 320 feet thick. Locally these strata rest upon the Ste. Marie sandstone[544e] or directly upon the pre-Cambrian quartzite ledges of the northeastern islands (Badgely Point, etc.), where they carry Black River fossils. Ami[24a] cites a number of collections of fossils from these strata.

"Hudson River" strata of the islands are described as bluish-gray and drab marls and shales, interstratified with thin limestone and fine-grained sandstone, altogether 250 to 300 feet thick, including a 30 to 40 foot band of limestone at the top. Ami states:

> It is extremely desirable that further collections be obtained from the Ordovician and Silurian succession of the Manitoulin Island district of Lake Huron, inasmuch as the sedimentation of that area is not only quite distinct from that of the Niagara and Toronto districts on the Ontario basin, but bears strong resemblance to the succession known and recorded in Indiana, Ohio, and Kentucky to the south, as well as to that of the Island of Anticosti, in the valley of the St. Lawrence, east.

The beds called Utica shale are described as black and bituminous and 60 feet thick. Some of the collections (Nos. 14–20) contain faunas which appear to indicate the presence of the summit beds of the Ordovician, either Lorraine or Richmond; elsewhere Lorraine (21–22) and Richmond (23–32) have been distinctly recognized. To the Clinton (Medina strata being absent) are assigned drab, buff, and purplish magnesian limestones.

L 17. LAKE NIPISSING, LAKE TEMISCAMING, AND MATTAWA.

Outliers of Ordovician limestone containing Black River and Trenton faunas occur on islands in Lake Nipissing, Lake Temiscaming, and 6 miles below Mattawa, on the Ottawa.[55] They are too small to be shown on the map but are important, as their correlation, according to Ami,[15a] shows "that in Ordovician times the marine waters of the Lake Huron Paleozoic basin were directly connected with those of the Nipissing and Mattawa or Upper Ottawa regions."

L 18–19. ST. LAWRENCE VALLEY.

The distribution of the Ordovician, exclusive of the Beekmantown ("Calciferous"), in the St. Lawrence Valley as here mapped is taken from the map sheets of Ontario and Quebec. The line at the base is that between the "Calciferous" and Chazy, and that part of the Ordovician above this line comprises the equivalent of the Chazy, Lowville ("Birdseye"), Black River, Trenton, Utica, and Lorraine of the New York section. The Pamelia limestone[204] and the underlying but unconformable "Theresa formation" have also been traced in the latest work (1908).[a]

The southwestern or upper part of the St. Lawrence Valley is known in Canadian geology as the Ottawa Basin. This basin is bounded on the southwest by the Frontenac axis, the belt of pre-Cambrian rocks which crosses the St. Lawrence and connects with the Adirondack area. On the east a similar area of older rocks, eroded to the Potsdam sandstone, separates the Ordovician of the Ottawa basin from the equivalent Ordovician strata that extend from Montreal to Quebec, down the north side of the St. Lawrence Valley.

[a] Ami., H. M., personal communication, Sept., 1908.

The St. Lawrence Valley east of the river between Montreal and Quebec is divided by the St. Lawrence-Champlain thrust fault into two zones, the line of division, according to Logan,[544h] passing through Quebec and curving thence to Lake Champlain. Strata that occur southeast of this line differ in lithology and faunas from those of probably equivalent age that are found northwest of it. The facies differ across the thrust fault. Those of the northwestern zone (Ottawa, Montreal, Quebec) may be described under the New York names cited above, but those of the southeastern zone ("Eastern Townships") belong to the Sillery, Levis, and Quebec formations (named in ascending order), which constitute the old Quebec group of Logan and Billings. The Sillery (Cambrian) and Levis (Beekmantown or "Calciferous") are described in Chapter III (pp. 131–134). The Quebec formation (restricted) is the equivalent of the upper Chazy and lower Trenton.[16b, 853]

In Ells's report on the geology of the area shown on the Three Rivers map sheet [314] occurs the following table, which is based on correlations by Ami:

System.	Formations.		Character of strata, etc.	
	West of fault.	East of fault.	West of fault.	East of fault.
Silurian	Medina		Red shales and sandstones.	
Cambro-Silurian or Ordovician.	Lorraine		Grayish shales and sandstones.	
	Utica		Black bituminous shales.	
	Trenton	(Farnham)	Limestones	Black graptolitic shales and black or dark impure limestones.
	Black River		Limestones	
	Chazy		Chiefly limestone; shale in lower part.	
	Calciferous		Magnesian limestones	
	Potsdam		Sandstones	
Cambrian		Sillery		Red and gray and green slates and greenish-gray sandstones.
Archean	Grenville		Gneisses and limestones with granites and igneous rocks.	

It is convenient to consider the formations northeast of the St. Lawrence-Champlain fault separately from those southeast of it. We first take up the Ottawa basin.

The Paleozoic rocks of the Ottawa Basin are bounded on the southwest by the Frontenac axis, an outcrop of pre-Cambrian rocks which extends across the St. Lawrence into New York and connects with the Adirondack mass; beyond this axis to the southwest along the upper St. Lawrence and Lake Ontario is another area of Ordovician strata, in which the section differs somewhat from that of the Ottawa Basin. Ami [20] contrasts them as follows:

Ordovician east of the Frontenac axis.

VII. Lorraine: Buff-weathering and dark siliceous shales and mudstones.
VI. Utica: Dark-brown and black bituminous shales and limestones at the base.
V. Trenton: Dark-gray impure and semicrystalline fossiliferous limestone.
IV. Black River: Heavy-bedded and hard compact fine-grained impure limestones, etc.
III. Chazy: Limestones, shales, sandstones, and grits; shallow water deposit at the base.
II. Beekmantown (Calciferous): Dark-gray impure magnesian limestone or dolomites, cavernous and fossiliferous.
I. Potsdam: Light-yellow and rusty-colored sandstones and conglomerates; shore deposits resting on the Archean crystallines.

Ordovician west of the Frontenac axis.

V. Lorraine: Arenaceous shales and mudstones, at times very fine-grained argillites.
IV. Utica: Dark-brown and black fossiliferous shales, etc.
III. Trenton: Gray impure fossiliferous limestones.
II. Birdseye and Black River [Pamelia, Lowville, and Black River]: Heavy-bedded impure fossiliferous limestones and fine-grained compact lithographic beds at the base.
I. Rideau [Ste. Marie [a]]: Mostly red and yellow (at times green) colored sandstones; shallow-water deposit; false bedding prevalent; a basal series resting unconformably upon the subjacent Archean crystallines [Chazy.—B. W.].

The following tables of the geologic formations which make up the Ordovician near Ottawa, Montreal, and Quebec, northwest of the St. Lawrence-Champlain fault, are taken from a paper by Ami. [16a]

[*Part of*] *synoptical table of the geological formations about Toronto, Ontario.*

System.	Formation.	Character of strata, etc.	Characteristic fossils.	Thickness.
Ordovician.	Lorraine	Light yellowish green and gray calcareous and magnesian and arenaceous shales or mudstones, some very fine grained argillites, bluish gray in color.	*Diplograptus hudsonicus* Nicholson, *Monotrypella undulata* Nich., *Zygospira headi* Billings, *Platystrophia biforata* Schlotheim, v. *lynx* Eichwald, *Drepanodus arcuatus* Hinde, *Distacodus incurvatus* Hinde, *Pronodus? politus* Hinde, *Lyrodesma poststriatum*, *Liospira subconica* Hall, *Modiolopsis modiolaris* Hall, *Byssonychia radiata* H., *Modiolopsis pholadiformis* H., *Orthocecus lamellosum* H., *Ormoceras crebriseptum* H., *Triarthrus becki* Green, *Favistella stellata* H., *T. calycina* N., *Tetradium minus* Safford.	Between 600 and 650 feet. Varies in thickness in different exposures. Thickness depends upon amount of denudation and erosion.
	Utica	Dark-brown and black bituminous shales (only reported and observed in drillings from deep wells).	The characteristic fossils of this formation as exposed at Whitby and vicinity east of Toronto are *Leptograptus flaccidus* Hall, *Orthograptus quadrimucronatus* H., *Leptobolus insignis* H., *Schizocrania filosa* H., *Zygospira modesta* Say, *Lyrodesma pulchellum* Emmons, *Trocholites ammonius*, *Triarthrus canadensis* Smith, *T. becki* Green.	About 100 feet.
	Trenton	Dark and light gray and yellowish-gray impure fossiliferous limestones with shaly partings.	Diplotrypa sp., Dicranopora sp., *Plectambonites sericea* Sowerby, *Orthis* (*Dalmanella*) *testudinaria* Dalman, Rhynchotrema sp.	About 550 feet in bore holes.
	Birdseye and Black River.	Dark-gray impure, but also and for the most part fine-grained compact yellowish-gray lithographic limestone, with basal beds of a calcareo-arenaceous or arkose nature.	*Isochilina lithographica* n. s.	About 160 feet in bore holes.
Unconformity.				
Pre-Cambrian.				

[a] According to a personal communication from Dr. Ami, the sandstones at Rideau are of Potsdam age. They are not of widespread occurrence in this district. Sandstones which are similar but are of Chazy age locally form the base of the Ordovician succession (Storrington, near Kingston, and island off Pallideau) and were described by Logan (Geology of Canada, 1863, p. 196) as the Ste. Marie sandstone. Hence in Dr. Ami's judgment Rideau in this section must give place to Ste. Marie.—B. W.

[Part of] synoptical table of geological formations about Ottawa, Canada.

System.	Formation.	Character of strata, etc.	Characteristic fossils.	Thickness.
Silurian.	Medina.........	Bright brick-red argillaceous and arenaceous shales or marls, occasionally spotted or mottled green.	No fossil organic remains have as yet been detected in these shales.	About 100 feet in thickness. On one of the outliers examined a 60-foot well was sunk in these shales.
Ordovician.	Lorraine........	Buff-weathering fine-grained brittle shales and mudstones, at times arenaceous.	*Zygospira headi* Billings, *Byssonychia radiata* Hall, *Modiolopsis modiolaris* Conrad, *M. pholadiformis* Hall, *Liospira subconica* Hall, *Calymene senaria* Conrad, *Cyrtolites ornatus* Con.	Exact thickness not ascertained, but probably not less than 100 or 150 feet.
	Utica...........	Dark-brown and black bituminous soft shales and limestone bands interstratified in the basal portion of this formation.	*Leptograptus flaccidus* Hall, *Orthograptus quadrimucronatus* Hall, *Schizambon canadensis* Ami, *Schizocrania filosa* Hall, *Batostomella erratica* Ulrich, *Turrilepas canadensis* Henry Woodward, *Stephanella sancta* Hinde, *Triarthrus spinosus* Billings, *Asaphus latimarginatus* Hall (=*A. canadensis* Chapman) *Endoceras tenuistriatum* Hall.	From 60 to 75 feet.
	Trenton........	Nodular and evenly bedded, for the most part bluish-gray, light-weathering impure limestones and shales, fossiliferous, marine sediments, in part bituminous, cherty.	*Licrophycus ottawaensis* Billings, *Pasceolus globosus* B., *Astylospongia parvula* Billings, *Streptelasma corniculum* Hall, *Archæocrinus microbasalis* Bill., *Cleiocrinus magnificus* B., *Glyptocrinus ramulosus* B., *Heterocrinus canadensis* B., *Iocrinus subcrassus* M. and W., *Reteocrinus stellaris* B., *Amygdalocystites florealis* Bill., *Ateleocystites huxleyi* B., *Comarocystites punctatus* B., *Pleurocystites filitextus* B., *Agelacrinites dicksoni* B., *Monticulipora billingsi* Foord, *Batostoma ottawaensis* Foord, *Prasopora selwyni* Nicholson, *Solenopora compacta* B., *Orbiculoidea circe* B., *Skenidium merope* B., *Rafinesquina alternata* Conrad (Emmons), *Trematis ottawaensis* B., *Ambonychia amygdalina* B., *Pterinea trentonensis* Conrad, *Conularia trentonensis* H., *Protowarthia cancellata* Hall, *Eccyliomphalus trentonensis* Con., *Ophileta ottawaensis* B., *Trochonema umbilicatum* H., *Hormotoma bellicincta* H., *Orthoceras python* B., *O. ottawaense* B., *Serpulites dissolutus* B., *Zygospira recurvirostra* H., *Isotelus gigas* De Kay, *Bronteus lunatus* B., *Harpes ottawaensis* B.	From 450 to 500 feet.

[*Part of*] *synoptical table of geological formations about Ottawa, Canada*—Continued.

System.	Formation.	Character of strata, etc.	Characteristic fossils.	Thickness.
Ordovician.	Birdseye and Black River.	Fine-grained and compact light-gray impure limestones, marine and fossiliferous, some beds massive, others shaly and nodular.	*Stromatocerium rogosum* Hall, *Receptaculites occidentalis* Salter, *Streptelasma profundum* Hall, *Tetradium fibratum* Safford, *Columnaria halli* Nicholson, *Maclurea logani* Salter, *Gonioceras anceps* Hall, *Heliocotoma planulata* Salter, *Orthis tricenaria* Conrad, *Strophomena incurvata* Shepard, *Cyrtodonta subtruncata* Billings, *Cyrtoceras sinuatum* B., *Oncoceras constrictum* Hall, *Actinoceras bigsbyi* Stokes, *Orthoceras rapax* B., *Illænus ovatus* B., *I. conradi* B.	About 150 feet.
	Chazy	Light-gray impure fine-grained and concretionary and fossiliferous limestones, cement rock.	*Leperditia canadensis* Jones, *Isochilina ottawa* J., *Camarotœchia plena* Hall, *Dinorthis platys* Hall, *Orthis* (*Hebertella*) *borealis*, Billings.	About 20 feet
		Yellowish-gray calcareous and arenaceous shales, rusty-weathering, with phosphatic nodules.	*Lingula belli* Billings, *Modiolopsis parviuscula* B., *Ctenodonta* n. sp., *Cyrtodonta breviuscula* B., Serpulites sp., Scolithus, n. sp.	30 feet 200 feet.
		Arenaceous shales and sandstones and magnesian bands, fine grained and light yellow weathering.	*Orthis imperator* Billings, *Asaphus canalis* Conrad, *Lingula lyelli* Billings.	150 feet
	Calciferous [Beekmantown].	Magnesian limestones, fine and coarse grained buff-weathering, hard and cherty, at times soft and saccharoidal or arenaceous and holding cavities lined with crystals of quartz, passing down into arenaceous layers or sandstones.	*Cryptozoon calciferum* Dawson, *Ophileta complanata* Vanuxem, *Hormotoma anna* Bill., *O. disjuncta* B., *Orthoceras lamarcki* B., *Pleurotomaria gregaria* B., *Ribeiria calcifera* B.	250 to 300 feet.
[Cambrian.]	Potsdam	Light-yellow or white and light-colored, at times rusty-weathering sandstones with conglomerates at the base.	*Ophileta* sp. cf. *O. complanata* Van. *Orthoceras* sp., *Scolithus canadensis* Billings, *Climactichnites wilsoni*. Logan, *Protichnites septem-notatus* Owen.	About 200 feet.
Unconformity.				
Pre-Cambrian.				

[*Part of*] *synoptical table of geological formations about Montreal, Canada.*

System.	Formation.	Character of strata, etc.	Characteristic fossils.	Thickness.
Post-Devonian.	Eruptives.	Nepheline syenite, dolerite, trachyte, breccias, diorites, olivine diabase, dikes, etc.	None.	Forming conspicuous masses coming through the Ordovician plain.
[Unconformity.]				
Devonian.	Oriskany and Hamilton(?).	Fragments of light-gray impure fossiliferous limestone.	*Spirifer mesacostalis* Hall (teste Prof. H. S. Williams); *Spirifer cumberlandiæ*, *S. pennatus?*, *S. arenosus?*, etc.	Not ascertained. Isolated patches and fragments.
[Unconformity.]				

[Part of] synoptical table of geological formations about Montreal, Canada—Continued.

System.	Formation.	Character of strata, etc.	Characteristic fossils.	Thickness.
Silurian.	Lower Helderberg.	Light-gray impure subcrystalline and altered limestone, as small outliers.	*Leptæna rhomboidalis, Strophodonta varistriata, Strophonella punctulifera, Pentamerus (Sieberella) galeatus, Atrypa reticularis, Platyostoma depressum.*	Only a few feet thick, preserved near some protecting dike of eruptives.
[Unconformity.]				
Ordovician.	Lorraine	Black or dark-brown and buff-weathering shales and arenaceous beds and mudstones; fossiliferous.	*Favistella stellata, Orthograptus quadrimucronatus, Zygospira headi, Pterinea demissa, Byssonychia radiata, Clidophorus planulatus, Orthodesma parallelum, Protowarthia cancellata, Cyrtolites ornatus.*	From a few feet to 400 or 600 feet, and runs to the south and west.
	Utica	Dark-brown and black bituminous shales or pyroschists with impure limestone bands at base; fossiliferous.	*Leptograptus flaccidus, Leptobolus insignis, Schizocrania filosa, Cornulites immaturum, Endoceras proteriforme* v. *tenuistriatum, Triarthrus becki, Trocholites ammonius.*	Between 100 and 450 feet.
	Trenton	Dark-gray impure fossiliferous limestones and shales extensively quarried for building purposes; at times semicrystalline.	*Glyptocystites logani, Heterocrinus tenuis, Pachydictya acuta, Phylloporina trentonensis, Prasopora selwyni, Plectambonites sericea, Trematis montrealensis, Dalmanella testudinaria, Lingula riciniformis, Parastrophia hemiplicata, Rafinesquina alternata, Platystrophia lynx, Cyclonema montrealense, Trochonema umbilicatum, Conularia trentonensis, Trinucleus concentricus, Isotelus gigas, Calymene senaria.*	Between 400 and 500 feet.
	Black River	Light-gray weathering, dark-gray and black impure fossiliferous limestones; building stone.	*Tetradium fibratum, Columnaria halli, Stromatocerium rugosum, Helicotoma planulata, Cyrtodonta huronensis, Bathyurus extans.*	About 75 feet.
	Chazy	Light and dark gray semicrystalline impure fossiliferous limestone; useful for building purposes.	*Bolboporites americanus, Malocystites murchisoni, Blastoidocrinus carcharixdens, Camarotœchia plena, Hebertella borealis, Dinorthis platys, Bathyurus angelini.*	Between 150 and 200 feet.
	Calciferous	Dark-gray, buff and yellow weathering impure earthy and semicrystalline limestones, for the most part magnesian, and holding numerous crystals filling cavities; lower measures arenaceous.	*Orthisina grandæva* Billings, *Pleurotomaria calcifera* B., *P. canadensis* B., *Hormotoma anna* B., *Metoptoma simplex* B., *Orthoceras lamarcki* B., *Amphion salteri* B., *Bathyurus cybele* B., *Ribeiria calcifera* B., *Leperditia anna* B.	Between 200 and 250 feet.
	Potsdam	Light-yellow and rusty-weathering sandstones and conglomerates occasionally present at the base and along certain divisional planes of stratification.	*Scolithus canadensis* Bill., *Protichnites multinotatus* Owen, *P. lineatus* Owen, *P. octonotatus* Owen, *P. septem-notatus* Owen.	Between 200 and 300 feet.
[Unconformity.]				
[Pre-Cambrian.]				

[Part of] synoptical table of the geological formations about Quebec City, Quebec.

System.	Formation.	Character of strata, etc.	Characteristic fossils.	Thickness.
Ordovician.	Lorraine	Buff-weathering fine-grained magnesian and arenaceous shales and limestone bands.	*Orthograptus quadrimucronatus* H., *Diplograptus hudsonicus* Nicholson, *Ambonychia (Byssonychia) radiata* H., *Orthodesma parallelum* Hall, Trinucleus sp., Modiolopsis, and Bellerophon.	Several hundred feet thick. Between 700 and 900 feet (719 feet, Logan).
	Utica	For the most part dark-brown and buff-weathering or black bituminous shales and thin bands of limestone.	*Leptobolus insignis* Hall, *Schizocrania filosa* Hall, *Serpulites dissolutus* Bill., *Triarthrus becki* Green, *Asaphus latimarginatus* Hall (=*A. canadensis* Chapman).	Estimated at between 250 and 300 feet (318 feet, Logan).
	Trenton	Thin and evenly bedded fine-grained and light-gray compact limestones, with thin shaly bands interstratified. Marine and fossiliferous; used for building purposes.	*Prasopora selwyni* Nicholson, *Discina pelopea* Billings, *Plectambonites sericea* Sowerby, *Rafinesquina alternata* Conrad (Emmons), *R. deltoidea* Con., *Dalmanella testudinaria* Dalman, *Protowarthia cancellata* Hall, *Calymene senaria*, Conrad, *Trinucleus concentricus* Eaton.	About 300 feet to 400 feet. Only a few feet observed in various outcrops overlying the Archean.
	Black River	Heavier-bedded coarser-grained and in part dark-weathering impure semicrystalline limestones, fossiliferous.	*Ambonychia bellistriata* Hall, *Trochoceras halli* Foord, *Trochilina amii* Jones, *Illænus milleri* Billings.	About 75 feet exposed.
	Quebec	Hard compact cherty and calcareous bands, dark-brown or black, more or less thick beds of bituminous shales, limestone beds, and evenly bedded conglomerates and bands holding arenaceous material. Fossiliferous throughout; much disturbed and faulted, folded, and considerably altered, slickensided, etc.	*Diplograptus angustifolius* Lapw., *Climacograptus bicornis* Hall, *Dicranograptus ramosus* H., *Dicellograptus anceps*, *Paterula amii* Schuchert, *Corynoides calycularis* Nicholson, *Shumardia granulosa?* Billings, *Bathyurus caudatus* B., *Aeglina redeviva* or n. sp., *Remopleurides? schlotheimi* B., *Primitia logani* Jones, *Aparchites mundulus* Jones.	Several hundred feet in thickness. The precise figures not yet ascertained.
	Levis	Dark-gray and brown and black carbonaceous shales with limestone beds and conglomerate bands, also light yellow colored dolomites. Fossiliferous throughout. The light yellowish gray limestone often semicrystalline, much folded and faulted and ofttimes slickensided.	*Tetragraptus quadribrachiatus* Hall, *T. serra* Brongniart (= *T. bryonoides* Hall), *T. bigsbyi* H., *T. approximatus* Nicholson, *Clonograptus flexilis* Hall, *Dichograptus octobrachiatus* H., *Phyllograptus typus* Hall, *Goniograptus selwyni* Ami, *Trigongraptus ensiformis* H., *Diplograptus dentatus* Bgt. (=*D. pritiniformis* H.), *Holograptus amii* Lapw. (MS.), *Dictyograptus dawsoni* (=*D. delicatula* Dn.), *Lingula quebecensis* Billings, *Elkania desiderata* Bill., *Serpulites westoni* n. sp., *Shumardia granulosa* Billings.	Several hundred feet in thickness. The precise thickness not as yet ascertained (about 1,400 feet).

[Part of] synoptical table of the geological formations about Quebec City, Quebec—Continued.

System.	Formation.	Character of strata, etc.	Characteristic fossils.	Thickness.
Cambrian.	Sillery.	Red, green, and black shales, the latter graptolitic at times, also coarse, gritty, evenly bedded sandstones and conglomerates occurring as lenticular masses of different sizes in the shales. Beds for the most part tilted at high angle and folded, faulted, and contorted. Fossil organic remains scarce.	*Protospongia tetranema* Dawson, *Lingula quebecensis* Bill. or n. sp., *Linnarssonia pretiosa* Billings (the typical fossil), Phyllograptus sp.	Probably several thousand feet in its greatest development.
[Unconformity.]				
[Pre-Cambrian.]				

The classic descriptions of these Ordovician terranes by Logan [544a] will be found in his comprehensive monograph of 1863. An interesting discussion of Logan's views on the stratigraphy and structure of this region is given by J. W. Dawson.[264] Selwyn[726] in 1884 prepared a general description, in which he stated his understanding of the stratigraphy and structure of the region.

The latest comprehensive and detailed account of the Ordovician of the St. Lawrence Valley away from the great cities is by Ells,[313d] as follows:

The newest rocks of the Cambro-Silurian found in this area are situated to the west of the great St. Lawrence and Champlain fault, between it and the River St. Lawrence. They are evidently the southwestern extension of the Utica-Lorraine beds which occur along the river on both sides between Quebec and Three Rivers. They are well characterized by fossils, which are found at several places and of which very considerable collections have been made, as at St. Hyacinthe and St. Hughes, on the Yamaska River, Chambly Basin, and St. Jean Baptiste village (the latter on the River Des Hurons, which joins the Richelieu a short distance above Mount St. Hilaire), and at Chambly. Rock exposures are, however, rare throughout this entire area. Farther north, on the lower part of the Becancour, opposite Three Rivers, a small collection of fossils was made in 1888, which showed the presence of the typical Lorraine shale formation at this place and served to indicate the apparently uniform extension of these rocks throughout this area.

The rocks of the Lorraine formation differ somewhat in character from those of Utica. They are more sandy in texture, and are generally of a grayish color or have frequent beds of gray sandy shales, which sometimes pass into sandstone layers. The Utica, on the other hand, is generally characterized by the presence of brown or brownish-black bituminous shales, with occasional hard bands of dolomitic limestone, but gray beds like those of the Lorraine are rarely seen.

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The valley of the St. Lawrence, from Lake St. Louis almost to Quebec City and for some miles on either side of the river, is occupied by strata of the Utica and Lorraine formations, between which the line of separation at most points is difficult to ascertain, owing to the great mantle of clay so widely distributed throughout this area. This region was one of the first studied by the Geological Survey. The strata exposed are nearly horizontal, disturbances being few and due to intrusive masses of doleritic matter. The rocks where exposed abound in fossils, and their true horizons can therefore be readily determined. The doleritic rocks which intersect these strata form mountain masses, sometimes of large extent, which present conspicuous features in the otherwise monotonously level landscape.

These rocks, both the fossiliferous sediments and the intrusive masses, have been well described in the earlier reports of the Survey.[a] In the first of these, viz, that for 1847, the characters of the rocks visible on the line of section between Montreal and Lake Memphremagog are so clearly stated that but little remains to be said on that subject.

As, however, the relations of certain groups, more particularly the crystalline schists and the red and green slates and sandstones of the Upper Cambrian (Sillery) were not at that time clearly understood, these will call for some remarks on a subsequent page. The general horizontality of the measures, except where this is disturbed by the presence of the intrusive masses or dikes, is maintained almost to the vicinity of the great St. Lawrence and Champlain fault, which, as already described in a former report, extends from the city of Quebec to the foot of the Missisquoi Bay. The fault brings beds of the Trenton formation against the Calciferous and Chazy at Phillipsburg and Stanbridge, and its existence is very evident wherever rock exposures are visible along its line, but as there is a heavy covering of drift over a considerable portion of the country which it traverses, its delineation on the map between exposed points must of necessity be largely conjectural.

This great fault marks one of the important geological features of the district under discussion, but the amount of displacement occasioned thereby is presumably no greater than that caused by other heavy faults which traverse the country in a northeast to southwest direction and which are seen as far east as Lake Memphremagog. Not only is this entire area greatly affected by these faults, but extensive crumplings of strata occurred, which have closely involved the rocks of the older or crystalline-schist area with the most recent sediments of the district. Narrow areas of the Cambro-Silurian are seen, which contain fossils but are apparently interstratified with the schists; while in some places the formations are so completely overturned that the fossiliferous Devonian now underlies the Cambro-Silurian.

The rocks of the Trenton formation, which underlie the Utica and Hudson River [Normanskill horizon—Ami] (Lorraine) just described, have also a wide distribution. In the earlier reports of the Geological Survey[b] certain portions of these rocks were included in the Upper Silurian; these comprise both the black graphitic limestones and associated clay slates.

Lists of fossils of these Ordovician terranes are given by Ami in appendices to Ells's reports on the areas covered by the Pembroke,[26] Perth,[23a] Montreal,[14] and Grenville[19] sheets.

In that part of the St. Lawrence Valley which lies east of the St. Lawrence-Champlain fault Ordovician rocks occur on both sides of the Sutton Mountain anticline. Omitting the Sillery and Levis (described in Chapter III, pp. 131–134), we have here to deal with the limestones and shales of Phillipsburg, Franklin, and Bedford, which range along the northwestern base of Sutton Mountain, and the Magog shales, which occur southeast of that anticline in the basin of Lake Memphremagog; also with the Quebec formation of Citadel Hill in the city of Quebec and the Ordovician strata which form islands and points along the south shore of the lower St. Lawrence.

The limestones and shales of Phillipsburg and Bedford occur between the St. Lawrence-Champlain thrust fault and Sutton Mountain. The thrust fault strikes Lake Champlain at its northeastern extremity, Missisquoi Bay, passing through the village of Phillipsburg. East of it occur rocks assigned by Ells[313g] to the "Calciferous" and Chazy. Logan's section of the "Calciferous" (divisions A and B) has been given in Chapter III (p. 134). The strata are gray to black dolomites and limestones, which according to Ells "shade gradually into the Chazy in the upper part,

[a] Logan, W. E., Rept. Progress Geol. Survey Canada, 1847–48, pp. 10–22. Hunt, T. S., idem, 1858, pp. 171–178. Logan, W. E., Geology of Canada, 1863, pp. 205–210.

[b] Logan, W. E., Geology of Canada, 1863, p. 434.

so that the point at which the exact line of division between the two formations occurs is scarcely indicated." Above division B Logan [544x] gives C and D, as quoted below, and according to Ami [14b] certain fossils (Ecculiomphali) cited from division C suggest the "Calciferous." The line between "Calciferous" and Chazy, which Ells placed in the upper part of division B but found obscure, may thus possibly lie at a higher horizon.

Logan's section of divisions C and D runs as follows, from the base upward:

[Division] C.

	Feet.
1. Black and dark-gray compact limestones, weathering lead-gray, with a few bands of dove-gray. The beds are all massive and afford abundance of a few species of Testaceæ, the whole of which appear to have the peculiarities of being large sized and thick shelled and occurring in numerous isolated patches, which vary in diameter from about 3 to 10 feet. The fossils are several undescribed species of Murchisonia and Pleurotomaria, *Ecculiomphalus canadensis*, *E. intortus*, *E. spiralis*, several undescribed species of Ophileta, *Maclurea ponderosa*, several undescribed species of Orthoceras, and one of Nautilus. Toward the base *Matlurea ponderosa* seems to be somewhat smaller than in the upper part of the deposit, and toward the top one or two beds appear to be of a partially conglomerate character...	150
2. Black slates, or possibly thin-bedded black limestones, with a few thicker beds toward the top; the mass is altogether very imperfectly seen..	170
	320

[Division] D.

1. Black limestone conglomerates, composed chiefly of the ruins of the thick-bedded limestones of division C. The inclosed masses vary in size from pieces of an inch in diameter to blocks containing 50 and 60 cubic feet and are cemented together by a calcareo-magnesian paste. Of this, however, from the closeness with which the masses are packed together, there is but a very small quantity. The limestones are generally close grained and black or dark gray in color, but there are mingled with them a few scattered blocks of a light-colored yellow-weathering dolomite, some of them a foot in diameter. Many of the masses of limestone contain fossils, and the species are almost wholly confined to those already stated as characterizing the parent beds C 1. There appear to be at least two principal bands of this conglomerate, each varying in thickness in different parts from about 50 to 100 feet. There is an interval between them of from 100 to 150 feet, occupied by black slates holding rounded masses of limestone, which convert parts of the mass, varying in thickness from 10 to 20 feet, into slaty conglomerates. In some parts either the interval between the main two bands of conglomerate increases considerably or there is a third band with similar slates, intervening between it and the second. The whole is contained in a thickness of from 250 to..	300
2. Black and greenish argillaceous slates, probably interstratified with occasional thin calcareous bands and thin lenticular patches of limestone conglomerate, as well as more important bands of yellow-weathering dolomitic slates. The whole is terminated by a band of black limestone conglomerate similar in character and thickness (from 50 to 100 feet) to those already mentioned and containing *Maclurea ponderosa* in one of the few places in which the band has been seen. This whole mass of strata is very imperfectly exposed, and much uncertainty exists as to its true general character. Its thickness may be from 750 to......	1,000
3. Gray and black striped slates, some parts of which are calcareous and weather slightly brownish. They are interstratified with occasional thin beds of black limestone, weathering lead-gray, as well as many strong and solid beds of brown-weathering magnesian limestone and brown-weathering dolomitic slates. Some of the latter are marked by an abundance of fucoids resembling *Buthotrephis flexuosa* of Emmons. Occasional beds of sandstone, from 1 to 3 feet in thickness, are met with. About the middle of the mass there has in one place been observed a bed of limestone conglomerate from 5 to 10 feet thick, and other similar ones may occur in different parts of the vertical thickness............	1,500
	2,800

In commenting on this section E. O. Ulrich states that division C is probably Beekmantown and division D suggests the Rysedorph conglomerate of the New York State Survey reports, although D 1 is probably older.

Following this description Logan gives a section on the international boundary showing two synclines, modified by thrust faults.

The equivalents of the above-described strata near Phillipsburg when traced south into Vermont are known as the Fort Cassin beds, according to Whitfield.[927] (See K–L 18, pp. 126–127.) Their extension northeastward along the northwest side of the Sutton Mountain anticline is minutely discussed by Ells.[313f] The fossils which have been collected at various times for the Canadian Survey from these rocks are reported by Ami[14c] under the heading "Phillipsburg series."

Southeast of Sutton Mountain Ordovician strata again occupy a large part of the section at least as far east as the international boundary. Their extent eastward in Maine is obscured by their resemblance to the soft slates of the Silurian, by the featureless drift and forest covered character of the country, and by intrusions of igneous rocks. (See Chapter VII, p. 350.) The strata identified in Canada are known as the Magog shales and classed as probably of Trenton and Utica age. Ulrich believes the Magog to be pre-Utica. They contain graptolites which are described as follows by Lapworth.[522] (See also a paper by Gurley.[388])

Matrix, soft, thin-bedded and flaking silvery shales, greenish gray in color (originally black), apparently altered and spotted by contact metamorphism.

1. Dicranograptus ramosus Hall.
2. Diplograptus angustifolius Hall.
3. Diplograptus foliaceus Murchison (=pristis, Hall).
4. Diplograptus perexcavatus Lapworth.
5. Climacograptus bicornis Hall.
6. Climacograptus cœlatus Lapworth.

The fossils are all in a most miserable state of preservation, but all the forms named above are easily recognizable. These fix the age of the strata as Utica or Marsouin or Normans Kill, but somewhat higher in the series than the typical Normans Kill beds. They may safely be termed Upper Llandeilo or Lower Bala and placed generally above or about the horizon of the Trenton or Utica rocks of the western area.

The Quebec formation,[a] distinguished by Ami,[12a] consists of dark bituminous shales with hard calcareous bands, limestones, and conglomerates, several hundred feet thick. The conglomerate forms Citadel Hill and has been described by Weston,[887] who quotes Ami as follows:

Alongside and up Mountain Street a bold cliff of conglomerate occurs, containing large bowlders, embedded in a shaly and calcareo-argillaceous paste with an admixture of quartz-grains.

According to Ami[12,13] and Ford[345] the fauna by which the Quebec formation is characterized comprises Black River and Trenton types and possibly upper Chazy forms.

Not only in the vicinity of Quebec, but thence along the lower St. Lawrence (Island of Orleans, St. Joseph de Levis, St. Simon, Riviere de Loup, Bic, etc.) there occur Ordovician shales, presumably of several horizons, which locally include fragments, bowlders, or pebbles of fossiliferous limestones of earlier Ordovician and Cambrian formations.

Logan[544i] describes the rocks in his account of the "Quebec group." Many of the occurrences probably represent rather the equivalents of the Sillery and Levis than those of the Quebec formation, as restricted by Ami.

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[a] See table of formations about Quebec, quoted on pp. 202–203.

L 19. CARLETON AND YORK COUNTIES, NEW BRUNSWICK.

The slate belt that extends from the boundary of Maine northeastward to Chaleur Bay is mapped as Cambrian and Ordovician, without distinction of the middle and later Ordovician, which, however, occur there. The lithology of the belt, according to Bailey,[44] is monotonous, yet the rocks range in age from Cambrian to upper Silurian. The sequence is not complete, the base of the Silurian being marked by a distinct basal conglomerate containing the older Paleozoic rocks as cobbles, but it is not known how much of Ordovician time is represented by the unconformity. Bailey [46] names the few localities at which the fossils have been found and Ami[25] describes those from Tete a Gauche River which are of Ordovician age. The latter describes "Fossils from the black carbonaceous and graptolitic shales from near the railway bridge on the Tete a Gauche River, near Bathurst, Gloucester County, New Brunswick," and names them as follows:

Diplograptus foliaceus Murchison.
Diplograptus truncatus Lapworth.
?Lasiograptus sp. indt.
Climacograptus bicornis Hall.
Cryptograptus tricornis Carruthers.
Dicellograptus sextans Hall.
Dicellograptus anceps Nicholson.
Orthograptus quadrimucronatus Hall.
?Didymograptus superstes Hall.
Leptobolus sp.

The above assemblage of forms suggests at once an Ordovician fauna belonging to one of those zones of graptolites occurring along the St. Lawrence and the Hudson rivers. Similar forms from rocks of presumably the same age have also been found in Penobscot County, Maine.[a]

These black and at times pyritiferous shales appear to be synchronous or homotaxial with the shales of Normans Kill, near Albany, N. Y., of the city of Quebec, of the north shore of the Island of Orleans, of the Marsouin River, and of numerous other localities in the Gaspe Peninsula. They find their equivalent in Europe in the Llandeilo rocks of Wales, the Moffatt shales of Scotland, and the County Down shales of Ireland.

M 11. BEAVERFOOT RANGE, CANADIAN ROCKY MOUNTAINS.

Graptolitic shales are described by McConnell[559d] as occurring between the Castle Mountain group (Cambrian and Ordovician) and the "Halysites beds," into both of which they appear to graduate in sections along the Canadian Pacific Railway, east of Columbia River. They are hard black fissile slates, 1,500 feet thick, which in some sections alternate with thin beds of limestone and here and there, near the top, with quartzites and dolomites. Lapworth, reporting on the graptolites, identified Didymograptus sp. nov., allied to *Didymograptus euodus* Lapworth, *Glossograptus ciliatus* Emmons, *G. spinulosus* Hall sp., *Cryptograptus tricornis* Carr sp. = *C. marcidus* Hall sp., *Diplograptus angustifolius* Hall, *D. rugosus* Emmons, *Climatograptus cœlatus* Lapworth, and doubtful species of Phyllograptus or Lasiograptus. These forms are referred to "the age of the Utica slate or at any rate to the Trenton-Utica fauna of the United States and Canada. The association of forms is just such as occurs in the Llandeilo (lower and middle) of Britain, and some forms are common to both sides of the Atlantic."

[a] Am. Jour. Sci., 3d ser., vol. 22, 1881, p. 434; vol. 40, 1890, p. 153.

The lithologic and faunal similarities of this terrane to those of Dease River, in latitude 60° north, and of the Alaska Range indicates the persistence of like geographic conditions along the trend of the Cordillera in middle and late Ordovician time. Ulrich says:

The graptolite faunas in the Cordilleran basins west of the Rockies from Nevada to Alaska seem to belong to nearly the same horizon. Its age appears to be intermediate between the Levis-Tetragraptus zone and the Normans Kill of the Atlantic side.

M 19-20. GASPE PENINSULA.

Along the south shore of the St. Lawrence, according to Logan,[544j] are black shales and gray calcareous sandstones of middle and possibly later Ordovician age. They have been described by Dawson [267] as the Marsouin River formation, and the horizon of the graptolitic fauna which they contain is discussed by Lapworth,[521] who states, under the heading "Griffin Point or Marsouin River zone:"

The most characteristic forms from the zone are—

Didymograptus sagittarius (Hall non Hisinger).
Cœnograptus gracilis Hall.
Dicellograptus sextans Hall.
Lasiograptus mucronatus Hall.
Climacograptus antiquus Lapworth.
Diplograptus whitfieldi Hall.

So far as known, these are peculiar to this zone, and the presence of a single one of these species is sufficient to settle the age of the rock in Great Britain, and in all likelihood in America. With these peculiar forms, however, are associated others which have a much longer vertical range and unite this zone to the one which follows it in order of time. These species of long range are—

Dicranograptus ramosus Hall.
Glossograptus ciliatus Emmons.
Diplograptus putillus Hall.
Climacograptus scharenbergi Lapworth.

They all pass up into the British zone next above the Cœnograptus zone, together with the following species, which range up through at least three complete zones:

Diplograptus foliaceus Murchison.
Climacograptus bicornis Hall.

This special Marsouin zone, now under consideration, has long been recognized by geologists upon the continent of America. Its fossils were described many years ago by Prof. J. Hall, in his "Paleontology of New York," from the dark shales of Normans Kill, near Albany, in the valley of the Hudson River. Hall also referred to the detection of the Normans Kill fossils on Marsouin River by Sir William Logan and the Canadian Survey; but the discovery of the existence of rocks containing the Normans Kill fossils as far down as Griffin Cove and between the Marsouin and Quebec, as demonstrated by the present collection, is wholly due to those officers of the Geological Survey of Canada who have studied the district since the retirement of Sir W. Logan. There can be no question of the general identity of this Griffin Cove rock and the Marsouin Cœnograptus zone with that of the Normans Kill of the Hudson River valley.

Lapworth further divides the fauna, which he calls the Trentonian, Marsouin River, or Normans Kill fauna, into two subfaunas, namely:

Subfauna A, the Cœnograptus zone of Griffin Cove and the Marsouin River, answering to the Middle Llandeilo beds of Great Britain to the Glenkiln beds of Scotland, etc.

Subfauna B, the Cove Fields and Orleans subfauna, apparently destitute of *Cœnograptus gracilis* and answering to the highest Llandeilo or Lowest Caradoc beds of England.

The last of these subfaunas shows evidence of a transition into the Utica-Lorraine graptolitic fauna of the Mohawk Valley, New York, and of Lake St. John, Canada.

Ulrich states that the fauna may be called Trentonian only if that term is used as a synonym of Mohawkian and that the so-called Normans Kill is as old as the Black River.

The stratigraphic succession and structural relations are involved in the overthrusts of the sedimentary strata, and the distribution is probably not so simple as it appears even on the detailed maps. The horizon of the Marsouin River formation is repeatedly referred to by Ells [310a, 311b, 313e] in tracing the sweep of Ordovician strata through the "Eastern Townships" of Quebec, the similarity of the rocks and graptolites indicating the continuity of the zone of deposition as far as the locality of the Magog shales on Lake Memphremagog. In Vermont and New Hampshire the terrane is probably represented in the metamorphosed Paleozoic rocks.

M 20. MINGAN AND ANTICOSTI ISLANDS.

Ordovician strata are exposed along the north coast of Anticosti Island, dipping gently southward under the Anticosti group (Silurian). The lowest strata seen at the base of the cliffs are assigned by Logan to the "Hudson River" [Richmond] formation. Farther north, across the strait, the Mingan Islands consist of rocks referred to the "Calciferous" (Beekmantown) and Chazy, with possibly part of the "Birdseye" (Lowville) and Black River formations. The closely adjacent coast of Quebec is "Laurentian." Thus it appears that the middle Ordovician strata in this region overlap the earlier Paleozoic (pre-Beekmantown) rocks and extend from the north margin of the Gulf of St. Lawrence southward beneath its waters to Anticosti, where the overlying upper Ordovician and Silurian are exposed.

Regarding the Chazy of the Mingan Islands, Logan [544b] says:

At the Mingan Islands the Chazy formation bears lithological characters somewhat different from those which have been given above. The lowest part seen of the deposit occurs in the bay above Clear Water Point, and the following is a section of the strata in ascending order:

	Feet.
Reddish cream-colored compact limestone with a conchoidal fracture, weathering pale yellow	1
Greenish and brownish-black shale	1
Reddish cream-colored limestone as before, in beds of from 1 to 2 inches to a foot, interstratified with greenish shale in beds of about the same thickness	28
Greenish shale with *Rhynchonella orientalis* (which is a variety of *R. plena*) in great abundance	3
Gray granular limestone with false bedding, holding comminuted fragments of encrinites and other organic remains, including *Bolboporites americanus*, *Rhynchonella orientalis*, a few of *Camerella longirostrata*, and other species	13
Gray nodular limestone with *Columnaria parva*, *Stenopora adherens*, *Fenestella incepta*, *Orthis piger*, *Strophomena incrassata*, *Ctenodonta nasuta*, *Nautilus jason*, *Amphion canadensis*, *Harpes antiquatus*, *Illænus globosus*	20
Gray magnesian limestone, with *Murchisonia aspera*, *Maclurea atlantica*, *Orthoceras multicameratum*, *O. bilineatum*, *O. natator*, *O. maro*, *O. antenor*, *O. minganese*, *O. shumardi*, *Illænus bayfieldi*, and other fossils	12
	78

Apparently above these strata but not in immediate sequence Logan lists gray and yellow limestone and green shale in thin beds to a thickness of 171 feet, almost without fossils, which he, however, regards as Chazy and possibly not including the top of that terrane. Ulrich suggests that these strata may be Lowville. Above them occurs a yellowish-white pure limestone, 30 feet thick, carrying *Maclurea logani*, which Logan[544c] refers to the "Birdseye" (Lowville) and Black River.

A detailed section of the strata exposed above the beach at the west end of Anticosti is given by Logan,[544f] with much refinement of distinction among the successive beds and lists of fossils found in each. Limestones and argillaceous shales in thin layers make up most of the thickness noted (959 feet). Gray limestone, greenish shale, and a few layers of limestone conglomerate alternate in the lower 229 feet; bluish and reddish-gray limestone separated by thin greenish shale partings and conglomerates succeed with slight variations throughout the upper 730 feet.

The Ordovician here passes without notable lithologic change or break into the Silurian, and a number of fossils are common to strata above and below the assumed plane of division, yet numerically the extinction of species is more marked than their persistence. Billings [82] states the facts as follows:

In the Lower Silurian rocks of Anticosti there have been collected 121 species of fossils, of which the proportionally large number of 85 have been described in this and other publications of the Survey as new forms. The remaining 36 are mostly of the common and widely distributed species of the Lower Silurian of Canada West, New York, and other countries. They are the following:

Stenopora fibrosa.
S. mammulata.
S. papillata.
S. explanata.
Halysites catenulatus.
Lingula quadrata.
Trematis ottawaensis.
Strophomena imbrex.
S. subtenta.
S. planumbona.
S. alternata.
Leptæna sericea.
Orthis testudinaria.
O. subquadrata.
O. lynx.
Rhynchonella capax.
R. recurvirostra.
Ambonychia radiata.
Subulites richardsoni.
Trochonema umnilicata.
Pleurotomaria americana.
P. helena.
P. subconica.
Murchisonia gracilis.
M. ventricosa.
Bellerophon acuta.
B. bilobatus.
Pterotheca transversa.
Oncoceras constrictum.
Asaphus platycephalus.
A. megistos.
Dalmanites callicephalus.
Cheirurus pleurexanthemus.
Harpes ottawaensis.
Calymene blumenbachi.
Leperditia canadensis.

There are no species which are exclusively Upper Silurian; the aspect of the whole fauna is eminently Lower Silurian. The rocks are very fossiliferous throughout, but on approaching the dividing line between this group and division 1 of the Anticosti group, which immediately succeeds, not less than 80 out of the 121 species suddenly disappear and are seen no more. It is evident, therefore, that there is here a break of considerable importance, probably in some way connected with the great gap that occurs between the Hudson River and Clinton formations in Canada West and New York. Of the 41 species that pass this break, 30 appear to have become extinct during the period of division 1; at least they have not been detected in division 2. Of the remaining 11 species, 7 pass upward into division 3 and 6 into division 4.

Ulrich comments to the effect that according to present understanding of the Anticosti problem, none of the beds in Logan's section is older than Richmond.

M 21. NEWFOUNDLAND, NORTHERN PENINSULA.

In 1863 Logan [5441] stated the observed sections of the strata along the western and northern coasts of the great northern peninsula of Newfoundland and distinguished divisions which he numbered from 1 to 16 or A to Q. Some of the fossils listed by him are grouped in associations which indicate that there was confusion, either because they became mixed in collecting or through the occurrence of fossils in conglomerate pebbles or on account of the presence of thrust faults; but no other systematic discussions than those by Logan and Billings are available. Divisions A to H inclusive have been discussed in Chapter III (pp. 149–153). Divisions I, K, L, and M are possibly equivalent to the upper Chazy, Black River, and Trenton of the epicontinental sea that spread to New York, though many typical species of those faunas are absent and Billings was in doubt. Divisions N, O, and P, described by Logan as higher in the series, are classed by Billings as being faunally related to the Sillery and Levis and apparently belong lower in the Ordovician.

Ulrich says (comments on manuscript):

Respecting the Newfoundland section I fail to see reasons for regarding division I and possibly up to and including division N as above the Beekmantown. Part of this series is almost certainly of Beekmantown age, but other parts seem no less certainly of later age. The Levis graptolites in division N are, I am convinced, of early Beekmantown age. Not to enter into detail, it may suffice to say that an analysis of the faunas suggests ages ranging from early Beekmantown to late Black River. As the oldest of these faunas occurs in the uppermost division (N), the succession of the others is not regular; the evidence indicates misinterpretation of the structure, with overthrusting and overturn instead of the regular and unbroken sequence described by Logan.

Logan's section of divisions I, K, L, and M is as follows:

I.

	Feet.
1. Light yellowish gray mottled and subcrystalline magnesian limestone, with geodes of calc spar. The limestone is divided into beds of from 6 inches to 1 foot and shows occasional fossils, the only recognizable species being *Maclurea matutina*	65
2. Light yellowish gray mottled magnesian limestone as before, interstratified with grayish-black limestone in beds of from 3 inches to 1 foot. The magnesian beds contain *Maclurea matutina*	70
	135

K.

1. Light-gray, subcrystalline limestone, with grayish-black limestone, both in beds of from 2 to 6 inches, and associated with a few bands of grayish-white dolomite, from 6 to 9 inches thick, the whole interstratified at intervals of from 10 to 20 feet with black and grayish-green shales. The light-gray limestone and whitish dolomite are fossiliferous, containing the genera Orthis, Ctenodonta, Ophileta, Maclurea, Pleurotomaria, Murchisonia, and Orthoceras. The described species are *Orthis electra*, *Maclurea matutina*, and *Orthoceras piscator*.	100

L.

1. Grayish-white dolomite and greenish-gray compact limestone, both in beds of from 2 to 6 inches thick, interstratified with about 3 per cent of black and grayish-green shale, all without observed fossils	104
2. Light reddish-gray magnesian limestone, in beds varying from 15 inches to 2 feet in thickness. The rock breaks from the cliff in which it is exposed, in rectangular blocks of several feet long and wide, and would make an excellent building stone. No fossils were observed.	16
3. Brownish-gray hard limestone, in beds of from 6 inches to 2 feet; fossils occur at the base, among which are the genera Stenopora, Orthis, Murchisonia, Asaphus, and Leperditia	65
4. Reddish-gray magnesian limestone, in beds of from 2 to 6 inches, without observed fossils	6
	191

M.

	Feet.
1. Brownish-gray limestone, in beds varying in thickness from 6 inches to 6 or 7 feet, interstratified at distant intervals with reddish-gray dolomite in beds of from 3 to 9 inches, which constitute 1 or 2 per cent of the whole. Both the limestone and the dolomite are fossiliferous throughout; the organic forms, however, are obscure in the whole, with the exception of about a foot of the limestone at the base and 6 feet at the top, including a bed of the dolomite, in the whole of which the fossils are silicified. The genera at the base are Eospongia, Orthis, Ophileta, Pleurotomaria, Murchisonia, Orthoceras, and Asaphus. At the top the same genera occur, but there is a greater number of species, and it is probable that the fossils of these two parts represent those of the whole mass	350
In the fossiliferous beds of divisions K and L, and in part 1 of M, there are several species of each genus, and the same species seem to range through the whole. The described species are *Orthis electra*, *Maclurea matutina*, and *Orthoceras piscator;* but the chief part of the species of the remaining gastropods and cephalopods are so closely allied to some of the common forms of the Trenton group that it scarcely appears doubtful that they are the same. The most striking resemblances are to *Orthoceras bigsbyi* and *O. allumettense* of the Birdseye and Black River, and to *Murchisonia gracilis*, *M. bellicincta*, and *M. perangulata* of the Trenton formation.	
2. Bluish-gray limestone, in beds varying from 6 inches to 10 feet in thickness, the thicker beds being made up of layers of 1 or 2 inches, distinguishable in section by slight differences in color but without any tendency to separate. Some of the beds are nodular and crumble under atmospheric influences. Fossils are abundant in all the beds but are not readily separated. They consist chiefly of *Stenopora fibrosa*, *Orthis* like *O. platys*, *Rhynchonella* allied to *R. plena*, *Camerella varians*, new species of Maclurea, and Orthoceras; with *O. piscator*, *O. allumettense?*, *O. bigsbyi?*, Amphion, Ampyx, Asaphus, Illænus, and Leperditia	308
	1,349

Commenting on the above section, Ulrich suggests upper Beekmantown for division I and middle Chazy for division M.

Billings[81a] discusses in the following terms the taxonomic relations of the Ordovician strata of Newfoundland which constitute Logan's divisions I, K, L, and M.:

These four divisions consist of 235 feet of magnesian limestones at the base, above which we have 844 feet of light bluish-gray limestones, making in all a thickness of 1,084 feet. Only 37 species of fossils have been collected in this series of beds; and of these, nine species are found in division H below, while ten of them pass upward into division N next above. Three of the species (*Stromatopora compacta*, *Orthoceras allumettense*, and *Asaphus canalis*) occur in Canada, the first two in the Chazy and Black River and the last in the Calciferous and Chazy. The following are closely allied to Black River and Trenton species:

Ctenodonta angela, allied to C. contracta, B. R.
Subulites daphne, allied to S. parvulus, B. R.
Murchisonia simulatrix, allied to M. gracilis, B. R. and Tr.
Murchisonia cicelia, allied to M. perangulata, B. R.
Murchisonia sororcula, allied to M. perangulata, B. R.
Murchisonia augustina, allied to M. bellicincta, Tr.
Orthoceras hæsitans, allied to O. bigsbyi, B. R.

The occurrence of great numbers of individuals of these species in a silicified condition and weathered out in bold relief gives to the slabs of limestone an aspect so remarkably like that of the well-known specimens from Pauquettes Rapids that at first sight one might be well led to say, This is surely the Black River limestone. But on careful comparison of perfect specimens it is seen that notwithstanding the resemblance none of the species are strictly identical. All present such differences that after a study of collections from both localities they can be separated if mixed up together without their labels. Even *O. allumettense*, which I have identified, differs by being much larger than any specimens that have been seen in the original localities.

If the succession were the same here as it is in Canada and New York, we ought to have the Chazy formation represented in these four divisions. But no one acquainted with the peculiar and strongly featured fauna of that formation could recognize it in this collection. Three of the species are, indeed, Chazy fossils, but then they are not characteristic forms. The typical and leading species which always go together in great numbers and in one compact army, as it were, in every exposure of the true Chazy, are totally absent.[a]

The Lamellibranchiata, Gastropoda, and Cephalopoda of these beds have, so far as the genera Ctenodonta, Subulites, Pleurotomaria, and Orthoceras are concerned, an aspect very like that presented by the same genera in the Black River and Trenton formation. But species similar to most of those above compared have a great range and are found in all the different groups of rocks up to the Devonian. Their occurrence here is not, in my opinion, sufficient to counterbalance the negative fact that (excepting those in question) not a vestige of any one of the species of the vast fauna of the Black River and Trenton has been detected. *Tetradium fibratum*, *Columnaria alveolata*, *Leptæna sericea*, *Strophomera alternata*, *Orthis testudinaria*, *Calymene blumenbachi*, and *Asaphus platycephalus* are sure to be found in every collection of any considerable extent from these two formations. If they occurred here as abundantly and persistently as they do in Canada and New York, it would be difficult to give any reason why these four divisions should not be regarded as the equivalents of the Black River and Trenton. But not one fragment of anything which could by any possibility be referred to any one of these species can be seen in this collection. A piece of red limestone was found at Bay St. Paul which is full of *L. sericea*, but it was a loose and worn fragment, lithologically differed from any of the strata in question. Judging from this specimen I should say that the Trenton may possibly occur somewhere near, but we can not refer, on any paleontological ground, the series of strata constituting divisions I, K, L, M to that formation.

Following Logan's section[544z] we note in ascending order the divisions N, O, P, and Q, occurring apparently above the divisions I, K, L, and M. The numbers 13, 14, 15, and 16 are those by which he first designated the separate divisions.

[N.]

	Feet.
1. Blackish-gray nodular fossiliferous limestone, in beds of from 1 to 3 inches thick, becoming bituminous toward the top. The fossils are Orthis, Strophomena, Rhynchonella allied to *R. plena*, a new species of Camerella, *Orthoceras piscator*, *O. allumettense?*, Amphion, Asaphus, *Holometopus angelini*, Illænus, and Leperditia	81
2. Black bituminous limestones, in beds of from 1 to 3 inches thick, interstratified with fine brittle black bituminous shale in layers varying from a quarter of an inch to 3 inches. The prevailing fossils are *Stenopora fibrosa*, Lingula allied to *L. philomela*, Orthis, Strophomena, Rhynchonella allied to *R. plena*, a new species of Camerella, with *C. varians*, Orthoceras, Agnostus, Amphion, Ampyx, Asaphus, *Endymion meeki*, *Holometopus angelini*, Illænus, *Nileus scrutator*, and Leperditia	174
3. Black bituminous shale, with Graptolithus, Lingula, Orthoceras, and Paradoxides or Olenellus	22
	277

[O.]

14. Gray calcareous sandstones, generally fine grained; in beds of from 6 inches to 2 feet, interstratified with black and greenish shales, which predominate toward the top. The sandstones are sometimes of a conglomerate character and include pebbles of white quartz and black limestone, varying in diameter from the eighth of an inch to 2 inches, with small fragments of red and black jasper and flat pieces of black and green shale. The sandstones and the shales are aggregated in masses varying from 6 up to 60 feet in thickness. No fossils have been met with in this rock	700

[a] Ulrich takes exception to the statement of Billings in regard to the Chazy and says that he (Billings) "was not well acquainted with the lower and middle Chazy faunas. He knew the upper very well, but this is very different from the two lower faunas. These middle and lower Chazy faunas contain species such as mentioned by Billings, greatly like 'Black River' forms. (See Raymond's papers.)"

[P.]

Feet.

15. Gray, drab, and whitish limestone conglomerates, interstratified in the lower part, with bands of black and greenish shale from 40 to 100 feet thick; and associated with black limestone holding layers of black chert from 1 to 3 inches thick. Graptolites occur in the black limestones and fragments of trilobites in the chert. In the upper part the conglomerate is more massive, great thicknesses showing no trace of bedding. The inclosed pebbles, bowlders, and fragments of limestone range in weight from 1 ounce to a ton and in color from white through various shades of drab and gray to black. Associated with the masses of limestone are occasionally others of gray calcareous sandstone, specimens of which can not be distinguished from those of the sandstone (14) which is beneath. Some masses, which are of the same character as smaller inclosed blocks, are 200 feet long by 30 feet thick. It is difficult to decide whether these are sediments deposited in the bed or inclosed transported masses, notwithstanding that they are divided into beds with partings of black shale. Some of the conglomerate beds are filled with pebbles of black chert. Near to the top, patches of several hundred yards, in the supposed direction of the strike but without observed bedding, consist of light reddish-gray pure limestone, in part highly crystalline, abounding with convoluted shells and other fossils. The genera found in these conglomerates and their interstratified masses are Graptolithus, Orthis, Rhynchonella, Camerella, Ophileta, Maclurea, Orthoceras, Asaphus, Illænus, Amphion, Bathyurus, Holometopus, Nileus, Ampyx, Agnostus, Endymion, and several trilobites of undetermined genera. The determined species are *Graptolithus headi*, *Camerella calcifera*, *Maclurea ponderosa*, *Bathyurus saffordi*, *Holometopus angelini*, *Endymion meeki*, and *Nileus scrutator* 700

[Q.]

16. Greenish sandstones of a chloritic aspect, made up apparently of fine grains of quartz and feldspar, with a few scales of mica, mixed with greenish argillaceous matter. Some beds are of a conglomerate character, the pebbles consisting of white quartz and reddish feldspar, varying from the sixteenth of an inch to an inch in diameter; the quartz pebbles are somewhat larger and much more numerous than those of feldspar. They are accompanied by occasional pebbles of red jasper, and by flat pieces of green shale. In some beds the masses inclosed consist of gray limestone. The finer beds are aggregated in thicknesses of several hundred feet, and the conglomerates are from 10 to 20 feet. These fine and coarse sandstones are interstratified with several bands of red shale from 10 to 20 feet thick; and one of 60 feet consists of red shale interstratified with green layers. The thickness of the whole was not measured, but it is supposed to be not much under 2,000

In his descriptions Logan included division N with divisions I, K, L, and M, in a major group, but Billings [81b] classed N with O and P and commented on the taxonomic relations as follows:

The rocks of these divisions, in ascending order, consist of 277 feet of black bituminous limestone, with some black shales, very fossiliferous; next 700 feet of sandstones, in which no fossils were collected or observed; and at the summit 700 feet of black shales, holding gray and white limestone conglomerates, abounding in fossils, although there are not a great many species. There appear to be in this series of strata two formations, distinguishable from each other both by lithological and paleontological characters. The first includes the black bituminous limestones and shales, forming the upper 277 feet at Table Head, and those of Pistolet Bay and 4 miles northeast from Portland Creek. The rocks at the latter locality appear to lie above the 700 feet of sandstone constituting division O and are therefore in the foregoing descriptions of species referred to division P. Taking these three localities to be on the same or nearly the same horizon, we have from them, in addition to a few not yet described, the following 48 species:

Lingula nympha.
Lingula iole.
Lingula cyane.
Acrotreta gemma.
Orthis delicatula.

* Strophomena aurora.
Strophomena imbecilis.
Strophomena decipiens (?).
Camerella parva.
Camerella varians. *

Rhynchonella corinthia.
Pleurotomaria sponsa.
* Murchisonia simulatrix.
* Murchisonia augustina.
* Maclurea crenulata.
* Maclurea acuminata.
Ecculiomphalus superbus.
* Orthoceras piscator.
* Orthoceras allumettense.
* Bathyurus nero.
Bathyurus breviceps.
Asaphus huttoni.
Asaphus morrisii.
Asaphus quadraticaudatus.
Nileus macrops.
Nileus scrutator.
* Illænus fraternus.
* Illænus consimilis.
Endymionia meeki.
Holometopus angelini. *
Harpides atlanticus.
Harpides concentricus.
Shumardia glacialis.
Cheirurus polydorus.
Cheirurus perforator.
Cheirurus sol.
* Amphion barrandei. *
Triarthrus fischeri.
Telephus americanus.
Encrinurus mirus.
Remopleurides panderi.
Remopleurides schlotheimi.
Ampyx læviusculus.
Ampyx normalis.
Ampyx rutilius.
Ampyx semicostatus.
* Agnostus galba.
Agnostus fabius.

In the above list those with an asterisk before them are found in some one or more of the divisions below N; those with an asterisk after them occur in the gray and white limestones of division P at Cow Head. *Camerella varians* is a Chazy species. *Orthoceras allumettense* is both Chazy and Black River. *Holometopus angelini*, *Endymionia meeki*, and *Cheirurus sol* occur in the Quebec group of Canada East. We find here, for the first time among American trilobites, the peculiar type of Cheirurus, with a spine upon the glabella—*C. perforator*. Another of the same structure, *C. glaucus*, was discovered in the Quebec group in the township of Stanbridge; and a third, *C. satyrus*, in the Chazy, at Montreal, by T. C. Weston, last year, 1864. This type has been known for several years among the Russian trilobites by *Sphærexochus cephaloceros* (Nieskowski) = *Zethus triplicatus* (Eichwald), which occurs in the Pleta limestone. The genus Triarthrus has not heretofore been found below the Trenton in America. Remopleurides occurs in the Chazy, and Amphion in both Chazy and Calciferous; but neither of these genera has yet been reported as occurring above the Chazy in Canada or New York. The general aspect of the trilobitic fauna of this series of strata seems to me to be more like that of the Pleta limestone of Russia and Angelin's two Swedish groups B C and C, than it is to that of any of the American Lower Silurian formations heretofore illustrated.

The second formation above mentioned consists of the 700 feet of black shales with gray and white limestone conglomerates, at Cow Head. In no other part of Newfoundland do we meet with the remarkable fauna which characterizes the Levis formation. It undoubtedly occurs here in full force. The following list contains the species collected at that locality, and also shows how many of them occur in Canada:

	C. H.	C. E.
Stenopora fibrosa (Chazy to Devonian)	×	
Graptolithus bryonoides	×	×
Graptolithus denticulatus	×	×
Graptolithus fruticosus	×	×
Graptolithus headi	×	×
Phyllograptus typus	×	×
Ptilograptus plumosus	×	×
Callograptus elegans	×	×
Orthis hippolyte	×	×
* Camerella varians (Chazy)	×	
Camerella calcifera (Calciferous)	×	×
Camerella costata	×	×
Lingula quebecensis	×	×
Maclurea ponderosa	×	×
Ophileta bella	×	×
Ecculiomphalus distans	×	
Asaphus pelops	×	×
Bathyurus cordai (Calciferous)	×	×
Bathyurus conicus (Calciferous)	×	

	C. H.	C. E.
Bathyurus saffordi	×	×
Bathyurellus nitidus	×	
Bathyurellus formosus	×	×
Bathyurellus fraternus	×	
Nileus affinis	×	×
Illænus tumidifrons	×	
Illænus arcuatus	×	
Illænus consobrinus	×	
* Holometopus angelini	×	×
Lichas jukesii	×	×
Cheirurus vulcanus	×	×
Cheirurus mercurius	×	×
Cheirurus prolificus (Chazy)	×	×
* Amphion barrandei	×	
Amphion julius	×	

In the above list those found at Cow Head are placed in the column C. H. and those which occur in Canada East (as well as Cow Head) C. E. The seven species of graptolites, with *Lingula quebecensis*, occur only in the black slates; all the others in the gray and white limestones. The three species with an asterisk before them are found in the next group of strata below. No one could compare the collections from Cow Head with those of Point Levis and Phillipsburgh without some feeling of astonishment that in localities nearly a thousand miles distant from each other there should be such a perfect identity not only in the fossils but also in the character of the rock. The specimens, if mixed together without their labels, could never be separated. Only a small collection was made at Cow Head, and there can scarcely be a doubt that further examination will bring to light a greater number of species common to the two countries.

This fauna, although upon the whole specifically distinct from the one next below, consists of the same types of trilobites, with the exception of *Bathyurus cordai* and *B. conicus*, which are Calciferous species, as is also the brachiopod *Camerella calcifera*. There are two species, *Amphion sol*, and *Endymionia meeki*, which are found in division N, in Newfoundland, and not at Cow Head, but they occur in the limestones of Point Levis, which are of the same age as those of Cow Head. There are thus five common species, instead of three, as would appear by the above list.

From Cow Head, Point Levis, St. Antoine, Stanbridge, Bedford, and Phillipsburgh we have in all 219 described species. Of these, the 51 species of graptolites described by Prof. Hall, and also *Lingula quebecensis*, *L. irene*, *Obolella desiderata*, and *Shumardia granulosa* have been found only in the slates and thin-bedded limestones interstratified in the slates. The other 162 species occur in the white and gray conglomerate limestones. That the slates and these peculiar limestones belong to the same group is proved by their occurring together in widely separated localities, although as yet we are unable to show that any of the species are common to both. At Cow Head *G. headi* was found in a loose piece of gray limestone, but it is not quite certain that the specimen belongs to the conglomerates.

The evidence that the rocks at Cow Head in Newfoundland are of the same age as those of the Levis formation in Canada East amounts to this: (1) They are precisely the same in lithological characters and (2) out of the 34 species collected at Cow Head 23 are perfectly identical with those collected at Point Levis, Bedford, Phillipsburgh, and other typical localities of the formation. There is, however, in Newfoundland an important series of strata, consisting of all the divisions from I to O inclusive, having a thickness of 2,061 feet, lying below the Levis formation and above the Calciferous, which has not been recognized in Canada. It thus appears that the Levis formation not only lies above the Calciferous but more than 2,000 feet above it. Yet it holds a large number of trilobites of the Potsdam type and several species, such as *Lingula mantelli*, *Camerella calcifera*, *Bathyurus cordai*, *B. conicus*, and *Asaphus canalis*, which certainly do occur in the Calciferous.

In the foregoing general catalogue (ante, pp. 366–370) there are 62 species placed in division P. But if we exclude from that division all the species except those collected at Cow Head, only those on the list on page 375 properly belong to it. The others should be placed in division N.

Ulrich (personal communication) comments as follows on the section:

These Ordovician fossils are in the conglomerate bowlders here as at Point Levis. The graptolitic shale itself is the Levis thrust inland over the Chazy. The remainder of the section is in question. It may be in part Chazy or all post-Chazy, with persisting Chazy species, as in the Liberty Hall limestone of Virginia.

M-N 14. LAKE WINNIPEG DISTRICT, MANITOBA.

Dowling[290] gives the following table of divisions of the later Ordovician in the Lake Winnipeg region and compares them with the formations known in Minnesota.

Formations in Minnesota.			Formations in Manitoba.		
Hudson River or Cincinnati period.	Richmond group. Utica group.			Stony Mountain. Utica (?).	Limestones and shales.
Trenton period.	Trenton group.	Maclurea beds.	Trenton period.	Trenton.	Upper Mottled limestone.
		Fusispira and Nematopora beds.			Cat Head limestone.
		Clitambonites beds.			Lower Mottled limestone.
	Black River group.	Fucoid and Phyllopora beds. [a]		Black River (?).	Winnipeg sandstone and shales.
		Ctenodonta beds.			
		Rhinidictya bed.			
	Stones River group.	Stictoporella bed.			
		Vanuxemia bed.			
		"Lower Buff."			
	Chazy formation.	St. Peter sandstone.			

[a] This is the widely spreading zone so well displayed at Silliman Mountain, Baffin Land. The Winnipeg sandstone of Manitoba is probably at the same horizon but may be in part St. Peter.—Comment by E. O. Ulrich on manuscript.

Dowling describes the several divisions of the Ordovician as follows:

The basal beds of the Cambro-Silurian [Ordovician] of Manitoba consist of a series of soft friable sandstones, shaly in the upper part but generally similar to those found in Minnesota beneath the Trenton limestone. Very few fossils have been obtained, and those from the upper part only, denoting merely lower beds of the Trenton. * * * The fossils give no definite information as to the age of the beds but suggest a passage from Black River to Trenton. * * *

In eastern Canada and New York State the Black River is usually a thick-bedded limestone, but in Minnesota it is composed mainly of greenish shales, so that the shales below the limestone in the borings at Rosenfeld and Selkirk may be taken as the passage beds from the Black River. These are represented on Lake Winnipeg by shaly bands in the upper part of the section. The sandstone below, being in the nature of a shore deposit, though occupying a position nearly similar to the St. Peter sandstone of Minnesota, can not be regarded as definitely of the same age, since no evidence of Chazy fossils has been found in it.

The thickness of pure sandstone in the Lake Winnipeg basin is apparently much less than to the south. The several sections give varying thicknesses [40–100 feet], owing to the uneven nature of the floor on which it was deposited. * * *

The Lower Mottled limestone is the lowest member of the limestone series and rests directly on the basal sandstones and shales. These limestones form the principal part of the sections at Grindstone Point, Bull Head, and Dog Head, and on the islands north to Berens Island. The combined section given by these several exposures amounts to a thickness of about 70 feet. The lowest beds are those seen at Deer Island and Grindstone Point capping the sandstone. Immediately above are the beds occurring at Dog Head, followed by the upper part of the Black Bear Island exposure. Those on Tamarack and Jack Head islands are evidently higher but belong to the same series and form, together with those mentioned above, the following descending section:

	Feet.
1. Hard mottled limestone, dark yellow, with brownish-yellow spots, breaking up into lumpy fragments not wearing discoidal on the beach but irregular. A few pieces from top beds are not so mottled and break smoothly (probably base of Cat Head limestone)	15
Exposure on west side of Jack Head Island.	
2. Thin-bedded, mottled buff and grayish-white limestone, weathering ashy-white, in which are many large cephalopods: Orthoceras, Sactoceras, Poterioceras, Oncoceras and Cyrtoceras, while specimens of *Maclurea manitobensis* and *Receptaculites oweni* are abundant	15
Eleven feet of these beds are exposed on Little Tamarack Island and similar beds are exposed on Little Black Island near Berens Island.	
3. Mottled limestone, buff-colored but weathering lighter, in rather thicker beds than above and not so rich in fossils	10
These form the upper part of cliff on Black Bear Island.	
4. Thin beds of similar rock, rich in fossil remains	20
This band occupies the lower portion of the exposures on Black Bear Island, on Snake Island, and Dog Head or Whiteway Point and the upper part of the cliffs of Bull Head and intervening exposures.	
5. Darker mottled impure limestone, where not weathered, almost blue on fracture; fractures into thin flags with surfaces covered with fucoidal markings. The lower beds are of very earthy limestone resting on the sandstone of the basal series	10
	70

* * * * * * * * *

The Cat Head limestone, the central portion of the limestone series, is best developed at the prominent point on the west side of Kinwow Bay, called Cat Head. The beds are of a fine-grained, evenly colored yellow dolomitic limestone, with numerous concretions of dark-colored chert, filling cavities apparently left by the decay of corals. These beds are seen in the high cliff at Cat Head and along the shore to Lynx Bay. At the western end of the section, 3 miles west of Cat Head, the cherty concretions attain large dimensions. Several are over a foot in length, and one measured 2 feet by 10 inches. The lower beds are fine grained, resembling lithographic stone, and are very rich in fossil remains. The total thickness as observed on the lake is 68 feet. This includes the top beds of Cat Head and Outer Sturgeon Island, which are similar in color but coarser in texture, becoming finally crystalline. The section is made up as follows:

	Feet.
1. Hard, flinty, coarse-grained limestone (Sturgeon Island)	10
2. Yellow granular limestone, weathering roughly and slightly honeycombed (Cat Head)	8
3. Similar coarse-grained, weathering dark-yellow, with fucoid-like markings, and very much honeycombed (Cat Head)	3
4. Yellow limestone with fucoidal markings similar to No. 2 (Cat Head)	10
5. Fine-grained yellow rock with numerous ashy-colored spots scattered over the whole face of the exposure, from the weathering of small impure flinty concretions (Cat Head)	27
6. Fine-grained yellow limestone, rich in fossil remains, with numerous large concretions of dark cherty material (Cat Head, McBeth Point, and Inmost Island)	10
	68

* * * * * * * * *

The two lower series—the Cat Head and the Lower Mottled—are not of any great thickness, but are in the district readily distinguished from each other. The dividing line is placed at a bed at which the mottled limestone becomes highly charged with siliceous material in the form of chert nodules, while the limestone above changes from a mottled grayish-white with darker spots to a uniform buff, less crystalline rock. The faunal change is not very marked, but it will be noticed that the numerous large cephalopods that characterize the lower are almost altogether wanting in the middle division.

The "Upper Mottled limestone" is described as varying in different localities and in partial sections from hard mottled dolomite exhibiting rough surfaces marked apparently by fucoids to soft, darker mottled impure earthy limestone which passes into the overlying Stony Mountain formation. The thickness is estimated at 130 feet near Winnipeg.

The Stony Mountain formation is stated to represent the interval between the top of the Trenton and the base of the Silurian (upper). Dowling describes the changes of thickness in strata which occupy this interval to the east and south and says:

Although this formation is supposed to thin out altogether in northern Minnesota, there is found at Rosenfeld, in the southern part of Manitoba, a great thickness of shale beds between limestone formations which are probably Trenton and Silurian. At Stony Mountain the section, although incomplete, in a known thickness below the Silurian of 110 feet, consists of shaly beds in the lower part with thick-bedded limestones above. The fossils from this part are mainly from the shaly beds below the limestone of the top of the section, and probably all these are collected from less than 50 feet below the top of the formation. We might infer from this that the upper part, that of which we have a section and a list of fossils, is referable to the Richmond group of Minnesota, and that the lower beds, mostly shales, are similar to the Utica of the Cincinnati formation. One species only, characteristic of the Utica of Minnesota has been found at Stony Mountain—*Primitiella unicornis* Ulrich. The majority of those common to the two localities are from the upper parts of the sections. It is noted in the Minnesota reports that several forms occurring in the Trenton appear in the Richmond group without any evidence of their presence in the Utica. The same might possibly be asserted of some of the Manitoba forms, as several are found to range from the Trenton to the Stony Mountain formation.

A complete list of fossils identified from these divisions of the Ordovician is given in Dowling's report. The faunas were earlier discussed by Whiteaves.[920]

Ulrich in commenting on this correlation states:

Dowling's determination of the Manitoba Ordovician formations is based entirely on the Minnesota section of 1896. Much having been learned in the last 14 years concerning the Ordovician of the middle and far West, it is desirable to revise the classification of the rocks in both areas according to the present status of information.

O 9. DEASE RIVER, BRITISH COLUMBIA.

Blackish graptolite-bearing slates occur on lower Dease River near its junction with the Liard, in the belt of unaltered Paleozoic rocks of the eastern Rocky Mountains, near the sixtieth parallel. They were first seen in 1887 by G. M. Dawson,[258a] who states:

From the second great bend to the mouth of the Dease the underlying rocks [underlying supposed Triassic] consist of gray and black schists, the former generally calc schists and the latter more or less highly carbonaceous. They are interbedded with thin limestones, which often weather brown. The calc schists are frequently glossy and in some places form very thin paper-like layers. Some of these rocks closely resemble those met with at the "Grand

Rapid" on the Stikine. The general strike is northwest by southeast, but the direction and angle of the dip is very varied and the beds are frequently much disturbed and twisted and traversed by veins of quartz and calcite. There are probably frequent repetitions of the same horizon, but the general arrangement may be synclinal, the dark shales and schists occupying the higher position and being most abundant about the middle of this length of the river section. Graptolites were found in the dark shales, particularly at a locality in a north bend of the river, 11 miles westward in a direct line from the mouth, and in appearance the whole series is much like that of the Cambrian calc schists and Cambro-Silurian graptolite shales of the Kicking Horse (Wapta) Valley, west of the summit, on the line of the Canadian Pacific Railway.

With reference to the geologic horizon, Lapworth [523] reports:

The graptolites collected by Dr. Dawson from the Dease River are identical with those examined by me from the rocks of the Kicking Horse Pass some time last year.

The species I notice in the Dease River collection are—

Diplograptus euglyphus (Lapworth).
Climacograptus comp. antiquus (Lapworth).
Cryptograptus tricornis (Carruthers).
Glossograptus ciliatus (Emmons).
Didymograptus comp. sagittarius (Hall).
New form allied to Cœnograptus.

The graptolite-bearing rocks are clearly of about middle Ordovician age. They contain forms which I would refer to the second or Black River-Trenton period—that is, they are newer than the Point Levis series and older than the Hudson and Utica groups. The association of forms is such as we find in Britain and western Europe, in the passage beds between the Llandeilo and Caradoc limestones. The rocks in Canada and New York with which these Dease River beds may best be compared are the Marsouin beds of the St. Lawrence Valley and the Normans Kill beds of New York. The Dease River beds, perhaps, may be a little older than these.

These rocks are also apparently very similar to the graptolite-bearing slates of the Alaska Range.

O 15. SOUTHWEST COAST OF HUDSON BAY.

An isolated occurrence of limestone containing Trenton fossils near Fort Churchill is described by Tyrrell.[818] The rocks had previously been observed by Bell on Churchill and Nelson rivers and assigned to the Galena-Trenton horizon of the Wisconsin Geological and Natural History Survey by Whiteaves,[912] who also recognized some probable upper Silurian or Devonian forms.

In 1880 Bell [66] wrote:

Geologically the basin of Hudsons Bay, excluding the western or Winnipeg division, lies within the great Laurentian area of the Dominion. Cambro-Silurian rocks, resting almost horizontally upon these, form an irregular border along the southwestern side of the bay, and in the valleys of some of the rivers they extend inland from 100 to 200 miles. To the south and west of James Bay the Cambro-Silurian [Ordovician] is overlain by Devonian rocks, which here occupy a considerable area.

Among the notes of a preliminary report on the region between Lake Winnipeg and Hudson Bay, Low [549] includes the following:

The limestones of the Severn and Fawn rivers, as roughly determined from the fossils collected, are not older than the Galena and may be as new as the Niagara; more investigation is, however, required to fix their precise horizon.

The rock is a coarse yellowish-white dolomitic limestone, closely resembling that of Lake Winnipeg. It lies almost flat, being broken only by long, low anticlines and synclines. At the Limestone Rapids of the Severn, where it is more contorted than usual, it rises in a number of low domes, closely resembling a sheet of letter paper when dampened. The total thickness of the beds exposed does not exceed 100 feet.

References to these limestones occur in subsequent reports, but on account of the isolation and small areas of the outcrops there is no complete section nor any definite knowledge of the area of strata of Trenton age or of higher strata. Brock[a] states:

With reference to the southwestern coast of Hudson Bay our information is not definite. There are very few exposures and only isolated fossils have been brought down, some possibly from loose bowlders. From Tyrrell's fossils and Bell's it is evident that there is at least a band of Trenton, and from other fossils it is certain that Silurian is present, but where the boundary lies between them we do not know.

P–Q 3–7. ALASKA.

Ordovician strata in Alaska are in general not distinguished on the map of North America, the areas in which they occur being classed as Paleozoic undivided. Their presence is known, however, through the discovery by Brooks and Prindle [104] of Ordovician graptolites on the western slope of the Alaska Range, in carbonaceous strata which are intimately associated with phyllites, limestones, and cherts and which have been called the Terra Cotta "series." These strata are probably represented in the metamorphic rocks of the upper Tanana region, formerly known as the "Tanana" schist [101b] but recently correlated with the Birch Creek schist.[104] Ordovician fossils have also been found on the Porcupine in bluish-gray nonmagnesian limestone 600 feet thick.[102]

Thus the presence of the Ordovician is shown on fossil evidence in the central eastern portion of the Alaska Peninsula. Similar fossiliferous beds are known at several points in British Columbia. Strata which have as yet yielded no fossils, the Wales "series," lie beneath and are older than upper Silurian in southeastern Alaska. On the other hand, toward the north and northwest from the Yukon region the more or less metamorphic schists of the Endicott Mountains and Seward Peninsula include early Paleozoic sediments, possibly Ordovician, and there are similar schists in southern Alaska about Prince William Sound and the Wrangell Range.[101]

P–Q 17–19. SOUTHAMPTON ISLAND, FOX LAND, AND UNGAVA BAY.

The central portion of Fox or Baffin Land is mapped as Silurian, as are also the islands in the north of Hudson Bay. The presence of Ordovician strata is established in Frobisher Bay, and is probable throughout the areas in this region shown with the Silurian color. (See pages immediately preceding.)

Akpatok Island, in the northern part of Ungava Bay, is described by Bell [68] as presenting a wall of gray limestone 400 to 500 feet high all along the coast from the north end to the middle of the east side. The strata are horizontal and the total thickness exposed in the heights of the island is estimated at 900 feet, to which

[a] Brock, R. W., Acting Director Geol. Survey Canada, letter May 27, 1908.

may be added an unknown thickness beneath the sea. Low[550] states that the strata range in age from "Galena-Trenton to Lower Helderberg."

Q 3-4. SEWARD PENINSULA.

Kindle has contributed the following note on the Silurian and Ordovician of Seward Peninsula:

The Port Clarence limestone furnished fossils which were determined as Silurian and Ordovician. Recent collections from this limestone show the presence of both Cambrian and Ordovician faunas and indicate that the fauna previously considered Silurian is of late Ordovician age.

R-T 10-20. ARCTIC ARCHIPELAGO.

Large areas in the Arctic Archipelago are colored as Silurian (upper Silurian or Gothlandian) in accordance with the dominant character of the fossils collected by several expeditions. Detailed references and descriptions are given in Chapter V (pp. 265-266). These Silurian strata, however, are in certain localities and probably as a rule underlain by Ordovician. Dawson[257a] summarizes:

In a paper printed in the report of the British Association for 1855 J. W. Salter states that the Silurian fossils obtained up to that time showed a uniform horizon of Upper Silurian limestone stretching from near the entrance to Barrow Strait to Melville Island and far to the south along Prince Regent Inlet and argues therefrom a wide extent of circumpolar land in lower Silurian (Cambro-Silurian) times. In this he was followed, two years later, by Sir R. Murchison,[a] who writes: "I am led to believe that the oldest fossiliferous rock of the Arctic regions is the Upper Silurian." Though the Upper Silurian beds undoubtedly occupy a great part of the American polar region, characterizing the "South of North Devon and nearly all the islands south of Melville and Lancaster sounds, including the south of Banks Land, Prince of Wales Land, King William Land, North Somerset, Boothia, Felix, etc.,"[b] the occurrence of Lower Silurian (Utica) fossils in Frobisher Bay, as shown by Hall's collections, on the shores of Kennedy Channel, as determined by Etheridge, and the occasional discovery of Lower Silurian forms in the regions above referred in a general way to the Upper Silurian prove that the generalization made by Salter and Murchison, on the evidence of less complete collections, can not now be admitted and that the limestones of the Arctic represent probably the whole of the Silurian [Lower and Upper], and possibly part of the Devonian.[b] Heer[c] enumerates the following places, besides those above particularly referred to, as yielding Lower Silurian types: North Devon, Cornwallis Island, Griffith Island, west coast of King William Land, Boothia.

Dawson's inference was verified in 1900 by Schuchert,[712] who studied new collections from Sillimans Mount, at the head of Frobisher Bay, and extended the basis of correlation with other areas in the Arctic Archipelago. After enumerating localities, Schuchert says:

From the foregoing description of localities, it appears that middle Lower Silurian horizons are very extensive in eastern Arctic America. Such are known in places on either side of Hudson Strait, Frobisher Bay, the interior of Baffin Land, and to the north of this land at various localities between latitudes 79° and 80° north. As far as known, these strata unconformably overlie very ancient crystalline rocks and are in turn overlain by Upper Silurian beds of Niagara or Wenlock age. Lower Cambrian rocks are found in southern Labrador, but in the region of

[a] Appendix to McClure's voyage, p. 402; Siluria, p. 440.
[b] Fielden and De Rance, Quart. Jour. Geol. Soc., vol. 34.
[c] Flora Fossilis Arctica, vol. 1, p. 24.

Baffin Land such are not known to be present. Here, then, there seems to be a complete break from the Laurentian to the Trenton, followed by another break paleontologically, in the absence of the Cincinnatian beds and probably the lower horizons of the Upper Silurian. The Lower Silurian fossils of this area indicate nothing older than the typical Trenton of New York and the Galena of Wisconsin and Minnesota,[a] and nothing younger than the Utica stage of the United States. The thickness of these beds is not less than 900 feet and probably exceeds this.

Schuchert cites lists of fossils collected by Hall and described by Stevens [792] and Emerson [318] and gives a new list of 72 species from Silliman's Fossil Mount and their distribution according to horizons (Lowville, Black River, Trenton, and Cincinnatian) and according to regions (Minnesota-Manitoba, New York-Ottawa). He concludes:[712a]

From Mr. Porter's description, it will be seen that the fossils recently collected at Silliman's Fossil Mount are from various horizons, and yet there is nothing to indicate the presence of more than one fauna. The foregoing list shows that at present there are 72 species known from this locality, and of these 28 are restricted to it. There are, therefore, 54 species which are common to other localities, a goodly number with which to make safe correlations. Of these 54 species, 41, or 57 per cent of the known fauna, are also found in the region of Minnesota, Wisconsin, and Iowa, while 17 are known to occur in New York and Ottawa.

On comparing the 54 widely distributed species with those from definite stages in Minnesota, it is seen that 10 are also found in Birdseye (Lowville), 17 in the Black River, 38, or about 70 per cent, in the Galena, the direct equivalent of the New York Trenton, and 11 in the Cincinnatian group.

From these figures it is evident that the stage of Silliman's Fossil Mount belongs in the Galena, and that the fauna is more intimately related to that of the Minnesota region than to the Trenton of New York. When the New York Trenton fauna is restudied in the light of recent researches in Minnesota,[b] however, it will be shown that the two faunas have more in common than now appears. On the other hand, the lithological similarities of the Minnesota Galena and Silliman's Fossil Mount, light-colored shales predominating in both areas, may explain in large measure the close identity of these widely separated faunas.

Schuchert [712b] closes his paper with the following summary of the information available on the Arctic Ordovician:

The only Lower Silurian horizons known in northeastern Arctic America are of Trenton and Utica age. The latter zone appears only on the north shore of Frobisher Bay, but the Trenton is found in various places from the north shore of Hudson Strait to latitude 81° north. The Lower Silurian is thickest on Akpatok Island, where it is from 400 to 500 feet in depth. Dr. Bell, however, estimates the entire thickness of these strata in this region to be not less than 900 feet.

In Baffin Land and apparently elsewhere in Arctic America the Lower Silurian strata rest unconformably on old crystalline rocks [except where Cambrian is present in the far north; see p. 155]. To the north of Baffin Land the former are overlain by beds of Niagara or Wenlock age.

The Trenton faunas, occurring in various places around the insular Archean nucleus of North America, have much in common, and this indicates that the conditions at that time were very similar, while the sea was in communication throughout. As yet, however, the distribution of the strata, together with their faunas, are well known only to the south and southeast of the Archean nucleus, yet that of the west (Manitoba) and of the northeast (Baffin Land) show direct communication.

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[a] See Cambrian of Bache Peninsula, Chapter III, p. 155.

[b] Paleontology of the Lower Silurian fossils of Minnesota: Geology of Minnesota, vol. 3, pts. 1 and 2, Geol. Nat. Hist. Survey Minnesota, N. H. Winchell, State geologist.

The Baffin Land fauna had an early introduction of Upper Silurian genera in the corals Halysites, Lyellia, and Plasmopora. In Manitoba similar conditions occur in the presence of Halysites, Favosites, and Diphyphyllum. Other Upper Silurian types do not appear to be present.

The Trenton fauna of Silliman's Fossil Mount, at the head of Frobisher Bay, has 72 species, of which 28 are restricted to it. This fauna shows an intimate relationship with that of the Galena of Minnesota, Iowa, and Wisconsin. Fifty-seven per cent of the species of Baffin Land also occur in the Galena of the regions just mentioned.

S 27. EASTERN COAST OF GREENLAND.

The Ordovician and possibly Cambrian of northeastern Greenland are described by Nathorst,[609c] who says:

> East from the Archean follows a formation of sedimentary rocks which are without doubt older than Devonian and at least in part must be considered of Silurian [Ordovician] age, since there were found at Cape Weber, besides others, Orthoceratites, together with small Orthis or a closely related brachiopod and small gastropods. Although these fossils in consequence of pressure and the poor condition of preservation resulting therefrom can not be specifically determined, a Silurian [Ordovician] age is nevertheless indicated, since the Orthoceratites are younger than Cambrian; still it is not impossible that in the lower formations there may be Cambrian strata.
>
> The strata of which the formation is composed are very variable and consist of white, yellowish, gray, and black limestone or dolomite; red, green, chocolate-colored, and dark slates; and red sandstone, together with perhaps in the lower portions yellowish sandstone.

The Ordovician strata of this region are much folded and conformably overlain by the Devonian.

CHAPTER V.

SILURIAN.

Color, violet.

Symbol, 16.

Distribution: General throughout northern and eastern North America, east of the Great Plains; represented by the Devonian color (15) in the Appalachian zone south of latitude 38°; known to be present in the Cordillera and Alaska but not generally distinguished by separate color, except in Mexico, Nevada, and British Columbia.

Content: In the Appalachians in general includes Medina to Cayuga; in the southern Appalachians is mapped with Devonian; in eastern Canada and New York Helderberg is included on the map; in the interior, includes strata of Niagara age; in the Arctic the Silurian color covers areas of the limestone series known to include Ordovician and Silurian.

Silurian areas.

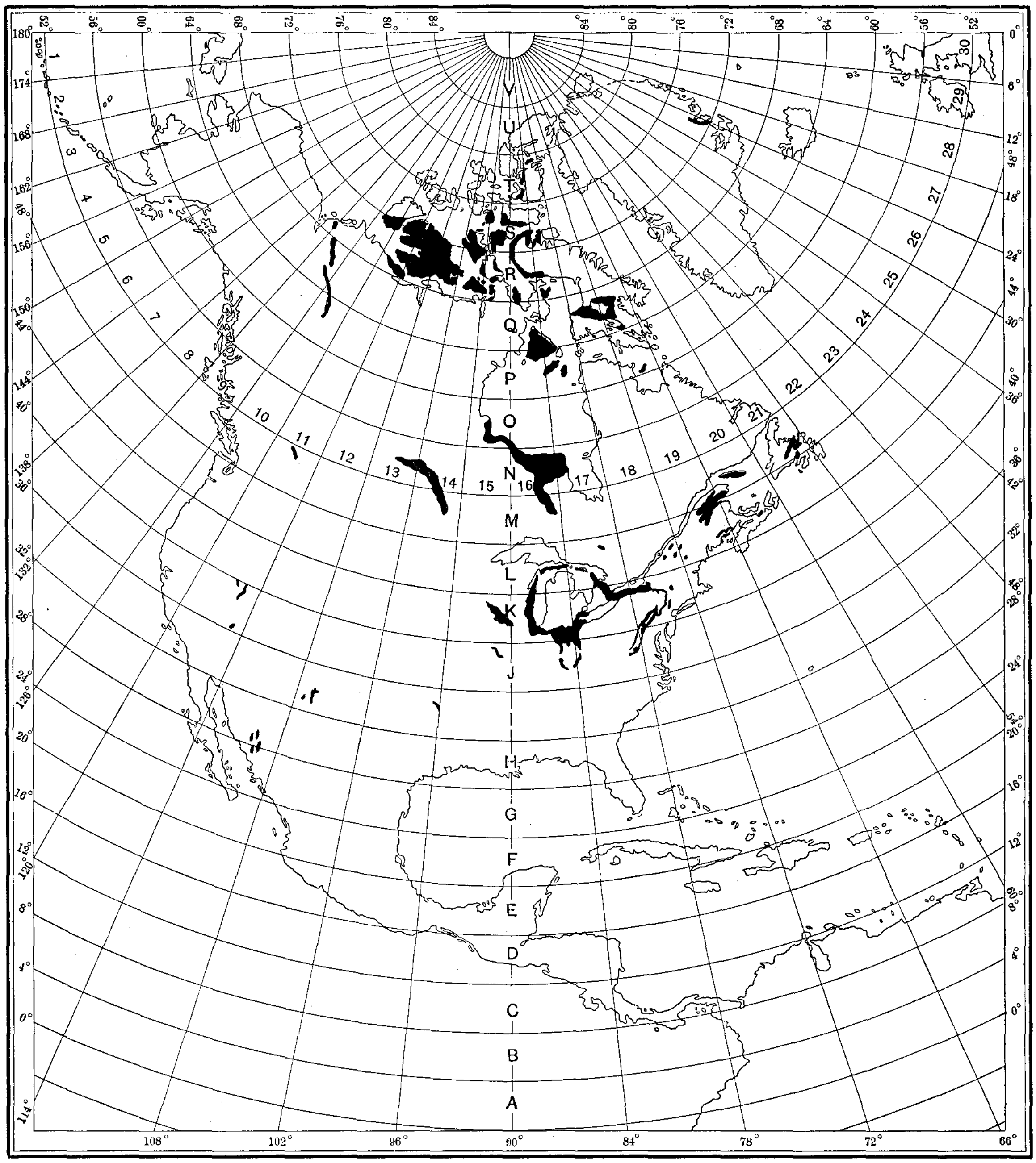

FIGURE 7.—Sketch map showing the distribution of Silurian rocks represented on the geologic map of North America and the key to references in the text.

G-H 12. SONORA, MEXICO.

Aguilera [9] in 1906 mentioned certain strata as "doubtful Silurian" in describing under that head "Quartzites and fossiliferous semicrystalline limestones, of gray color and siliceous character, with *Encrinites cyathophyllum* and Heliolites; these overlie compact gray and yellowish limestones which occur above a series of breccias and limestones." Aguilera does not name localities at which these rocks occur.

The areas mapped as Silurian in Sonora are so assigned on authority of a manuscript map furnished by Robert T. Hill, and the strata may be similar to those described by Udden and Richardson as occurring in southwestern Texas.

H 13. WESTERN TEXAS.

Describing a region near Marathon, Tex., J. A. Udden [819a] says:

There must be several thousand feet of sediments exposed in this area. They have been folded and faulted and dip, usually at high angles, either to the southeast or to the northwest. * * * In the south part of the area they consist largely of dark shales and limestones. These contain heavy ledges of cherty quartz, which rise in long ridges running from the northeast to the southwest. The chert is usually interbedded with ledges of dark limestone, which now and then contain round and loaf-like concretions of chert. The prevailing color of the chert is white, but it is sometimes black, green, bluish, or of a brown or a pinkish color. With some of the limestones there are thin seams of sandstones and conglomerates. The latter usually consist of well-worn pebbles, mostly of limestone, but also of hard quartzite. In some shales, which are associated with chert and limestones in a ridge on the south side of Edwards Creek, about 10 miles northeast of Santiago Peak, there is one stratum which contains large concretionary aggregates of crystals of barite. Some of these aggregates are a foot in diameter and consist of columnar crystals radiating from the center of the concretions. The mineral was seen to follow a stratum about 3 feet in thickness, and the concretions in one place appeared to be present in large quantity. The limestones themselves are frequently bituminous. Some ledges consist of small worn organic fragments. From one of these some fossil fragments were taken which Dr. Charles Schuchert has identified as the outer portions of the glabella of a Trinucleus. Associated with this there were also a Plectambonites (*sericeus*?), a Rafinesquina, and possibly a Zygospira. A gastropod of the genus Cyclora was found in another ledge, and in still another limestone a Nodosaria was noted. All of these fossils were collected along the wagon road near Ridge spring and at different points south from this place for a distance of 10 miles. The same kind of rocks continue north from this spring as far as to Peña Colorado, 4 miles south of Marathon. North from Peña Colorado we find shales, limestones, and thin conglomerates, but no chert beds. An Athyris, a Fistulipora(?), a Dentalium, and joints of crinoid stems were observed in the vicinity of Marathon, where the dip of these rocks is quite generally to the northwest. Evidently these sediments are younger than the formation which contains the chert south of Peña Colorado.

The thickness of the ancient sediments, which are seen on these plains around Marathon, is no doubt several thousand feet, and they very likely contain formations of more than one age. For 25 miles the road from the Chisos runs over the edges of beds tilted at high angles. The fossils associated with the chert show that some of these strata belong to the Ordovician, and Dr. Schuchert infers that these are of the Trenton period. In his "Physical geography of the Texas region" Prof. R. T. Hill expresses it as his opinion that the limestones, shales, etc., of these plains may be of Lower Helderberg age,[a] and there is no good reason to doubt that the Silurian rocks are represented in this extensive complex of folded strata.

[a] Folio 3, Top. Atlas U. S., U. S. Geol. Survey, 1900, p. 4.

H 13. TRANS-PECOS TEXAS.

With reference to the Silurian in the district lying north and east of El Paso Richardson [668b] states:

The Silurian system in trans-Pecos Texas is represented in the El Paso region [by] the Fusselman limestone in the Franklin and Hueco mountains. This is a massive whitish magnesian limestone approximately 1,000 feet thick. It overlies the Montoya limestone apparently conformably, although in one locality fragments of the underlying limestone included in the Fusselman give evidence of an unconformity. Throughout the greater part of the formation fossils are scarce, but at a few horizons they are very abundant. The commonest form is a species of radially plicated pentameroid shell which, with Amplexus and Favosites, determined by Mr. Ulrich, proves that the upper Niagaran stage of the Silurian is here represented. Gordon and Graton [a] have recently found Silurian fossils in the Silver City region and at Lake Valley, N. Mex.; and Taff's Hunton formation in Oklahoma [b] also contains a Silurian fauna.

I 12. ARIZONA.

Reagan [663] states in regard to the Silurian:

The Upper Silurian.—Immediately overlying the Tonto at its outer edge and possibly conformable with it are red to brown fossiliferous coarse-grained lime rocks having a thickness of about 70 feet. They form only a narrow band but are continuously exposed from the Tonto basin to Nantan Mountains, where not covered with talus or lava. The best exposures observed by the writer are on the trail to the Salt springs, some 10 miles southwest of the farmer's residence on Cibicu, and on the John Dazen trail near the Oak Creek break about a half mile southeast of Oak Creek cliff houses. This formation is Silurian; at least the fossils obtained, *Orthis davidsoni, Strombodes pentagonus*, etc., seem to bear out this conclusion.

I 13. NEW MEXICO.

Lindgren [542b] gives the following account of the Silurian of New Mexico:

The Silurian is recognized at Silver City, at Lake Valley, and probably also at Hillsboro as thin beds of limestone and quartzite, but does not seem to be present everywhere between these places. It lies conformably above the Ordovician and at Silver City can not be differentiated from it. In the Franklin Range of Texas Richardson measured 1,000 feet of Silurian limestone.

I 14. OKLAHOMA.

The Arbuckle Mountains of Oklahoma comprise Silurian and Devonian strata which were separated by Taff into two mapped formations. The lower formation, the Sylvan shale, is of Silurian age, and the upper, the "Hunton limestone," is of Silurian and Devonian age. The Sylvan overlies the highest known fauna of the Ordovician, yet its fauna is related to the Utica of the New York Ordovician. The "Hunton" contains strata carrying in succession Niagara, Helderberg, and Oriskany faunas. The following is the stratigraphy and paleontology according to Taff and Ulrich: [808b]

The Sylvan shale and the succeeding Hunton limestone are comparatively thin formations. * * * The nearly pure lime deposits laid down at the close of Viola [upper Richmond, latest Ordovician] time were succeeded by dark-blue to black and green clay in apparently conformable succession. The deposition of the greenish Sylvan shale continued without interruption until it reached a thickness of from 60 to 300 feet. * * *

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[a] Am. Jour. Sci., 4th ser., vol. 21, 1906.
[b] Tishomingo folio (No. 98), Geol. Atlas U. S., U. S. Geol. Survey, 1903.

A preliminary study of the fossils occurring in the dark basal shale shows the following forms:

Diplograptus sp. undetermined.
Climacograptus sp. near typicalis.
Leptograptus sp. undetermined.
Lingula; short, obtuse form.
Lingulops? sp. nov. (platform obsolete).
Leptobolus sp. near insignis.
Leptobolus? sp. nov. (has six strong radiating plications).
Conularia sp. nov., with surface sculpture very similar to that of the Trenton C. papillata Hall.
Conodonts of forms resembling those referred by Hinde to Prioniodus and Polygnathus.

The fauna of the Sylvan shale as far as known is generally remarkably similar to that of the Utica. The specific differences, however, are such as to distinguish them; yet a study of the fossil nvinces one that the fauna of the Sylvan is a direct development from the much older fauna of the Utica shale and not of the intervening faunas of the Cincinnati group. From this evidence it would seem that the position of the Sylvan shale in the time scale is problematical. The highest known fauna of the Ordovician, that of the Richmond group, occurs at the top of the Viola limestone, beneath the Sylvan shale, and the Clinton occurs immediately above the Sylvan, in the base of the Hunton limestone. According to the present classification, therefore, the Sylvan shale should be correlated with the Medina, and the line separating the Ordovician and Silurian in the Arbuckle Mountains should be placed between the Viola limestone and the Sylvan shale.

The green clay shales of the Sylvan [Silurian] are succeeded abruptly by hard white to light-blue limestone of the Hunton formation. Usually the contact rock at the base of the Hunton is a massive bed of oolitic limestone. Locally hard bluish limestone beds are found at the base, with rarely a thin layer of brecciated limestone or limestone conglomerate in contact with Sylvan shale. * * *

The Hunton formation is composed of hard, thick crystalline limestones, thin earthy limestone, and marls. It may be separated into three fairly distinct members according to lithologic characteristics, and to a less extent according to color. Except where the formation is very thin * * * the three members can always be distinguished. An average section of the formation on the south side of the Arbuckle Mountains west of Washita River is approximately as follows:

Section of Hunton limestone.

	Feet.
Upper member: Semicrystalline limestone, in places cherty, interstratified with occasional thin marly layers	30
Middle member: Marly limestones and calcareous clays, with some hard limestone layers, more abundant in the lower part	170–190
Lower member: Thick-bedded crystalline limestone succeeded by hard thin limestone with occasional marly layers. At the base of this limestone is an oolite, 4 to 5 feet thick, which locally is silicified	35–40

The lithologic differences by which the members are distinguished are accompanied by faunal changes which afford a basis for age distinctions. The more massive crystalline beds in the lower part of the basal member, ranging in thickness from a thin bed to 25 feet or more, contain forms which are distinctly Clinton. Four Bryozoa and *Triplecia ortoni* are characteristic of the Clinton limestone of Ohio, and their horizon occurs in the St. Clair limestone of northern Arkansas. * * *

The hard thin limestone beds in the upper part of the basal member contain fossils which indicate Niagara age. * * *

The middle member of the Hunton limestone as a whole is abundantly fossiliferous. * * * There can be no question as to the Helderbergian age of this member of the Hunton formation.

The uppermost member of the Hunton formation is probably lower Oriskany in age and equivalent to the Camden chert of Tennessee. * * *

According to the classification of the Paleozoic rocks at present in vogue, this member should be called Devonian, but it is so intimately united, both faunally and structurally, with the underlying Helderberg member, that, for this region at least, it would be doing violence to the natural classification of the rocks to draw a line of systemic importance between them. According to a classification taking into account both the life history and structure of the strata, this divisional line should be drawn either between the flinty beds at the top of the Hunton limestone and the base of the black shale and chert of the overlying Woodford formation, or between the Niagara and Helderberg members. In the latter case the lower member only would be Silurian, and the two upper members Devonian.

I-J 16-17. ALABAMA, GEORGIA, TENNESSEE, WEST VIRGINIA, AND VIRGINIA.

In the zone of Appalachian folds from Maryland southward, the Silurian strata consist of the basal littoral formations and the overlying Clinton ("Rockwood" or "Dyestone") of the Southern States. The basal sandstones (Bays, Ordovician, and Clinch, Silurian) extend from Virginia along the valley of east Tennessee to the longitude of Knoxville. The Clinton or "Rockwood" alone is continuous to Alabama. Higher Silurian deposits, the equivalents of the Niagaran and Cayugan, thin and disappear in southwestern Virginia and northeastern Tennessee, as shown in the sections given below. The Helderbergian is here classified as Devonian, and the upper limit of the Silurian therefore falls in the lower part of the Lewistown limestone of the following sections. The Silurian outcrops in narrow belts intimately associated with and practically coextensive with the Devonian and is, in view of the small scale of the map, indistinguishable from the Devonian in the generalized drawing of the complex structure. The Silurian is therefore represented with the Devonian by the color of the latter south of northern Virginia.

In eastern West Virginia (Piedmont quadrangle) the Silurian has been classified by Darton [228] as follows:

Top.	Feet.
Monterey sandstone, in part; massive calcareous blue-gray sandstone (in part Devonian).	215–300
Lewistown limestone (equivalent to Lower Helderberg [Devonian], Salina, and Niagara):	
Cherty limestone (Lewistown chert lentil)	130–300
Massive light blue gray limestone	20– 80
Shaly limestone	100
Dark-colored limestone	30– 60
Flaggy limestone	450–980
Thin beds of impure limestone with alternations of greenish and gray calcareous shale.	250–310
Rockwood formation (Clinton):	
Gray sandstone	12– 20
Gray, brownish, and greenish shale with iron ore and thin limestone beds	525–750
Cacapon sandstone: Red sandstone, mainly thin bedded	300
Tuscarora quartzite: White or gray massive quartzite	480
Juniata formation: Brownish-red sandstone and shale	750+

The Juniata, Tuscarora, and Cacapon Darton regarded as the representatives of the Medina of New York.

Traced through the Franklin quadrangle, south of the Piedmont, the divisions of the Silurian in the Staunton quadrangle, in central Virginia, are similar but reduced in thickness, as shown by Darton [226a] in the following section:

Silurian rocks in Staunton quadrangle, Virginia.

	Feet.
Monterey sandstone (Silurian and Devonian, Oriskany), in part calcareous	0–300
Lewistown limestone (Silurian): Cherty limestone, pure limestone	300–500
Rockwood formation (Clinton): Gray quartzite, sandy shale	150–200
Massanutten sandstone (Medina): Reddish sandstone, gray quartzite, red and gray sandstones.	500–600

In southwestern Virginia, in the Pocahontas quadrangle, Campbell [123] did not distinguish the "Monterey" sandstone (Oriskany) and Lewistown limestone but named the strata which occupy the interval between the Clinton and the Devonian the Giles formation. His section is as follows:

	Feet.
Giles formation (Oriskany and Lower Helderberg [Devonian]): Coarse yellow sandstone, cherty limestone, coarse reddish sandstone, blue limestone	30–200
Rockwood formation (Clinton): Heavy sandstone or quartzite, sandy shale and ferruginous sandstone with siliceous red fossil ore and hematite	20–400
Clinch sandstone (Upper Medina): Coarse white sandstone or quartzite	150–250
Bays sandstone (Lower Medina) [Ordovician]: Red sandstone and sandy shale	250–350

The Giles formation comprises strata which are grouped because they are usually covered and can not be distinctly traced. In the Kimberling Wilderness, in the eastern part of the Pocahontas quadrangle, Campbell recognized the following divisions:

Section of the Giles formation [*Devonian*].

	Feet.
Greenish sandstone locally containing pebbles of the limestone at the base of the group; thickness not determined.	
Cherty limestone or chert	30–40
Coarse ferruginous sandstone locally composed of small quartz pebbles cemented by iron oxide	15–20
Blue limestone, shaly at the base	30–40

At the boundary between Virginia and Tennessee (in the Bristol quadrangle) the Silurian consists of the Clinch and Clinton or "Rockwood" formations, together with the Hancock limestone (Silurian and Devonian). Here the Bays, Ordovician (350 to 450 feet), and Clinch (250 to 450 feet) are thicker; the Clinton or "Rockwood" (200–300) is similar in thickness to the last section cited. The characters of these formations remain the same.

The Hancock is a blue fossiliferous cherty limestone. It also appears in the northwest corner of the Morristown quadrangle, Tennessee, in latitude 36° 30′ north, longitude 83° 30′ west, but does not occur farther south. Keith [477] states:

In the Powell syncline are found the only areas of this formation [the Hancock limestone] in the valley of east Tennessee, and from its occurrence here in Hancock County it derives its name. The formation consists entirely of interbedded massive and shaly limestones of a blue, gray, or dove color. Massive beds are more frequent at the bottom and top of the formation and attain a thickness of 20 feet. Great numbers of fossils, largely brachiopods, corals, and crinoids, are found throughout the formation and show it to be of upper Silurian [Helderberg, Devonian] age.

In the Greeneville quadrangle, Tennessee (longitude 82° 30′ to 83° west, latitude 36° to 36° 30′ north), east of the Morristown quadrangle, the Silurian comprises the Clinch and part of the Clinton ("Rockwood"). The section as given by Keith [481a] is as follows:

	Feet.
Rockwood formation: Green, red, and yellow sandy and calcareous shale	700+
Clinch sandstone: Massive white sandstone	300–500
Bays sandstone [Ordovician]: Massive and shaly red sandstone	50–400

In the northwestern part of the quadrangle the Clinton ("Rockwood") is lacking and the Chattanooga shale (Devonian) rests on the eroded Clinch sandstone.

In the Briceville quadrangle, 60 miles west of the Greeneville, the Bays (Ordovician) is a "red argillaceous and sandy limestone, 160 to 200 feet thick;" the Clinch sandstone is absent, and the Clinton ("Rockwood"), which rests conformably on the Bays, consists of red and brown calcareous shales, is 400 to 500 feet thick, and carries beds of fossiliferous limestone 4 to 8 feet thick which constitute the fossil iron ores so far as the lime has been replaced by iron.[478]

The type locality of the "Rockwood" formation is in the Kingston quadrangle, Tennessee. The "Rockwood" is there the only representative of the Silurian, but no unconformity is noted either below it at the contact with the Athens shale or Chickamauga limestone (Ordovician) or above it at the contact with the Chattanooga shale (Devonian). Hayes[420] states that the "Rockwood" (Clinton) varies widely in character and thickness within the quadrangle. About the head of the Sequatchie Valley "it is 165 feet thick and is composed of calcareous shales interbedded with blue limestone." Along the foot of the Cumberland escarpment "it is about 600 feet thick and consists of calcareous and sandy shales. Still farther east * * * the formation attains a thickness of 850 to 1,000 feet, a considerable part of which is coarse sandstone interbedded with sandy shales. Toward the top are sandy shales and a few calcareous beds, with which is associated the iron ore."

A similar description applies to the "Rockwood" (Clinton) as it occurs in the Chattanooga quadrangle, Tennessee, as far south as latitude 35°.

I-K 16. INDIANA, OHIO, KENTUCKY, AND TENNESSEE.

Silurian strata envelop the Cincinnati arch and the Nashville dome in the States of Indiana, Ohio, Kentucky, and Tennessee. There is in many places an unconformity at their base corresponding to the latest Ordovician. The strata themselves are very largely limestones, which differ locally in character and in faunal contents. They have been minutely classified, and the details are to be found in the State reports and in recent articles.[336, 337, 340, 341, 342, 431]

The Silurian strata of Indiana may be divided, according to Foerste,[342] into—

	Feet.
Louisville limestone (at the top)	55+
Waldron clay	4–20
Laurel limestone	40–48
Osgood clay and limestone	11–16
Clinton limestone (at the base)	0–11

The "Clinton" is regarded by Foerste as distinct. The other four divisions he assigns to the Niagara.

The "Clinton" succeeds the Ordovician with local unconformity and contains rounded fragments of Ordovician rocks around the margins of islands, which it did not cover. It is in many places a detrital limestone but has also dense siliceous or clayey facies.

The Osgood consists chiefly of clay shale with 8 to 15 inches of limestone at the base. Where the shale gives place to lime the limestone thickens, and it is correlated with the Dayton limestone of Ohio.

The Laurel limestone is usually hard, white, and evenly bedded. Toward the south it becomes softer and more argillaceous.

The Waldron shale is a distinct bed overlying the Laurel, and is mainly a clayey shale having the facies of the Osgood shale. It becomes calcareous toward the north.

The Louisville limestone, which at Louisville is unconformably overlain by Devonian limestone and has a thickness of 55 feet, is described as thinning out toward the north and east. Foerste [342b] comments as follows on the relations of Silurian and Devonian:

The absence of any mention of distinct unconformity at most localities so far examined suggests that the Silurian-Devonian contact is not marked everywhere by strong unconformity, but that at many points in northern Indiana the unconformity is slight. In the southern part of the State the Silurian-Devonian contact is also accompanied by a slight unconformity.

The Waldron shale and its abundant fauna constitute the subject of an article by Kindle and Barnett,[504] who refer to the paleontologic work of Hall and state in part:

The Waldron shale is composed mainly of fine-textured blue to greenish clay shale. Thin bands of impure limestone and calcareous nodules sometimes occur in the shale but represent a comparatively insignificant proportion of the formation. The Waldron shale has a thickness ranging generally from 4 to 10 feet. So far as observed by the writers the Waldron beds are conformable with the Niagara limestone beds above and below. * * * Although a very thin formation, the Waldron is very persistent and extends southward from southern Shelby and Rush counties to the Ohio River, a distance of about 85 miles. The Waldron shale is not known north of the central part of the State. The heavy mantle of drift to the north of its northernmost exposures in Rush and Shelby counties conceals a large area in which important stratigraphic changes take place, the precise nature of which is unknown. All that we know certainly about them is that they result in a Silurian section in the Wabash Valley in which neither the Waldron shale nor its two accompanying limestone formations have been identified. It may be that the Cincinnati geanticline, which is believed to have been in existence during the Waldron shale interval, as pointed out elsewhere in this paper, swung to the westward across north-central Indiana, making distinct marine basins in northern and southern Indiana. Certain differences in the faunas as well as the stratigraphy of the Silurian of the northern and southern Indiana sections could be cited in support of this hypothesis.

The fauna of the Waldron, which comprises 160 species, is contrasted by Kindle and Barnett with that of the Louisville limestone, with which it has remarkably little in common. Full lists of fossils are given.

The faunas of the several divisions of the Silurian in Indiana are distinguished by Foerste,[342a] who recognizes close affinities between those of the Laurel and Louisville on the one hand and between those of the Waldron and Osgood on the other.

The divisions enumerated are described particularly from occurrences in southeastern Indiana; in northern Indiana the Niagara strata are not differentiated. The identification of these Niagaran formations and their correlation with the New York section are considered by Foerste. He also identifies a water-lime rock occurring at Kokomo, Ind., as the probable equivalent of the Bertie water lime (lower Cayugan) of the New York State reports.

The Silurian of Ohio was classified by Prosser [651] in 1905 as follows:

Northwestern Ohio.		Feet.
Monroe formation	Lucas limestone; Sylvania sandstone; Tymochtee member (?)	50–600

Northern Ohio.	Southern Ohio.	Feet.
"Niagara group"	Hillsboro sandstone; Cedarville limestone; Springfield limestone; West Union limestone; Osgood beds; Dayton limestone	150-350
Clinton limestone		10-50
Medina shale (?)	Belfast bed (5 feet)	50-150

Detailed descriptions of the formations are given by Prosser[649] in another article.

The Silurian and Devonian limestones of Tennessee and Kentucky are discussed by Foerste[336a] in some detail. He locates the Cincinnati anticline in these States and says:

This fold was in existence in early Devonian, if not in Silurian times. No Silurian formations occur along the crest of the fold in central and southern Kentucky, or in northern and central Tennessee. * * * Surrounding this area and overlapping the Ordovician on the flanks and ends of the anticline are Silurian strata, the total thickness of which diminishes on approaching the crest of the fold.

The result is that Devonian strata rest on Silurian formations along the flanks and ends of the anticline, but along the crest, from north of central Kentucky to southern Tennessee, they rest directly on the Ordovician. * * *

There is * * * a remarkable similarity in the characteristics shown by the most southern Silurian exposures in Kentucky and the most northern outcrops in Tennessee. This similarity extends even to the minor subdivisions of the group. * * *

The most accessible of the Silurian sections in northern Tennessee is that along the Louisville & Nashville Railroad, near South Tunnel, about 10 miles south of the Kentucky border.

In several railroad cuts Foerste found the Chattanooga shale (Devonian) resting upon the Waldron shale (Silurian), and that in turn upon the Laurel limestone, 28 feet thick.

Both in Kentucky and Tennessee the top of the limestone [Laurel], especially the oolitic layer, contains fossils which also occur but in greater abundance in the Waldron shale. At South Tunnel *Whitfieldella nitida* occurs in the oolitic layer. *Orthoceras amycus* is found near the middle of the Laurel limestone. *Pisocrinus gemmiformis* is common near the base. This fossil is especially abundant at a fourth railroad cut. * * * The base of the formation is here a crinoidal limestone. In Indiana and northern Kentucky *Pisocrinus gemmiformis* occurs abundantly, both in the base of the Laurel limestone and in the limestone layers placed at the top of the Osgood beds. Farther south it becomes difficult to determine where to draw the line between the limestone layers belonging to the Laurel and those referred to the top of the Osgood beds. In Tennessee it is impossible to make such a separation, and here all of the limestone section is referred to the Laurel.

Foerste mentions localities where the Laurel limestone rests on clayey material which stratigraphically undoubtedly represents the Osgood shale of Kentucky though lithologically it is much less shaly.

At South Tunnel the Clinton is first seen in the form of fragments of fossiliferous chert. * * * The lower part of the Clinton is a bluish limestone, containing much less chert and only a few fossils. It resembles so much the top of the immediately underlying Ordovician rock, in which fossils are also scarce, that it requires patience to determine where to draw the line between the Silurian and the Ordovician rocks.

Foerste [340a] also discusses the limestones of western Tennessee, in part as follows:

In southern Indiana the Silurian strata are divided into the following beds, named in descending order:

Louisville limestone.
Waldron shaly clay.
Laurel limestone.
Osgood shaly clay.
Clinton limestone.

Southward, along the western flank of the Cincinnati geanticline, the equivalents of these beds may be traced with varying success even as far as northern Alabama. * * * Very little change is shown in the lithological characteristics of any of these subdivisions between southern Indiana and northern Tennessee. North and south of this area, however, the Osgood bed rapidly becomes more calcareous and is changed from a shaly clay to a soft limestone, weathering more readily than the Clinton limestone below or the Laurel limestone above. The Waldron bed also becomes calcareous northward and is replaced by limestone in central Indiana. Southward it may be traced as far as northern Alabama, but in central and southern Tennessee it is only 3 to 4 feet thick, and along the middle part of the bed the clay is replaced by a layer of limestone 6 to 10 inches thick. Both northward in Indiana and southward in Tennessee the Waldron bed maintains its characteristics as a shaly clay farther than the Osgood bed.

The thickest sections of the Osgood bed are found in central Kentucky. * * * At Bledsoe in northern Tennessee, the Osgood bed consists chiefly of soft clay. * * * In central and southern Tennessee the Osgood bed consists of rather thin bedded limestones weathering back more readily than the Laurel bed above and the Clinton bed beneath. Here its identity can often be established only with difficulty. The Waldron bed maintains its character as a shaly clay horizon much farther southward than the Osgood bed. It is typically developed along the Harpeth River near Newsom. At this locality it contains a large part of the fauna characteristic of this horizon at Waldron, Ind. In central and southern Tennessee a thin bed of limestone, 6 to 10 inches thick, replaces the clay along the middle of the bed. * * *

Along the western flank of the Cincinnati geanticline, in southern Indiana, Kentucky, and Tennessee, the name Louisville bed has been given to the Silurian rocks overlying the Waldron bed. In the Tennessee River valley, in western Tennessee, the Silurian section overlying the Waldron bed is so thick that it has been found necessary to subdivide it.

At the base is a series of limestones, varying from 30 to 45 feet in thickness, to which the name Lego limestone is here given. Stratigraphically this bed occupies the same position as the Louisville bed. Its paleontological equivalence, however, has not yet been determined, owing to the small number of fossils so far obtained in the Lego limestone. Overlying the Lego limestone is a series of red clays, 30 to 45 feet thick, to which the name Dixon clay is given. This clay has so far proved comparatively unfossiliferous. * * * Above the Dixon red clay is a section of white limestones and clays, exceeding 100 feet in thickness. This section is often richly fossiliferous. * * * To this section overlying the Dixon red clay the name Brownsport bed is here given.

Lithologically the limestones forming the middle and lower part of the Lego bed often resemble those forming the Laurel bed so much that, in the failure to identify the Waldron horizon, it is impossible to distinguish the same.

Foerste [340d] gives the early and later nomenclature applied to the strata and the equivalence of the limestones to other beds. The Clifton formation (the Meniscus limestone of Safford) includes all the Niagaran strata present in western Tennessee.

J 15. EASTERN MISSOURI AND SOUTHERN ILLINOIS.

According to Savage [703a] the Silurian is represented in southern Illinois only by thin-bedded dark-gray limestone with chert overlain by heavy-bedded pink or mottled limestone, the whole 29 to 75 feet thick, to which he applied the name Clinton. Savage states that the fauna corresponds to that obtained from the Clinton (so called) of Dayton, Ohio.

In eastern Missouri there is a white oolitic limestone followed by buff dolomite, 10 to 30 feet thick altogether, which may represent the Niagara [491b] or may be of Devonian age. It rests on Maquoketa shale (Ordovician) and is overlain by the Louisiana limestone (Mississippian). The occurrence is not shown on the map accompanying this volume.

J-K 11-12. NEVADA AND UTAH.

In the Eureka section, Nevada, the Eureka quartzite (Ordovician) is according to Hague [391a] unconformably followed by "steel-gray, almost black gritty limestone" and "dark bluish-gray limestone" about 300 feet thick, which contain Trenton fossils. There is no lithologic division but a gradual passage—

> into light-gray siliceous limestone, with a peculiar saccharoidal texture, in places becoming almost white and wholly without bedding. On the surface the limestones weather brown and buff, their light colors throughout a great vertical range standing out in strong contrast with the other massive beds of the Paleozoic. It weathers in rounded outlines, breaking with an irregular fracture and presenting a monotonous appearance wearisome to the eye. Rock of this character makes up by far the greater part of the horizon, and then by slow, imperceptible changes it becomes darker in color, with more and more tendency to develop planes of stratification, and gradually passes into the overlying limestone of the Devonian.
>
> As already mentioned, an unconformity exists between the Eureka quartzite and the Lone Mountain limestone. There is therefore no direct evidence in the district of the thickness of the limestone. The average thickness of strata exposed has been taken at 1,800 feet, but it is probable that this is under rather than over estimated, and at Lone Mountain they attain a somewhat greater development, at least 2,000 feet being exposed. * * *
>
> Above the Trenton no good grouping of fossils has as yet been discovered until the Devonian rocks are reached. The other portion of the Silurian limestone presents a most forbidding aspect for the preservation of organic remains, and although diligent search has been made throughout the horizon it was rewarded only by finding a few imperfect corals, belonging to the species *Halysites catenulatus*, which is so characteristic of the Niagara of the East, and here found in what should be its true geological position. They have a wide range and occur nearly 1,500 feet above the summit of the Eureka quartzite. The same coral has been obtained from Lone Mountain and White Pine, and in both these latter localities associated with the genus Zaphrentis.

See also Walcott [847] on the paleontology of the Eureka district.

The distribution of the Lone Mountain limestone (now regarded by Ulrich as all Ordovician and so treated by Emmons [324] in a recent report) or its equivalent strata has been traced chiefly by Spurr [772] and by Weeks (in an unpublished paper), from whose maps the formation is sketched.

A recent note on the occurrence of a Silurian fauna in Utah has been given by Kindle.[498b] The section corresponds with that at Eureka, the fauna occurring in a magnesian limestone 200 to 300 feet thick, below which is a much darker limestone of undetermined age and above which lie dark magnesian limestones of Devonian age. The locality is in the Wasatch Mountains in northeastern Utah, and the same section was observed in Logan Canyon, 12 miles farther north.

Blackwelder [846] as a result of recent work says:

As exposed on the crest of the range [Wasatch] there is, between the Ordovician quartzite and the identifiable part of the Mississippian limestone, a succession of dark limestones * * * having a thickness of 1,000 to 1,500 feet. In the lowest beds there are corals such as Halysites and Favosites. At a slightly higher horizon there are abundant shells which Kindle thinks are the same as his Pentamerus fauna of the Bear River Range.

J-K 17-18. EASTERN NEW YORK, NEW JERSEY, PENNSYLVANIA, AND MARYLAND.

Grabau [384] describes the Silurian of New York and its relations to other sections in part as follows:

The following divisions of the New York Niagaran are in common use as the North American standard: Guelph, Lockport, Rochester, Clinton.

The Clinton of the best-known section, that of western New York, begins with the true or Upper Medina, which, along the Niagara River, admits of a number of subdivisions, which are, however, of only local significance.[a] The total thickness is nearly 125 feet, with 25 feet of white quartzose sandstone (Whirlpool sandstone) at the base and about 8 feet of a similar sandstone at the top. The middle series consists of red sandstones and green and gray sandstones and shales. The red sandstones generally show eolian cross-bedding and appear to have accumulated above water. The green sandstones and shales are fossiliferous. The white Whirlpool sandstone exhibits beach features [b] and probably marks the advance of the sea, though it is likely that the sand was originally dune sand, as suggested by A. W. G. Wilson.

The fossils are generally most abundant in the shales and thin-bedded sandstones. The heavy-bedded sands are either free from fossils or have only scattered shells of Lingulæ. At Lockport and elsewhere some layers are crowded with gastropod shells.

A list of fossils from the Medina follows, and Grabau continues:

This is a Lower Siluric [lower "Upper Silurian"] fauna, and favors more especially the Clinton and Rochester faunas. It is so far known only from western New York, with the exception of *Arthrophycus harlani*, which is widely distributed. In western New York this species occurs at the top of a heavy-bedded unfossiliferous sandstone with an eolian type of cross-bedding, and just below the upper white quartzite. In east-central New York it is found at the base of the Oneida conglomerate, which is the approximate equivalent of the upper white sandstone of Niagara. In the Appalachians it is found mostly in the upper part of the Tuscarora and Clinch sandstones, the stratigraphic equivalent of the Medina. * * *

The Tuscarora has a thickness of 820 feet in Logan's Gap, Jack's Mountain, Mifflin County, Pa., but thins perceptibly westward and southward, being 400 to 500 feet thick in Bald Eagle Mountain and 287 feet in Wells Mountain and the Pennsylvania-Maryland line. This thinning appears to be due to failure of the lower beds, showing a true case of nonmarine progressive overlap. In New York the upper part is represented by the true Medina, which has a thickness of 125 feet and begins and ends with a pure white quartz sandstone. More strictly speaking, the upper white sandstone alone represents the true Tuscarora, but the lower beds, still partly red, and the shales probably are the equivalent of the lower reddish sandstones and greenish shales underlying the true white Tuscarora, and sometimes referred to the Upper Juniata. The Oneida conglomerate of central New York, 40 feet thick, is likewise the representative of the upper part of Tuscarora, though it may have had a more local origin. * * *

The Clinton shales succeed the Oneida conglomerate in Oneida and Herkimer counties, N. Y., and the Upper Medina quartzite in western New York. In the southern Appalachians

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[a] See Bull. New York State Mus. No. 45, pp. 88-95.

[b] Fairchild, H. L., Am. Geologist, vol. 28, 1909.

the series is largely composed of sandstones (Rockwood), highly impregnated with iron and often containing beds of workable iron. It is generally succeeded by late Siluric (Monroan) or by Helderbergian or later beds, there being a pronounced disconformity at the summit of the Rockwood throughout. That part of the series in Virginia is of continental origin is indicated by the general character of the rocks, but marine intercalations are not uncommon. In some cases in eastern Tennessee the iron ore itself is fossiliferous, having replaced a marine limestone. In such cases the bulk of the formation is shale. In no case is the original thickness preserved, since the formation is everywhere bounded above by an erosion plane. In northern Virginia to-day the thickness is 750 feet (Piedmont folio), and not over 400 feet in southern Virginia. In southern Tennessee and northern Georgia it is from 1,100 to 1,600 feet thick, decreasing westward and northward. With our present knowledge of the formations, it is safe to say that the eastern sandy phase represents near-shore deposits, if not actually continental conditions, formed probably at the embouchures of several Appalachian rivers; and that westward these deltas merged gradually into true marine deposits, mainly sands and clays, with some limestones intercalated. That the Rockwood represents more than the Clinton of New York can not be questioned. Where the series is developed in its totality, it probably represents the entire Niagaran, if not a part of the Salinan as well. Along the Allegheny Front fossiliferous shales and iron ores represent this series, with a thickness of not less than 1,000 feet, on the western branch of the Susquehanna. The lower series, 700 feet thick, consists mainly of fissile shales, including an iron sandstone, and with Buthotrephis in the upper part. This is succeeded by 110 feet of calcareous fossiliferous shales; and this by 230 feet of fossiliferous shales and limestones with a Niagaran fauna. Above this follows 350 feet of red shales, probably representing the Upper Salina and separated by a hiatus from the fossiliferous Niagaran shales.

In eastern New York, at Swift's Creek, the type locality for the Clinton, this formation is 226 feet thick and is followed by 5 feet of Niagaran and then by the red shales of the Upper Salina. On the Niagara River the Clinton shale with the two succeeding limestones has a total thickness of 32 feet, followed by 68 feet of Rochester shale. The total of the Niagaran, including the Guelph, is from 270 to 325 feet, as shown by borings. This is followed by Lower Salinan. In the Rochester region the Clinton has a thickness of 80 feet, including the Irondequoit or upper limestone (17 feet), which Chadwick refers to the Rochester. The eastward thinning of the Upper Niagaran beds indicates either that these beds were eroded before the deposition of the red shales, probably during the Shawangunk epoch, or that the Rochester-Lockport of the west is in part represented by Upper Clinton in the east. The Guelph element may never have extended to the Clinton type region, which may have been above water and so subject to erosion.

Local details are given in papers by Darton,[222-225] Ries,[672] Clarke,[156] Grabau,[378, 380] Hartnagel,[409-412] and Merrill [592] published in the New York State reports and elsewhere.

A critical and comprehensive report on the Silurian formations in New Jersey has been made by Weller.[880b] The following is a condensed section of the formations which he distinguishes from the base up.

	Feet.
Shawangunk conglomerate: Coarse quartz conglomerate, of white or yellowish pebbles in a gray or red matrix; unfossiliferous; unconformable on Hudson (Ordovician) shale.	1,500–1,600
Medina-Longwood sandstone: Soft, often somewhat shaly, and deep red; unfossiliferous.	2,300–2,400
Poxino Island shale: Greenish, calcareous, unfossiliferous	1–200 (?)
Bossardville limestone: Fine-grained, compact bluish-gray banded limestone, unfossiliferous	12–100
Decker Ferry formation: Sandstone with thin calcareous beds or limestone with some thin bands of greenish shale; highly fossiliferous; divided into three faunal zones and the uppermost into three subzones; correlated with the "Coralline" (Niagaran) limestone of eastern New York; presumably contemporaneous with but faunally not closely related to the Niagara limestone of the Mississippi Valley	50

	Feet.
Rondout formation: Shales and earthy limestones; sparsely fossiliferous; name restricted to the upper cement bed of the section at Rondout	39
Manlius limestone: Thin bedded, knotty, dark blue to black; fauna limited, exhibits from base to summit a passage from life conditions suitable only for Leperditia to normal marine conditions; gradual transition from Rondout faunally and stratigraphically; pronounced faunal break in passing to the overlying Coeymans (basal Helderbergian) Devonian limestone	35
	4,424

The Silurian rocks described by Weller extend into Pennsylvania, but with changes which are described in great detail in the county reports of the Second Geological Survey of Pennsylvania under the names Lewistown limestone, Bloomsburg shale, and Bossardville limestone. The facts are assembled by Lesley.[535] A typical section, which shows the great thickness of strata and their intimate lithologic similarities or gradual changes, is that of Logan Gap, Mifflin County, in the central part of the State. The descending section is summarized by Lesley[535a] as follows:

		Feet.
j. Salina gray shale		164
k. Salina variegated shale	423 feet	348
l. Logan limestone		$3\frac{1}{2}$
m. Logan shale		72
n. Salina upper red shale		432
o. Salina upper lime shale		326
p. Salina lower red shale		272
q. Clinton lower lime shale. r. Clinton upper olive shale		251
s. Ore sandstone and ore beds		38
t. Clinton middle olive shale		178
u. Iron sandstone		7
v. Clinton lower olive shale		571
w. Medina white sandstone		820
x. Medina red sandstone and shale		1,280
y. Oneida red conglomerate		309
z. Oneida gray sandstone		313
a. a. Hudson River slates.		
		5,384

The Silurian rocks recognized in New Jersey have been traced southward through Pennsylvania. The strata become thinner to the south. The unconformities observed in New York and New Jersey at the base of the Silurian are not noted in the Pennsylvania sections, where the basal gray sandstone succeeds the Martinsburg ("Hudson River") shale (Ordovician) in apparent conformity.

The littoral and calcareous marine strata which constitute the Silurian in Pennsylvania pass across Maryland into Virginia. They have been described by Prosser [646] and O'Harra.[619] The section, which measures 2,200 to 2,400 feet in thickness, is fully described and correlated by Prosser, the following being a condensed section of the subdivisions recognized by him, from the base up:

	Feet.
Juniata formation: Alternating beds of shale and sandstone, deep red, unfossiliferous, probably equivalent to the older part of the Medina of New York	550+
Tuscarora formation: Quartzose sandstone, white to light gray; *Arthrophycus harlani*	250–300
Clinton formation: Shales, yellowish green to red, with thin fossiliferous limestones in upper part, and two beds of iron ore	550–600
Niagara formation: Thin-bedded blue limestone with thin shale partings, becoming shaly and blackish above; represents the Decker Ferry formation of New Jersey and is equivalent in time to Rochester shale and Lockport limestone or Niagara of New York	250–300
Salina formation [Cayuga group]: Shales, impure limestones including four cement beds, and sandstone, gray and blue, sparsely fossiliferous	700

The overlying Helderberg limestone is assigned by Prosser to the Devonian.

The Silurian of New Jersey has also been described by Kümmel[513b] as follows:

Contrary to long prevalent and apparently well-established belief, the lower and middle portions of the Silurian system are not represented in New Jersey. Their absence in this and adjoining regions is indicative of somewhat widespread earth movements unaccompanied in this region by folding, which closed the period of deposition indicated by the Martinsburg sediments or possible overlying beds afterwards removed by erosion and raised the region above the zone of sedimentation. When deposition began again, late in Silurian time, beds of coarse conglomerate were laid down, followed by sandstones, shales, and limestones, the earlier sediments being those of a low-grade delta in an arm of the Appalachian gulf.[a] These conditions of deposition prevailed with but slight changes of elevation into Devonian time.

The Shawangunk conglomerate (the Oneida conglomerate of many previous publications) is chiefly a coarse quartzite and conglomerate composed of small white-quartz pebbles embedded in a siliceous matrix. Its color is generally steel-blue, but some beds have a yellowish tinge and reddish layers occur near the top. Layers of black shale a few inches in thickness are locally intercalated between thick beds of conglomerate and grit. Between this formation and the Martinsburg shale there is a gap representing the upper part of the Ordovician and all of the Silurian below the Salina of the full New York section, but there is no marked divergence of dip and strike where the two formations outcrop in proximity, and the actual contact is nowhere exposed in New Jersey. The beds overlying the Shawangunk conglomerate are red sandstone and shale, and the transition from the Shawangunk is made through a series of alternating red sandstone and gray conglomerate, so that the upper limit of the Shawangunk is not sharply defined. Its thickness is probably from 1,500 to 1,600 feet.

So far as known, the formation is barren of fossils in New Jersey, but at Otisville, N. Y., a eurypterid fauna has been found in the black shale intercalated with the conglomerate. In the Otisville section this fauna, which elsewhere appears only and briefly at the base of the Salina, repeats itself many times through a thickness of 650 feet.[a] The Shawangunk conglomerate is followed by 2,500 feet or more of shales and limestones also referable to the Salina; hence for this region it represents only the lower portion of that group.

The red sandstone and shale which immediately overlie the Shawangunk conglomerate have until recently been regarded as the equivalent of the Medina sandstone of New York and have been so called, but, for the reasons just cited, it is evident that they are much younger than Medina and that they must be included in the Salina group. Moreover, they lie some distance below a limestone which is correlated with the Cobleskill of the New York section. The name High Falls has been applied to the red shales that overlie the Shawangunk conglomerate in Ulster County, N. Y., and has been adopted for New Jersey in place of Medina, which is not applicable.

The lower beds consist of a hard red quartzitic sandstone, intercalated with some green or gray sandstones and softer red shales which become more abundant in the upper part of the formation. The formation has an estimated thickness of 2,300 feet at Delaware Water Gap. It is not known to contain fossils, but its age is fixed by its stratigraphic position.

The formation known as the Green Pond conglomerate occurs in an isolated belt of Paleozoic rocks which extends through the middle of the pre-Cambrian Highlands of New Jersey. In constitution it is similar to the Shawangunk conglomerate, with which it is correlated, but, inasmuch as it is still an open question whether the Paleozoic strata of the Green Pond Mountain region were once continuous with the great mass of Paleozoic sediments which lie some distance to the northwest, or whether the Green Pond region represents a separate basin shut off on the northwest from the large Paleozoic sea although communicating with it to the northeast, it has seemed best to retain for the present at least both Shawangunk and Green Pond as names for these conglomerates in their respective fields.

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[a] Clarke, J. M., Bull. New York State Mus. No. 107, 1907, p. 303.

Immediately above the Green Pond conglomerate, and conformable with it, is a soft red shale [Longwood shale], in which an irregular cleavage is usually so highly developed that the bedding planes can be determined only with difficulty. The formation is not known to contain fossils, but, as it rests directly upon the Green Pond conglomerate and is followed by a limestone carrying a Salina fauna, it is probably of Salina age. Its stratigraphic position is, in general, the same as that of the High Falls formation, but the two may not be exactly synchronous.

The higher Silurian and the Devonian formations of New Jersey occur either in Wallpack Ridge, which lies along the northwestern border of the State in the upper Delaware Valley, or in the narrow belt of Paleozoic rocks in the midst of the highlands in the Green Pond Mountain region. In Wallpack Ridge they aggregate 1,300 feet or more, while in the Green Pond Mountain region they have a thickness of about 4,000 feet, of which all but 250 feet are referable to beds higher than any of those along Wallpack Ridge.

The top of the High Falls shale in New Jersey is everywhere buried by glacial drift which also conceals the beds immediately superjacent. The next recognizable formation is the Poxino Island shale, a buff or greenish calcareous shale in thin layers and nonfossiliferous so far as known. Its outcrops along the base of Wallpack Ridge in the upper Delaware Valley are few, small, and widely separated, and very little is known regarding it. In the adjoining portion of Pennsylvania it is reported to be 200 feet in thickness and to rest on a thin limestone formation which in turn rests on the High Falls shale. It is not known to occur in the Green Pond Mountain region.

A fine-grained, compact bluish-gray banded limestone, known as the Bossardville limestone, lies conformably upon the Poxino Island shale in Wallpack Ridge. It increases in thickness from 12 feet at the New York State line to about 100 feet where it crosses the Delaware River into Pennsylvania. Owing to its marked banding it was for many years known as the "Ribbon" limestone and was correlated by Cook and later geologists with the Ribbon or Manlius limestone at Rondout, N. Y. In reality it lies below the Manlius limestone. It is only sparingly fossiliferous but is immediately succeeded by a series of beds containing a well-defined Salina fauna. It has not been recognized in the Green Pond Mountain belt, but this may be from lack of exposures.

Under the name Decker Ferry formation a series of beds has been described, which are chiefly limestones at the north and calcareous sandstones at the southwest. Their thickness is 52 feet at the Nearpass quarry near Tristates, where the section can be accurately measured. Thin bands of more or less fissile green shale separate the limestone beds. A thin band of red, crystalline, highly fossiliferous limestone occurs about the middle of the series and is a striking feature. The lower 42 feet of these beds as exposed at the type locality are correlated [a] with the Wilbur limestone (the so-called "Niagara" or "Coralline" limestone of Hall and other authors) and the "black cement" beds—that is, the Salina "water lime" of the Rondout section of New York. These form the top of the Salina group, the base of which in New Jersey is the base of the Shawangunk conglomerate. The upper 10 feet of the Decker Ferry series contain fossils, particularly in the lower half, which render necessary their correlation with the Cobleskill limestone of eastern New York.

In the Green Pond Mountain region isolated outcrops of impure limestone occur a short distance above the Longwood shale, which contain a fauna that correlates them with the lower beds of the Decker Ferry formation—that is, to the part referable to the Salina group.

Along the upper Delaware the beds immediately above the Decker Ferry limestone and referred to the Rondout consist of more or less earthy shales and limestones the thickness of which is 39 feet. They are usually only sparingly fossiliferous, although in some beds the crustacean Leperditia is abundant. A typically marine fauna, with an abundance of brachiopods, trilobites, etc., is conspicuously absent in these beds. In general lithologic features this formation resembles the Rondout as developed in New York State, but the cement beds which are so characteristic of this formation farther north are not present here.

[a] Hartnagel, C. A., Bull. New York State Mus. No. 69, 1903, p. 1152.

The Rondout is succeeded conformably by a somewhat thin bedded, knotty dark-blue or almost black limestone, 34 to 35 feet thick where best exposed. It is the bed which constitutes the quarry stone of the Wallpack Ridge and its outcrop is marked by a line of quarries and limekilns. It is referred to the Manlius or "Tentaculite" limestone of the New York series, although well-preserved specimens of the characteristic fossil *Tentaculites gyracanthus* Eaton are rare. In the lower beds there is evidence of environmental conditions similar to those of the Rondout. In the middle portion Leperditia is still abundant but is associated with a prolific brachiopod fauna, suggestive of the recurrence of more typical marine conditions. In the upper beds Leperditia has entirely disappeared and the fauna is normally marine. No beds referable to the Rondout or Manlius have been detected in the Green Pond Mountain region, although their attenuated representatives may occur.

K 10. TAYLORSVILLE DISTRICT AND KLAMATH MOUNTAINS, CALIFORNIA.

The Paleozoic section of the Taylorsville district, in the Sierra Nevada just north of the fortieth parallel, comprises at the base the Grizzly formation (400 feet, possibly Ordovician), the Montgomery limestone (10 to 60 feet), and the Taylorsville formation (1800 feet). The Montgomery limestone has yielded fossils which Walcott determined as representing the "Niagara horizon of the Mississippi Valley and Appalachian provinces." [271a]

In the Klamath Mountain region the Abrams and Salmon formations of Hershey[435] are assigned by Diller[276b] to a pre-Devonian age, as they are older than the fossiliferous Devonian.

The Silurian area of the Taylorsville district is too small to show on the scale of the map of North America.

K 15–16, L 16. IOWA, NORTHERN ILLINOIS, AND WISCONSIN.

Chamberlin and Salisbury[134c] have compiled the following section of the Silurian of Iowa from the reports of the Iowa Geological Survey:

Silurian formations of Iowa.

Formations.	Thickness (feet).	Characteristics.
Anamosa limestone	50–75	Soft, granular, evenly bedded dolomite; white to buff and gray; important building stone.
Le Claire limestone	50	Massive or heavy-bedded, highly crystalline dolomite. Upper surface undulating; cross-bedded on a large scale.
Delaware stage	200	Limestone containing large quantities of chert.
Unconformity.		

The middle formation of the section is described by Samuel Calvin[116] as follows:

The Le Claire limestone constitutes the second stage of the Niagara formation as it is developed in Iowa. The first or lower stage has been called the Delaware, from the fact that all its varying characteristics are well exhibited in Delaware County. The Delaware stage embraces many barren beds and presents a very great number of phases, but at certain horizons it abounds in characteristic fossils. The typical faunas of this lower stage embrace such forms as *Pentamerus oblongus* Sowerby, *Halysites catenulatus* Linnæus, *Favosites favosus* Goldfuss, *Strombodes gigas* Owen, *Strombodes pentagonus* Goldfuss, *Ptychophyllum expansum* Owen, and *Diphyphyllum multicaule* Hall. The beds of the Delaware stage furthermore contain large quantities of chert.

The Le Claire stage of the Niagara follows the Delaware. The exact line of separation between the two stages has not been and probably can not be definitely drawn. There are massive, barren, highly dolomitized aspects of both stages that, taken by themselves, can not be differentiated in the field. Under such circumstances the observer must work out the stratigraphic relations of the particular group of strata under consideration before referring it to its place in the geological column. In general the Le Claire limestone is a heavy-bedded, highly crystalline dolomite. It contains scarcely any chert, and in the lower part there are very few fossils. There are occasionally a few specimens of Pentamerus, of the form described as *Pentamerus occidentalis* Hall, and the principal coral is a long, slender, tortuous Amplexus which is represented only by casts of the vacant or hollow parts of the original corallum. On account of the complete solution of the original structure, the spaces occupied by the solid parts of the corallum are now mere cavities in the limestone. In the upper part of the Le Claire stage small brachiopods abound. They belong to the genera Homeospira, Trematospira, Nucleospira, Rhynchonella, Rhynchotrepa, Atripa, Spirifer, and probably others. In most cases the fossils have been dissolved out, leaving numerous cavities. The calcareous brachial apparatus of the spire-bearing genera is often the only part of the original structure represented. No statement can well give any idea of the numbers of the small shells that crowded the sea bottom near the close of the Le Claire stage, nor of the corresponding number of the minute cavities that are now so characteristic a feature of this portion of the Le Claire limestone. In some localities in Cedar County the small brachiopods of this horizon are represented by very perfect casts that were formed by a secondary filling of the cavities left by solution of the original shell. The external characters are thus fairly well reproduced.

Compared with the beds of the Delaware stage, the Le Claire limestone as a rule lies in more massive ledges, it is more completely dolomitized, and its fracture surfaces exhibit a more perfect crystalline structure. It contains an entirely different fauna, a fauna in which small rhynchonelloid and spire-bearing brachiopods are conspicuous. Its fossils are never silicified, and, in marked contrast with some portions of the Delaware, its upper part at least is notably free from chert. * * *

The Le Claire limestone is in some respects unique among the geological formations of Iowa. In the first place it varies locally in thickness, so much so that its upper surface is exceedingly undulating, the curves in some places being very sharp and abrupt. In the second place it differs from every other limestone of Iowa in frequently exhibiting the peculiarity of being obliquely bedded on a large scale, the oblique bedding often affecting a thickness of 15 or 20 feet. The phenomena suggest that during the deposition of the Le Claire limestone the sea covered only the southwestern part of the Niagara area, that at times the waters were comparatively shallow, and that strong currents, acting sometimes in one direction and sometimes in another, swept the calcareous mud back and forth, piling it up in the eddies in lenticular heaps or building it up in obliquely bedded masses over areas of considerable extent. The oblique beds observe no regularity with respect to either the angle or direction of dip. Within comparatively short distances they may be found inclining to all points of the compass. Again the waters at times were quiet, and ordinary processes of deposition went on over the irregular sea bottom, the beds produced under such circumstances conforming to the undulating surface on which they were laid down.

In Illinois and Wisconsin the Silurian is known simply as the Niagara dolomite or limestone, the formation varying in lithology in different areas. The formation in Illinois is thus described by Bain: [51a]

Above the soft shale of the Maquoketa is a fine-grained dolomite, carrying more or less chert. This forms the uppermost member of the stratigraphic section in this area. The beds in the lead and zinc district form only the lower portion of the great thickness of strata which have long been known collectively as the "Niagara." There is no established local name for these particular beds, and since they were doubtless formed at some time within the "Niagara" epoch the group term will be provisionally used for them. * * * A thickness of 150 feet is present.

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The "Niagara" dolomite is distinguished from that of the Galena not only by the occurrence of certain characteristic fossils, of which *Halysites catenulatus* is probably most widespread and easily recognized, but also by fairly constant lithologic differences. In general, the "Niagara" is much lighter colored, finer textured, and is relatively free from the small irregular cavities which mark the Galena.

K-L 12. SOUTHWESTERN MONTANA AND WESTERN WYOMING.

Silurian strata may be absent in southwestern Montana and western Wyoming. They have not been identified by their fauna. In general the Cambrian, or the Ordovician where present, is succeeded by Carboniferous, but the Jefferson limestone (Devonian) intervenes in some sections and is underlain by strata that appear to represent the Silurian in seemingly conformable sequence.

Kindle [499a] studied the distribution of the Jefferson limestone (see p. 320, Chapter VI) and discusses the Silurian in certain sections. For the section on Boulder Creek, west of Princeton, Mont., in the Philipsburg quadrangle, he says:

> No fossils were procured from the 200 feet of beds [gray to brownish shale and sandstone, the latter predominant at the base] at the base of the Jefferson limestone, so that the age of the beds intervening between the Cambrian and Devonian faunas remains undetermined in this region. No evidence of any stratigraphic break in this part of the section was observed.

About 20 miles south of Princeton, on the east fork of Rock Creek, the Jefferson limestone occurs immediately above the following beds:

	Feet.
E. Shales and covered	30
D. White limestone	5
C. Brownish arenaceous thin-bedded magnesian limestone	90
B. Limestone [Upper or late Middle Cambrian].	

The beds C, D, and E represent both Ordovician and Silurian, unless there is an undetected hiatus. Kindle says:

> No fossils were obtained from the beds separating this formation [Cambrian] from the Jefferson in either the Rock Creek or Boulder Creek sections. These beds, measuring 210 feet in thickness in the Boulder Creek section and 125 feet in the Rock Creek section, may provisionally be referred to the Silurian.

In southwestern Wyoming occurs a similar sequence of Cambrian limestone, unfossiliferous strata, possibly Silurian, and a limestone correlated with the Jefferson. Describing a section near Viola, Wyo., Kindle says:

> We are without positive information regarding the age of the 700 feet of gray limestones below the saccharoidal limestones of the Jefferson. These beds may be in part of the same formation and age as the 40 feet of limestone at their base, the age of which is known by fossils to be Cambrian. It seems probable, however, that Silurian or Ordovician strata, or perhaps both, may be included in the series. The Ordovician is present in the Bighorn Mountains to the north, and both are present in northeastern Utah.

K-L 17-18. ONTARIO AND WESTERN NEW YORK.

The belt of Silurian strata which extends from Georgian Bay to western New York comprises the Clinton and other subdivisions of the Niagara, together with the Medina, below the Clinton, and several formations above the Niagara. The latter are not uniformly extensive. In Canada they include the "Onondaga Salt group" and the "Water lime" (Bertie or Cayuga dolomite of Chapman[136]), which was referred by Logan [470, 544o, 919] to the "Lower Helderberg" but is now regarded by Clarke as a member of the Salina formation.

In New York the Guelph dolomite, the uppermost formation of the Niagara in Canada, has a restricted extent only.[158] The "Onondaga Salt group" (called Salina by Dana [215]) and the "Water lime" are now included in the Cayugan, the recognized subdivisions [159] of which are known as Salina formation, Cobleskill limestone, Rondout water lime, and Manlius limestone. Their relations and the western representatives of the formations of New York are discussed by Grabau.[377] In this part of Canada the "Lower Helderberg" of Logan and Chapman comprises only a part of the "Water lime" which in central New York underlies the strata which were formerly known as "Lower Helderberg" but which are now called Helderberg or Helderbergian and assigned to the Devonian.[159a] Merrill, whose geologic map of the State [592] has (generally) been followed in the map of North America, placed the line between Silurian and Devonian at the top of the "Lower Helderberg." The North America map of 1906 followed this delineation. The present map does not depart therefrom, for the scale is too small to show the difference, but the Helderberg ("Lower Helderberg") is included in the Devonian in the citations contained in this volume.[378, 642, 711a, 933]

L 16-17. NORTHERN MICHIGAN AND ONTARIO.

There seems to be some question as to the presence of the Clinton in Michigan. Certain beds which have been referred to by several authors as Clinton are, in the opinion of Ulrich, more likely to prove of Richmond age. Aside from these doubtful beds the Silurian consists of the dolomitic limestones commonly referred to the Niagara and the divisions which have been grouped by Lane and others under the term Monroe. Of the Niagara as mapped by the Michigan State Survey and others Lane [517] recognizes the following subdivisions: Clinton, 0 to 130 feet; Rochester shale, doubtfully identified, 20 to 30 feet; Lockport and Guelph dolomites, 270 to 600 feet, the greater thickness being in the northern part of the State. The two latter Lane combines under the name Manitoulin.

Rominger [677] describes the "Niagara" of the Upper Peninsula of Michigan in detail for different localities and sums up the section as follows:

> The rock beds of the Niagara group allow a subdivision in three well-marked sections. It is exclusively a limestone formation. The lower section is always very regular and even-bedded, composed of comparatively thin layers of a fine crystalline grain, or with a dull, more earthy fracture. In composition most of the strata are dolomites; only a few layers are found to be a pure limestone. Fossils are rare in it. The middle division is made up by more massive, highly crystalline dolomite ledges, which usually contain a large number of the casts of the *Pentamerus oblongus* and some ill-preserved corals. The upper division is a series of thin, uneven layers, with intermixture of much siliceous matter with the dolomite mass, and of seams and nodular concretions of hornstone. In this upper division, also, the greatest abundance of fossils is found.

With reference to the "Niagara" of Manitoulin Island, Bell [67a] states:

> The southern portion of the peninsula between South Bay and the eastern side of Manitoulin Island belongs to the Niagara formation, which has here a thickness of about 405 feet. It consists principally of heavy-bedded light-gray, light bluish-gray, and buff dolomites. Good fossils

are rare, although much of the rock is made up of comminuted fragments of organic remains. The thicker beds are rendered somewhat porous by the numerous small cavities left between these fragments. Most of the beds show a crystalline character on fresh fracture.

* * * * * * *

On the south end of Fitzwilliam Island and on the eastern part of the south shore of Manitoulin Island there is a thickness of about 100 feet of heavy-bedded, coarsely spongy gray and buff dolomite, which contains a few fossils like those of the Guelph formation.

Monroe is a term formerly applied by Lane to all the Silurian above the "Niagara" (that is, between the "Niagara" and the Dundee limestone), as he found it impracticable to separate the strata consistently. Although a division can not be made distinctly in the field, Lane [517] now recognizes the following subdivisions, in ascending order: Salina, or Lower Monroe; Bass Islands series, or Lower Monroe [in the restricted sense]; Sylvania sandstone, or Middle Monroe; and Detroit River series, or Upper Monroe. He discusses their thickness and character at length.

The "Salina" he defines as extending from the top of the "Niagara" to the uppermost salt bed. The base of the "Salina" should be marked, according to Grabau, as quoted by Lane, by a hiatus and "disconformity." According to Lane the strata thicken greatly northward from Monroe County, presumably by the addition of beds at the bottom in the deeper part of the basin. At Milan rock salt seems to occur almost directly above the "Niagara," whereas at Wyandotte there is 275 feet of dolomite below the rock salt and above the white dolomite.

The top of the "Salina" Lane would determine by measuring from the Sylvania sandstone down to the top of the first salt bed. He would then class all the beds between that stratum and the "Niagara" below as "Salina." He thus obtains thicknesses for the "Salina" which range from 370 feet (at Britton) to 959+ feet (at Royal Oak). Inasmuch, however, as the salt bed thus determined is by no means certainly at one horizon, and gypsum if not salt occurs above the Sylvania sandstone, the division is very indefinite and of little stratigraphic significance.

Although the top of the "Salina" is thus difficult to determine, it is made the base of a division which comprises all the Silurian above the "Salina" and which in distinction to that formation is strictly marine. Unfortunately the name "Monroe" has been given to this division in a limited sense excluding the "Salina," in contrast to the broader definition including "Salina," which has become established. This limited "Monroe" has been subdivided into three parts and the upper and lower of these each again into four members. Lane, Prosser, Sherzer, and Grabau [518] have published the following:

MONROE FORMATION.

The highest Siluric strata of America are represented by the Monroe formation of Michigan, using this term in its limited sense for the post-Salina Siluric. The Monroe formation is a strictly marine series succeeding the abnormal (nonmarine [Grabau]) Salina. It is traceable throughout lower Michigan westward into Wisconsin and eastward through Ohio, Ontario, and into western New York. Where recognizable a strong dividing line separates the lower from the upper part, and in general this division is emphasized by the occurrence of the Sylvania sandstone, a rock of pure quartz grains, and representing, according to Grabau and Sherzer, an eolian deposit formed under conditions similar to those now found in the Libyan Desert. According to this interpretation, the Sylvania sandstone represents a long time interval the depositional marine equivalent of which is still unknown. This long interval is further emphasized by the entire distinctness of the faunæ of the lower and upper divisions of the Monroe.

The subdivisions recognized so far in the Monroe, with their faunal characteristics (determined by Grabau), are as follows:

LOWER MONROE.

For this stratigraphic unit the name Bass Islands series is proposed, from the group of islands of that name in western Lake Erie. No other appropriate term seems to be available, though characteristic exposures of all the divisions are not found in these islands.

(*a*) *Greenfield dolomite.*—This term was proposed by Grabau in 1898, though previously used in a commercial sense, for the dolomite found about Greenfield, Highland County, Ohio, and exposed again in the regions about Ballville, in northern Ohio. The name is here accepted for this division, which is characterized by *Schuchertella hydraulica* (Whitfield), *Hindella? whitfieldi* Grabau, *H.? rostralis* Grabau, Leperditia, etc. The faunal zone may be called that of *Schuchertella hydraulica*. The thickness is 100 feet or more and the formation is the lowest known subdivision of the Monroe.

(*b*) *Tymochtee shales and limestones.*—This name was proposed in 1873 by N. H. Winchell for the shales and thin-bedded calcilutytes of the Monroe (Waterlime) series exposed in the creek of that name in Crawford Township, Wyandot County, Ohio. The thickness there is something over 100 feet, but the relation to the overlying and underlying formation is unknown. Its fauna likewise is unknown, and the formation must be considered a tentative division of the Lower Monroe. It is not impossible that it represents in part one or more members recognized elsewhere.

(*c*) *Put-in Bay dolomites.*—This name is proposed for the extensive fossiliferous series of water lime exposed on Put-in Bay Island, one of the Bass Islands, and characterized by the fauna comprising *Spirifer ohioensis* Grabau, *Goniophora dubia* Hall, *Eurypterus eriensis* Whitfield, and Leperditia. From the abundance of the pelecypod, the paleontologic zone may be called that of *Goniophora dubia*. Something over 100 feet of strata is exposed on Put-in Bay Island, where the higher beds are in contact with the succeeding zone. The formation is also known from Marion County, Ohio. Its thickness is over 100 feet, but the base is unknown.

(*d*) *Raisin River dolomites.*—This name is proposed for the highest division of the lower Monroe exposed in Lucas and Wood counties, Ohio, and in Monroe County, Mich., especially along the Raisin River. It is perhaps 200 feet thick and contains several oolite zones. Its known fauna comprises nearly 20 species, of which the most significant are *Whitfieldella prosseri* Grabau and *Pterinea lanii* Grabau. These are restricted to this horizon, so far as known. *Spirorbis laxus* and numerous minute gastropods, besides plant remains, further characterize this horizon. From the abundance of the brachiopod mentioned, which is everywhere found and characteristic, the faunal zone is designated as that of *Whitfieldella prosseri*.

MIDDLE MONROE.

This is represented in Michigan only by the Sylvania sandstone. This is believed to represent a long interval at the end of which a new series of faunæ invaded this region upon resubmergence. The thickness of the Sylvania seldom exceeds 150 feet.

UPPER MONROE.

For this stratigraphic unit the group name Detroit River series is here proposed, from the exposure of all its members along that stream. It comprises four subdivisions or faunal zones.

(*a*) *Flat Rock dolomites.*—These are exposed at Flat Rock, on the Huron River, and are also found in the lower part of the salt shaft at Oakwood, near Detroit. The fauna so far obtained is meager, comprising only the corals *Syringopora cooperi* Grabau, *S.* cf. *hisingeri* Billings, and *Favosites* cf. *maximus* Troost. The first mentioned seems to be characteristic and restricted to it, and the zone is provisionally called the *Syringopora cooperi* zone. The thickness of the formation varies from 40 to 150 feet or more.

(*b*) *Anderdon limestone.*—This name, suggested by the Rev. Thomas Nattress, was adopted by Sherzer and Grabau for the coral reef limestone exposed in the Anderdon quarry, Essex County, Ontario, 2 miles from Amherstburg, Ontario, and in the salt shaft at Oakwood, Detroit.

Its thickness is from 40 to 50 feet and its fauna a rich coral and Stromatopora fauna. It varies from a pure calcilutyte to a moderately coarse calcarenyte. Six species of stromatoporoids and eleven of coral have been determined by Grabau. Among the former *Stylodictyon sherzeri* Grabau and *Idiostroma nattressi* Grabau are characteristic and restricted. From the abundance of the latter the faunal zone may be named the *Idiostroma nattressi* zone. Favosites of Devonic affinities are characteristic.

(*c*) *Amherstburg bed.*—This name is proposed by Sherzer and Grabau for the next higher stratum, a dolomite not over 20 feet thick and forming a transition zone to the overlying Lucas. This zone is rich in fossils, 52 species having been identified by Grabau, most of them being new and of Devonic affinities. The fauna unites the Anderdon and Lucas elements to a certain degree. *Panenka canadensis* Whiteaves, though not absolutely restricted to it, is its most characteristic fossil and may serve to name the zone. The genus Heliophrentis Grabau is further characteristic and distinctive, while *Schuchertella interstriata* links it with the Bullhead (Akron) dolomite of western New York, this and the Cobleskill being its eastern extension. Stropheodontas of Devonic aspect further characterize the faunæ. In common with the Anderdon, it has an abundance of *Conocardium monroense* Grabau, which is the zone fossil of the two formations combined. The spiriferoid genus Prosserella Grabau has species in the three upper members of the Upper Monroe to which it is restricted (Prosserella horizon).

(*d*) *Lucas dolomite.*—This name was proposed by Prosser in 1903 for the upper dolomites so well exposed in Lucas County, Ohio. Here they mostly rest directly on the Sylvania, the other beds being cut out by overlap. The fauna is rich and peculiar, European types of gastropods predominating. The genus Acanthonema Grabau, though represented in the Amherstburg, is most characteristic, and the faunal zone may be designated the Acanthonema zone. Its thickness varies up to 200 feet or over. *Cylindrohelium profundum* is restricted to it and may be regarded as another good zone fossil.

The proposed classification of these authors in tabular form is as follows:

Upper Monroe or Detroit River series (L., P., S., and G.); zone of Prosserella:
- (*d*) Lucas dolomite (Prosser). (Zone of *Cylindrohelium profundum* and *Acanthonema.*)
- (*c*) Amherstburg dolomite (Sherzer and Grabau). (Zone of *Panenka canadensis.*)
- (*b*) Anderdon limestone (Nattress). (Zone of *Idiostroma nattressi.*)
- (*a*) Flat Rock dolomite (Lane, Prosser, Sherzer, and Grabau). Zone of *Syringopora cooperi.*

Disconformity.

Middle Monroe: Sylvania sandstone.

Disconformity.

Lower Monroe or Bass Islands series (L., P., S., and G.); zone of Leperditia:
- (*d*) Raisin River dolomite (Lane, Prosser, Sherzer, and Grabau). (Zone of *Whitfieldella prosseri.*)
- (*c*) Put-in Bay dolomite (Lane, Prosser, Sherzer, and Grabau). (Zone of *Goniophora dubia*).
- (*b*) Tymochtee beds (N. H. Winchell).
- (*a*) Greenfield dolomite (Grabau). (Zone of *Schuchertella hydraulica.*)

The characteristic faunas of the above-named divisions are listed by Sherzer and Grabau in a preliminary article [738] and appear with full descriptions in a report published by the Michigan Survey.[385] The authors deduce from the faunas and stratigraphic relations three interruptions in the process of sedimentation, or "disconformities," and comment on the relations as follows: [738a]

A survey of these faunas brings out the remarkable fact that there is nothing in common (a few doubtfully identified gastropods excepted) between the Lower and Upper Monroe. So distinct are the faunas that they may be considered as derived from widely separated provinces. The Lower Monroe is apparently an Atlantic fauna or series of faunas, and we are led to believe that an embayment from the Atlantic extended as far as Wisconsin in post-Salina time and that the successive members of the Lower Monroe were deposited in this. The marine "Salina" described by Schuchert from Maryland most probably belongs here, the path of invasion being approximately across that region. There appears to be nothing in New York which corresponds to this series, that State being apparently north of the embayment. The embayment covered Ohio, Michigan, and probably a part of Indiana and extended into Wisconsin.

Following the deposition of the Lower Monroe came a retreat of the sea and eolian deposits of quartz sands accumulated upon the limestone foundation. These are now seen in the Sylvania sandstone, the source of the material of which probably was the St. Peter sandstone. The Upper Monroe invasion was from the northwest, and it brought with it a wholly new fauna, in which the prevailing element was of Devonic aspect. A large proportion of the species of the Anderdon and Amherstburg beds is most nearly related to the Schoharie fauna, the similarity being often so great that species have been described as Schoharie or Onondaga forms.

For a list of species more nearly related to Middle Devonian forms than to known Silurian see the publication cited. On these species Sherzer and Grabau[738b] comment as follows:

This list of species shows that the Anderdon-Amherstburg fauna is most nearly related to the Schoharie fauna of eastern New York, and that it probably represented the stock from which that fauna was derived. Coral-reef conditions existed in Michigan and Ontario at that period, the eastern extension of these conditions being first manifested in the water-lime deposits, and later in the Akron, and finally in the Cobleskill. This latter marks the period of reestablishment of connection with the Atlantic, and we find that this formation is especially characterized by an Atlantic fauna in its more eastern development (Halysites, etc.). The faunas mingled in the neighborhood of the Schoharie region.[a]

With the opening of the Atlantic connections the late Siluric gastropod and cephalopod fauna entered this region and became characteristic of the succeeding Manlius-Lucas deposits, while the typical Anderdon fauna soon disappeared. A comparison of the Anderdon and the Lucas fauna shows scarcely a common species. In the Amherstburg, however, there is more or less of the commingling of the two faunas. That the junction with the Atlantic was effected while the Amherstburg beds were forming is shown by Siluric gastropod and cephalopod elements in its fauna, and their absence from the Anderdon fauna. The correlation of the Amherstburg and Cobleskill thus seems evidenced.

Considering the Anderdon fauna as a whole, we see a blending of types of the Siluric with those of Devonic affinities. Recognizing that this fauna is interpolated between two Siluric faunæ, we are forced to admit that here is an example coming perilously near satisfying the demands of Barrande's theory of colonies. Somewhere the Siluric fauna must have developed into the Devonic, while in other regions the Siluric fauna still lingered. That this Devonic aspect is that of the mid-Devonic fauna of America rather than the lower shows that this evolution was progressing along different lines from that of the Helderbergian fauna. This latter fauna is alien to North America, as is well known, having come to us from Europe. Somewhere in northwestern America an indigenous Lower Devonic fauna existed, which in turn gave rise to the Middle Devonic faunas of America. This indigenous American Lower Devonic must have been much like the Middle Devonic fauna, seeing that the indigenous Upper Siluric is already so far advanced as to have a decided mid-Devonic aspect.

It might of course be argued that the Upper Monroe is the indigenous Lower Devonic of America and that it existed contemporaneously with the Helderbergian fauna. On such an interpretation the Sylvania marks the Siluro-Devonic hiatus, and the upper hiatus representing the folding and erosion of the entire of Monroe and earlier rocks falls into the Oriskany. That period, as we know it, was scarcely long enough for the accomplishment of such extensive erosion as is implied in the pre-Onondaga hiatus, though it is known that a considerable amount was accomplished during that time. The strongest argument against such an interpretation is, however, the Siluric character of the fauna of the Lucas dolomite and the evident correspondence of the Amherstburg and Cobleskill horizons.

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[a] Grabau, A. W., Bull. New York State Mus. [No. 92, 1906], p. 131.

Lane [517] states his views on the significance of the stratigraphy in the article already cited, together with details of well records.

L 17. LAKE TEMISCAMING, ONTARIO.

The Silurian outlier of Lake Temiscaming, first described by Logan,[543, 544n] has more recently been mapped and discussed in detail by Barlow.[15, 55a] At those points where the formation was deposited on the pre-Cambrian rocks there is a basal conglomerate, consisting in part of subangular talus blocks, in part of smaller pebbles of the adjacent older rocks in a calcareous cement. The deeper-water deposits are fine-grained yellowish limestone, with some shale and a considerable proportion of chert in some beds. The large collections of fossils from this section represent the Niagaran (including the Clinton).

L 18–19. SOUTHERN QUEBEC.

Isolated areas of Silurian strata occur in synclines southeast of the St. Lawrence. They are composed chiefly of limestone, characterized by Silurian corals. They lie unconformably upon the Ordovician strata. Detailed local descriptions are given by Ells.[310, 311a, 313b] A noteworthy correction of earlier descriptions is the determination of a so-called conglomerate of St. Helen's Island, Montreal, as a volcanic breccia "of later date than the Helderberg limestone."

In the Memphremagog area[313c]—

the formation is characterized by a considerable thickness of limestone, some of which is graphitic, while other portions are highly dolomitic and are associated with dolomitic grayish slates. * * * The structure in this area is that of a folded basin resting, on either side of the lake, upon fossiliferous lower Trenton rocks [Magog formation]. The rocks are altered from calcareous slates and limestones to talcose and mica schists or to graphitic crystalline marble, and are cut by numerous dikes, which are often of large size.

L 19. NEW HAMPSHIRE (LITTLETON).

In the township of Littleton, in northern New Hampshire, is an occurrence of fossiliferous strata, in part at least of Niagaran age, with possibly slates of Helderberg age as well.

Under the heading "Silurian and Devonian strata," Hitchcock [454] includes "the Coos mica schist and quartzite, the Niagara limestones, and slates, sandstones, and argillites." There is no good evidence as to the age of the mica schist.

The unaltered strata occur in Blueberry Mountain, which is believed to have a synclinal structure. If so, the sequence of formations in ascending order is as follows: Limestone, sandstone, coarse conglomerate, bluish and black slates. Hitchcock [454a] reports the following fossils from the limestone: "*Favosites basaltica, F. niagarensis*, Zaphrentis, *Astrocerium venustum, Halysites catenulatus, Pentamerus nysius*, a lingula, crinoidal fragments, a gastropod, *Dalmania limulurus*, and fragments of a Lichas," determined by Billings and Whitfield.

L 20. NOVA SCOTIA.

Under the heading "Siluro-Devonian rocks of Digby and Annapolis" (the southwestern counties of Nova Scotia) Bailey [43] gives a detailed account of the slates and intercalated impure limestones which lie along the north side of the intrusive granite and which contain fossils of late Silurian and early Devonian age, as determined by Sir William Dawson, by Logan, and on fuller collections by Ami.

Farther northeast in Pictou and Colchester counties, Fletcher [335a] distinguishes strata which he assigns to Medina, Clinton, and Niagara horizons. Fossils determined by Ami include *Cyrtograptus grayiæ*, "characteristic of the lower half of the Silurian system."

The Silurian rocks of Arisaig, in Antigonish County, on the coast of Northumberland Strait, were first described by Honeyman.[461] Fletcher [334a] gives a somewhat detailed section, from which the following is condensed:

	Feet.
Lower Helderberg, argillaceous sandy flags with thin fossiliferous limestone	1,038
Niagara, argillaceous, calcareous rocks with numerous layers of richly fossiliferous limestone (400 feet) followed by dark shales, also fossiliferous	1,293
Upper Clinton, green arenaceous shales and fine sandstone	148
(Break in section.)	
Lower Clinton, dark-gray, crumbly, papery argillites	345
Medina, greenish to gray, more or less massive sandstone	182

These strata lie in a "syncline, 6 miles long and 1½ wide, bounded on the south by a fault indicated by an escarpment of Cambro-Silurian rocks; on the north by pre-Cambrian; and on the west by Devonian and Carboniferous, which overlie them." The relation of conformity or unconformity to the "Cambro-Silurian" (Ordovician) is not clearly stated. With reference to the Silurian-Devonian contact Ami [18a] suggests a possible unconformity, but says: "On the whole, the general trend and behavior of the strata referred to the Silurian and Devonian systems are fairly uniform and generally identical." On the other hand, the lower Carboniferous conglomerates and limestone extend with marked unconformity across the Silurian and Devonian.

The Arisaig section and other sections of the Silurian in Nova Scotia have been classified by Ami [17] as follows:

The Silurian system as understood in Canada, and restricted to the upper division of Sir Roderick Murchison's Silurian, is extensively developed both in Nova Scotia and New Brunswick. At Arisaig, in Antigonish County, Nova Scotia, several thousand feet of more or less disturbed and inclined strata, including an almost regular succession of different members of this system, made up of sandstones, slates, iron ores, and black graptolitic slates and limestones, with mudstones, are well exposed and present a compact fauna, which in facies closely resembles rocks in Herefordshire, in Cumberland, Westmoreland, in the Kendal and Ludlow regions of England. The "Knoydart" formation, consisting of red shales and sandstones and calcareous bands holding pteraspidian and ostracoderm fishes and crustaceans referable to the Cornstone or lower Old Red sandstone of Great Britain, almost immediately overlies the Silurian strata, though no actual contact has been observed. The Silurian series at Arisaig consists of at least four distinct geological formations. Beginning above we have first the "Stonehouse" formation, consisting for the most part of dark-red, fine-grained shales and mudstones, holding a conspicuous lamellibranchiate fauna, of which *Grammysia acadica* Billings is a well-known species, together with a number of interstratified more or less thin calcareous bands holding brachiopods, gastropods, trilobites, and ostracods in abundance. Below this we find the "Moydart" formation, which consists of more or less heavy bedded light greenish-gray and rusty-weathering calcareous strata (in which the "Red stratum" of authors occurs) and holds brachiopods, gastropods, cephalopods, and crinoids. Beneath this again we have the "McAdam" formation, consisting for the most part of impure black carbonaceous shales, which are splintery at times, holding a lamellibranchiate fauna and graptolites. At the base occurs the "Arisaig" formation, which comprises buff-weathering fine-grained compact sandstones and shales, containing corals (chiefly Streptelasma), brachiopods, gastropods, and trilobites. The thorough investigation of this series of strata, which, indeed, may require further subdivision, is expected to furnish data bearing on the settlement of the mooted question as to where the Silurian stops. * * *

In the county of Annapolis, Nova Scotia, and in the vicinity of Nictaux Silurian strata occur, including the Nictaux iron ore beds and the Torbrook sandstone formation, whilst near Kentville the Kentville formation is seen, as well as on Angus Brook, in the Gaspereau Valley, also at New Canaan, with *Dictyonema websteri* Dawson, and at Wolfville, in King's County, where coralline limestones, red and green graptolitic slates, and other strata, at times highly cleaved, squeezed, and metamorphosed, form conspicuous ridges and constitute the oldest sedimentaries in the vicinity of the Bay of Fundy and the Blomidon region in the "land of Evangeline."

In Cumberland County, along the northern slope of the Cobequids, isolated areas of Silurian strata have been mapped out and described by Mr. Scott Barlow and Mr. H. Fletcher, the Wentworth and Farmington areas being among the most important and best known. These appear to belong to the lower half of the Silurian.

L-M 19-20. MAINE, NEW BRUNSWICK, AND GASPE.

Northeastern Maine, northwestern New Brunswick, and the Gaspe Peninsula are occupied by a broad synclinorium of Silurian strata, which appear to lie unconformably upon folded and eroded Cambrian rocks and are overlain conformably by Devonian rocks.

A section which is typical for Maine and New Brunswick is that observed on Temiscouata Lake, just across the boundary in Quebec. This section was described in great detail by Logan [544t] and has been reexamined by Bailey,[47b] who has also traced out the distribution of the sediments in New Brunswick and Quebec as well as in Maine. As determined by him on fossils, the sequence of strata ranges from lower Niagara (Clinton) to "Lower Helderberg" (Helderberg), with possibly an unconformity also at the base of the latter. The section is partly concealed, the structure involves older beds apparently overlying younger, in consequence of overthrusting, and his Lower Helderberg rocks appear to overlap his earlier Niagara and lie upon the Cambrian. The strata dip southeastward, but the sequence from northwest to southeast is shown to be Cambrian, unconformity (?), Lower Helderberg, thrust fault (?), Niagara, unconformity (?), Lower Helderberg. For details we quote Bailey's report:

The rocks of Lake Temiscouata have been described in considerable detail and are given with sections illustrating the relations and probable thickness of the principal beds in the "Geology of Canada," 1863, pages 419–425. * * * The following section is a condensation of that in the "Geology of Canada," with such additional information as has been recently obtained. The section begins on the north side of Mount Wissick or Mount Lennox, where the rocks of the Silurian system may be seen to rest unconformably upon those of the "Quebec group."

Greenish-gray and black slates, alternating in thin bands, 2 to 3 inches wide, with gray or buff weathering dolomitic limestones. These beds occur on the northeast side of a small cove above Mount Wissick and are a part of a similar series of rocks, supposed to be of the same age as those of Point Levis which occupy all the upper part of the lake. They have been subjected to much crumpling and exhibit considerable irregularity of inclination, their dip, where nearest to the Silurian, being N. 40° W. $<$70°–80°. They have as yet yielded no fossils, and their thickness is unknown.

Measures concealed for about half a mile.

	Feet
Gray quartzose sandstone, containing white quartz pebbles, mingled with fragments of limestone in a greenish sandy matrix. These grits or conglomerates apparently occupy a space across the measures of about 1,000 feet, and with a dip of S. 65° E. <40° would give a thickness of.....	642
White sandstone or quartzite in massive beds. These rocks are gray within but weather almost snow-white, with vitreous surfaces, often drusy with small quartz crystals. Some portions are pinkish or reddish and others spotted with small red dots. Their thickness, as given in the "Geology of Canada," is only 40 feet, but they were found to have a surface breadth of 250 paces, which, with an average dip of 50°, would give a thickness of..........................	420
Coarse shaly and rubbly conglomerate, holding limestone pebbles (with some quartz). They dip S. 60° E. <70° and have a breadth of 60 paces, corresponding to a thickness of..........	114
Dark-gray sandstones. Dip S. 70° E. <20°. Thickness about................................	10
Gray calcareous shales, filled with bands, nodules, and lenticular masses of limestone, abounding in fossils. [For partial list, see op. cit.] These beds are regarded by Mr. Ami, by whom the fossils have been examined and in part collected, as corresponding to the Chat River limestones, equivalent to the upper part of the Chaleur group, and about equivalent to the lower part of the Lower Helderberg formation. Dip S. 65° E. <60°. Thickness about....................	10
Red and green shale, in alternating bands, with green argillaceous sandstones. The dip of these beds where they overlie those last mentioned is S. 65° E. <15°, their strong slaty cleavage having an underlay of N. 65° W. <80°, but in following them along the precipitous face of the mountain they are found to fold over and exhibit a dip N. 40° W. <40°. They are also broken by a fault. Their estimated thickness is..	125
Gray nodular limestones, conspicuously divided by vertical joints, which often present curved surfaces and produce an appearance resembling that of fluted columns. These beds rest directly upon the red and green shales and are probably arched with them, but toward the southern end of the bluff resume their normal dip S. 65° E. at an angle of 50°. The columnar limestones, which contain but few fossils, have a thickness of about 10 feet and are followed by about the same thickness of finely banded massive limestones, having at the top a zone, from 1 foot to 18 inches thick, filled with branching corals, chiefly Favosites; it also holds shells of *Atrypa reticularis* and Pentamerus. This is capped by more columnar limestone, the whole having an aggregate thickness of about..	50
Gray hard sandstone, with beds of impure limestone, the sandstone containing remains of Meristellæ..	30
Gray nodular limestone, without observed fossils..	30
Gray banded limestone, filled with corals and other fossils, including *Favosites gothlandicus* Lamarck, *Strophodonta varistriata* Conrad, in great abundance and forming the typical representative of the zone [together with a number of other species; for list, see op. cit.]. (Mr. Ami considers these fossils also to indicate the horizon of the lower portion of the Lower Helderberg series.) Thickness about..	30
Gray arenaceous limestones and sandstones forming the upper portion of Mount Wissick but sloping to the level of the lake, with a dip S. 70° E. <13°. These higher beds contain comparatively few fossils, among which are the following: A stromatoporoid form; crinoidal fragments, in abundance; Chonetes sp., a rather arcuate form, smaller than *C. nova-scotica* Hall and larger than *C. tenuistriata* Hall, resembling somewhat *C. melonica* Billings; Meristella sp. Their supposed thickness is about..	500

The beds may, therefore, be correlated with the Lower Helderberg or with the Ludlow formation of Britain.

A summary of the above section is given in a later report by Bailey[48] from which the following is taken:

As represented upon Lake Temiscouata the portion of the Silurian system which immediately adjoins and overlaps the Cambrian strata to be presently described does not represent the lowest member of that system, being composed of white sandstones and overlying calcareous rocks, of which the fossils indicate an age ranging from the lower to the upper part of the Lower Helderberg horizon, while at a short distance south are heavy conglomerates followed by hard sandstones and shales containing fossils chiefly of the Niagara formation. * * *

Immediately to the south of the above undoubted Silurian strata is found the great series of slates first described in the "Geology of Canada" in connection with the Gaspe series and which has since been found to spread so widely over the northern portions of New Brunswick, as well as adjacent areas in Quebec and Maine. These slates, as seen along the lower half of Temiscouata Lake and on the Madawaska River, are of gray, bluish-gray, and dark-gray, rarely black colors, often weathering to a dull olive-green, very fine grained but including harder bands, and generally more or less calcareous. They are throughout characterized by numerous and often intricate contortions and these, with a strongly developed slaty cleavage, make any attempt to determine their thickness or relations well-nigh hopeless. Neither on the lake nor on the Madawaska have they been found to contain any fossils, these having probably been obliterated by molecular movements; but the occurrence of fossils at many different points in the resembling strata which spread so widely to the east and south, and all of which indicate a Silurian horizon, seems to justify the position first assigned them as also Silurian, and as the equivalent of the upper part of the Gaspe series.

Southwestward from Temiscouata Lake the gray to olive-green slates called by Bailey Lower Helderberg occupy the basin of St. John River in northwestern Maine. Their relations to the overlying Devonian in Aroostook have been described by Bailey [47d] and more recently by Williams and Gregory.[937] (See Chapter VI, L 19, pp. 325, 328.)

Northeastward from Temiscouata Lake to the Metapedia section, the outline of the Silurian beds in relation to the Cambrian on the north has been retraced by Bailey and McInness.[47a] Beyond the Metapedia Ells [308] and Low [548] determined their distribution between the Cambrian and the Devonian as far east as the Cascapedia, whereas from the headwaters of the Magdalen to Cape Rosier the lines are placed as worked out by Logan [544s] and Ells.[307] The areal geology of the peninsula south to the Bay of Chaleur is according to the same authorities.

The strata thus mapped as Silurian are those assigned to that period according to the past and current usage of the Canadian Survey, and they include the strata identified by Bailey as Lower Helderberg, which is now classed as Devonian, according to Schuchert [711] and Clarke.[157] The literature contains a number of doubtful references to Silurian or Devonian, the uncertainty being due to the transitional character of the fauna, which has commonly been assigned to the uppermost Silurian but contains Devonian forerunners. Ells [308a] cites observations of unconformity between Silurian and Devonian on the tributaries of the Cascapedia, and Bailey [47c] infers an unconformity between the rocks identified by him as Niagara and Lower Helderberg on Lake Temiscouata, which might be at the same horizon. The overlap of the latter formation beyond the former seems to be well established. The base of the Niagara, as thus identified by Bailey, is a white sandstone associated with bodies of calcareous conglomerate, consisting of limestone pebbles and angular fragments in a sandy matrix. No fossils have yet been found in the limestone pebbles, but the position of the strata at the base of the rocks identified as Niagara and their relation to the near-by Cambrian rocks are such as to suggest their derivation from the Cambrian. A marked unconformity is thus indicated. Logan [544u] describes two unconformable contacts seen on the coast near the line between Gaspe and Bonaventure counties, as follows:

The vertical strata of this group [the "Quebec group"] extend along the coast toward Anse a la Vieille, where they are overlain by the inclined strata of the Gaspe limestones, which in their turn support the Bonaventure conglomerates, the three series being unconformable with each other.

The proofs of this double discordance lie within a space of half a mile, a little less than 2 miles westward of the line between the counties of Gaspe and Bonaventure; and as there is no concealment of strata, the whole is readily apparent to the eye. The smoothly worn edges of the vertical strata of the Quebec group here support an even layer of 4 feet of hard grayish-white strong siliceous conglomerate, which divides into layers of a foot or two, and would make good millstones. It dips S. 4° W. $<38^\circ$ and is conformably overlain by a great series of fossiliferous limestones and shales. At a point about 230 yards along the beach from the millstone layer these calcareous strata dip S. 3° E. $<45^\circ$, in a cliff 100 to 120 feet high. Upon the basset edges of these the beds of the upper conglomerate are seen to repose, with a dip S. 42° E. $<20^\circ$. These stretch along for 200 yards, presenting a perpendicular precipice in front; while the underlying calcareous series forms a talus and occupies sometimes more and sometimes less than one-half the height of the cliff.

This unconformity is well established farther south. From the Bay of Chaleur the eastern margin of the Silurian extends southwestward across New Brunswick into Maine. The areal distribution is not well known, the structure being complicated, the Cambrian, Ordovician (?), and Silurian rocks being similar, and intrusive rocks abundant; but in the course of a resurvey of the line between the "Cambro-Silurian" (Ordovician) and the Silurian, Bailey[44] found "incontestable evidence of discordance along its whole length." He cites occurrences of conglomerates containing pre-Silurian rocks at the base of the Silurian strata.

Bailey[47e] summed up the known facts of the stratigraphy of the Silurian of northern and southern New Brunswick as follows:

Sequence of Silurian strata in southern New Brunswick.

Mascareen Peninsula.	Feet.	Southern Queen's County.	Feet.
I. Gray feldspathic slates, about	400	I. Gray and dark-gray slates	400
II. Gray and black banded siliceous slates, with nodular layers	620	II. Dark-gray and black siliceous clay slates, distinctly banded	600
III. Gray flaggy sandstones, with some conglomerate. Shells of Lingula, Modiolopsis, and Loxonema?, with comminuted vegetable matter	350	III. Dark-gray and greenish-gray, sometimes purplish sandstones, becoming slaty above	600
IV. Red and green slates and sandstones, with diorites and felsites	300	IV. Ash-gray and greenish-gray schistose beds, dioritic and amygdaloidal	300
V. Dark-gray and reddish porphyritic felsites	300?	V. Gray and dark-gray, sometimes reddish porphyritic felsites, with chloritic schist and breccia conglomerate	800+

In the same work Bailey details the relations of the strata of southern New Brunswick, northern New Brunswick, Quebec, and Maine, and sums up as follows:

Supposed sequence of Silurian strata in northern New Brunswick, Quebec, and Maine.

[Ascending section.]

Divisions I and II.—Gray argillaceous and siliceous slates, including (locally) heavy beds of conglomerate. Fossils somewhat numerous in upper part, including shells and graptolites, indicating a low Silurian horizon.

Conglomerates and succeeding slates of Black and Burnt points, on Lake Temiscouata; feldspathic and siliceous slates of Fish River and Alleguash River, Aroostook County, Me.(?). Conglomerates and graptolitic slates of Beccaguimic River, Carleton County, New Brunswick. Supposed to be equivalent to the Medina and Clinton groups of New York, divisions 2 and 3 of Anticosti group, or groups B and B′ of Arisaig.

Division III, A.—Gray flaggy and massive sandstones, with some conglomerate, becoming frequently greenish or purplish and more or less amygdaloidal. Fossils rather numerous, including corals and shells, as well as worm tracks and comminuted remains of plants.

Sandstones and conglomerates of Pointe aux Trembles, Tuladi and Squatook rivers, Quebec; similar beds of Siegas River, New Brunswick; sandstones and conglomerates of Aroostook County, Me.; similar beds of Beccaguimic River and other parts of Carleton County, New Brunswick.

Niagara formation, or Wenlock group.

Division III, B.—Lower sandstones, shales, and limestones of the Gaspe Peninsula. Similar sandstones and limestones of the head-waters of the Chatte and Matane rivers, Metapedia Lake, Metis and Rimouski rivers, and lower part of Mount Wissick. Fossils numerous, marine.

Supposed to be equivalent to the Guelph formation of Ontario.

Divisions IV and V.—Red and green shales of Cape Gaspe; red and green slates and sandstones of Mount Wissick; similar slates on Fish River (Eagle Lake) and Aroostook River, Maine; red and green slates of Grand River and Carleton County, New Brunswick; often including argillaceous iron ores. (?)Felsites and associated trappean rocks of Campbellton and Bay Chaleur, Moose Mountain, New Brunswick, Haystack and Spider Lake, Maine.

Division VI.—Gray, often nodular or columnar limestones, abounding in fossils.

Upper limestones of Cape Gaspe; middle and upper rocks of Mount Wissick, regarded as equivalents of the lower portion of the Lower Helderberg.

Fossiliferous limestones of Square Lake and Ashland, Me.; Lower Helderberg.

Fossiliferous limestones of Carleton County, New Brunswick.

Fossiliferous slates and sandstones of Metapedia River, Restigouche, Victoria, Madawaska and Carleton counties, New Brunswick. Similar slates, etc., of Aroostook County, Me. Lower Helderberg (?).

Silurian strata of southern New Brunswick (Charlotte County) and adjacent parts of Maine have in later years been found to be more extensive than had been supposed, the Silurian age of certain metamorphic rocks and of slates previously assigned to older horizons having been determined.[70] The geologic relations are similar to those about Penobscot Bay, Maine. (See L 19, pp. 134–135.)

L-M 21. NEWFOUNDLAND.

Under the heading "Upper Silurian series" Murray, in 1864, described conglomerates, slates, and mica schists, together with intrusives of granitoid character, all of which are exposed in sections on Jackson's and Sop's arms of White Bay, Newfoundland. Murray [608] states:

Jackson's Arm runs into the land nearly at right angles to the strike, and here these upper rocks have a transverse breadth of about 2 miles. The following section of them, in ascending order from the mica slates on which they are seen to rest, is taken from the north side of the arm, on which the measures appear to be broken by three considerable faults, causing what are supposed to be modified repetitions of some of the masses.

	Feet.
1. Coarse conglomerates, with a light-gray arenaceo-micaceous slaty matrix which is slightly calcareous. The masses inclosed consist of pebbles and bowlders of gneiss, large rounded fragments of whitish or light-gray mica slate, some of a darker-gray greenstone, reddish-gray quartzites, and occasional smaller masses of limestone; among these there is a good deal of finer material of the same character, slightly calcareous, and mica schist runs in irregular flakes and patches in the general direction of the stratification, but its cleavage often partially conforms to the rounded surface of the bowlders and pebbles. The beds are very massive, and they appear to be divided by gray micaceous schist	400
2. Sea-green slates, occasionally interstratified with dark-gray or blackish fine silky-surfaced slates, some of which are harder than others	300
3. Gray, coarse, rough arenaceo-micaceous schist, frequently passing into a fine conglomerate, with pebbles similar in mineral character to those of the coarse conglomerates beneath, but none of them exceeding the size of a hen's egg; the pebbles are sometimes arranged in regular layers, parallel to the stratification; bands of dark-gray clay slate are occasionally interstratified in the mass	400
4. Gray micaceous and arenaceous slates	250
5. Green and black slates at the base, succeeded by gray arenaceous slate, which is interstratified with thin bands of sandstone	650
6. Green, bluish, and blackish slates, interstratified with gray flaggy sandstones; the slates inclose nodules of pinkish calc spar, and veins of the same cut the strata	250
7. Grayish-blue limestone in a single bed	7
8. Gray calcareo-arenaceous slates, interstratified with grayish sandstones, with a heavy mass of gray, white-weathering sandstone at the top	543
	2,800

The above section can only be considered as giving an approximation to the truth. The three faults which dislocate the rocks and are all considered to be upthrows on the east side render it difficult to follow the sequence with exactitude; and some of the masses, which are supposed to be in a general way equivalent on opposite sides of the faults, appear in different parts to be modified in volume and somewhat in lithological character by different degrees of metamorphic action.

The intrusive relations of the igneous rocks and the metamorphosed condition of the sediments, particularly on Sop's Arm, are described by Murray, who states further:

Between the conglomerates of Sop Island and those of the eastern end of Sop's Arm the rocks of the western part of Sop Island, of Goat Island, and of the main coast appear to be slates of various shades of green, often marked by pink calc spar in nodules, patches, and short veins; of occasional interstratified sandstones, sometimes fit for flagging, with calcareo-arenaceous bands; and occasional impure limestones, weathering brownish. East of Bartlet's Cove, which is an indentation on the south side of the southwestern extremity of Sop Island, there was seen a thickness of 50 feet of black slates. These rocks are, in several places, characterized by fossils, which are somewhat obscure; but though few of them could be specifically determined, they have yet, according to Mr. Billings, a general aspect allied to that of Upper Silurian types. It would, however, for the present, be impossible to say to what horizon in the series the different divisions of the rocks of Jackson's Arm and of Sop's Arm may belong, and it may be proper to remark that while no doubt is entertained of the general equivalency of the rocks of the two localities, all the places in which organic remains were observed occur in the neighborhood of Sop's Arm.

One of these localities is Bartlet's Cove. Here the fossils occur in calcareo-arenaceous flagstones, and the genera observed, in addition to numerous fucoids and crinoidal stems, were a Murchisonia, an Orthoceras, and a Graptolithus. At a point on the main coast halfway between Spear Point and the promontory occupied by the porphyry which strikes from Sop Island organic remains were met with in strata somewhat similar to those of Bartlet's Cove; they consisted of fucoids, crinoidal stems, and an Orthoceras. On the western side of Goat Island, still in the same description of strata, in addition to fragments of crinoidal columns, there were met a Syringopora and *Favosites gothlandica.*

In Murray's report for 1871,[608a] based on Howley's exploration of Exploits and Gander bays and vicinity, the Silurian is described as the "Upper, unconformable formation," which is said to occupy a rudely elliptical trough.

The evidences, so far, tend to show that while the formations butt up against the Quebec group on the northern and southern sides of the trough, they overlap the junction of the latter at the eastern and western extremes.

The central part of this elongated trough has been greatly disturbed for the whole length of its course, from the head of the Red Indian Pond to the Dildo Run, where vast dikes were seen to cut through the strata at very many parts, while great areas are spread over by overflows of trap, or breccious intercalations. * * *

The base of the Upper and unconformable formation consists of conglomerate and sandstones, with slaty divisions, which, at Goldson's Sound, seem to come against the older and altered rocks in a slightly oblique direction, as if brought into their present position by a fault, the lower beds dipping about S. 55° E. <24°. The lower conglomerates are of a reddish general color, the matrix being constituted of fine reddish sand, sometimes slightly calcareous, which incloses well-rounded pebbles of quartz, red jasper, green jaspery slate, and fragments of magnesian rocks. The pebbles are not usually large, the largest being about the size of a hen's egg. The strata in ascending succession are still of conglomerate character, but the color gradually passes into gray, and there are numerous pebbles of gneiss and syenite mingled with the other qualities, and they are frequently characterized by the presence of hard blue or blackish cherty concretions, which weather a bright yellow, are sometimes concentric in structure, and of an elliptical shape. The islands of Goldson's Sound expose an alternation of conglomerates and red sandstones, with dark-gray slates, which are themselves occasionally finely conglomerate and were found to contain numerous stems of encrinites. The dip of the slates is south by west 80°. In front of the encrinal beds, on the long projecting point between the arms of the sound and on the islets at the head of the northern arm, some strong beds of coarse conglomerate are exhibited, which are overlain by black or dark-gray slates, with thin beds of gray sandstone, of from 1 to 6 inches thick. The conglomerate is often very calcareous and frequently contains irregular intercalations of limestone. The dip of these rocks is S. 20° E. $<60°$. Both the conglomerates and associated beds above the encrinal slates were found to be very fossiliferous and in their strike up the southern shore of the eastern arm were there found to pass beneath another mass of coarse conglomerate, which forms the escarpment to the hills which strike in the direction of the point between Pike's and Little Cobb's Arm. The total thickness of this part of the formation, from the junction with the older group to the last-mentioned conglomerate, was estimated to be about 2,000 feet.

The fossils recognized in the strata alluded to appear to be types of the Middle or Upper Silurian series, or about the horizon of the Llandovery group of the British Survey. Some of those previously collected were referred to Mr. Billings, of the Canadian Survey, who identified the following genera and species: *Favosites gothlandica,* Heliolites ?, *Zaphrentis bellistriata,* an encrinite referred to the genus Glyptocrinus, a coral referred to the genus Heliophyllum, *Orthis ruida, Leptæna sericea* or perhaps *transversalis,* ventral valve of an orthis like *O. davidsoni, Strophomena rhomboidalis, Atripa reticularis, Stricklandinia lens,* Modiolopsis, Ambionychia, a trilobite, genus Encrinurus, and some others not determinable.

The conglomerates of the escarpment above mentioned are succeeded by a set of slates which are occasionally slightly micaceous, with beds of quartzite from 2 inches to a foot thick, the strata of which run out upon the coast on the southeast side of Goldson's Sound, usually called Burnt Arm, at the head of which arm the slates pass beneath a mass of limestone, with black slate and trap breccia. At this part trap intrusions are met with and the strata are violently disturbed and altered in some parts in such a degree as to assume somewhat the aspect of the inferior formation, but the occasional presence of fossils, amongst which was one resembling Zaphrentis and some Encrinites, was supposed to indicate a horizon of later date than the Quebec group.

M 11. ROCKY MOUNTAINS OF BRITISH COLUMBIA.

In a section examined along the Canadian Pacific Railway McConnell [559] found the Castle Mountain group (Cambrian and Ordovician) to be succeeded in the eastern ranges of the Rocky Mountains by the "Intermediate" limestone and in the western ranges by the Ordovician "Graptolitic shales" and the "Halysites beds." Neither the "Intermediate" limestone nor the "Halysites beds" is stated to be of widespread occurrence, owing presumably to erosion and unfavorable structural conditions, and they have not been observed in contact. On paleontologic evidence the "Intermediate" limestone is assigned to the Devonian, whereas "*Halysites catenulatus,* Favosites, a coral like Zaphrentis, and some badly preserved brachiopods" indicate the Silurian age of the "Halysites beds." The latter consist of about 1,300 feet of dolomites and quartzites, the quartzite being at the base and the upper part of the formation missing through erosion of the syncline in which the strata occur.

This isolated occurrence and that in the Finlay-Omenica section (N–O 10) appear possibly to connect the Silurian dolomite of the Porcupine section, Alaska (Q 5–6), with the Silurian of Utah.[498c]

M 20. ANTICOSTI ISLAND.

The Ordovician-Silurian sequence is unusually complete in the island of Anticosti, there being no apparent interruption of sedimentation nor any abrupt change of faunas in the passage from one system to the other. Logan [544m] gives a detailed section, which is presented below in condensed form, lists of fossils being omitted.

The strata of this [Hudson River] formation occupy nearly the whole of the north side of the island [Anticosti] and extend from Fox Point, which is toward the east end, to Junction Cliff, on the south side, about 4 miles from the west end. The remaining portion of the island is occupied by newer rocks, to which the name of the Anticosti group has been given. Their position in the geological series is that occupied by the Oneida conglomerate, the Madison sandstone, the Clinton group, and the Niagara group of the New York geologists, but these subdivisions, although apparent in the western basin, disappear in the Anticosti strata, which are lithologically unlike their equivalents in western Canada. * * *

The rocks of this group on the island of Anticosti may be considered in four divisions, * * * in immediate succession to the Hudson River formation, as follows, in ascending order:

1.

	Ft.	in.
1 to 3. Greenish argillo-arenaceous shale at base of yellowish-gray compact argillaceous limestone interstratified with light reddish-gray limestone beds of from 1 to 3 inches thick, with many fossils, all together	32	6
4. Measures partly concealed but supposed to be of the same character as the preceding, both lithologically and paleontologically	25	
5 to 7. Ash-gray argillaceous limestone, in beds from 1 to 3 inches thick, alternating with beds of calcareo-argillaceous shale of from 5 to 7 inches. Both of these are interstratified with light-gray pure limestone beds, 1 or 2 inches thick	67	
8. Measures concealed	21	
9 to 10. Gray limestone, interstratified with gray and sometimes greenish calcareo-argillaceous shale	17	
11. Yellowish-white coralline limestone	5	
12 to 14. Gray compact argillo-calcareous beds, slightly bituminous, interstratified with argillaceous bands	139	
	306	6

2.

	Ft.	in.
1 to 2. Ash-gray and light reddish-gray limestones, in beds of from 2 to 6 inches thick, interstratified in the upper part with conglomerate beds of some thickness, at intervals of from 2 to 10 feet. The pebbles are calcareous, from 1 to 3 inches in diameter, and lie flat in the beds	120	6
3 to 5. Reddish-gray limestone, in beds from one-quarter of an inch to 3 inches thick, some of which weather to a reddish brown; interstratified with occasional conglomerate layers of from 2 to 4 inches thick (toward the top)	143	6
6. Measures concealed	40	
7. Gray, yellowish-weathering limestone, containing but few fossils	34	
8. Measures concealed	17	
9. Ash-gray, smoke-gray, and reddish gray, slightly bituminous limestones	65	
10. Measures concealed	27	
	447	

3.

	Ft.	in.
1. Measures concealed	27	
2. Greenish-gray and brown fine arenaceo-argillaceous shales, interstratified with one another, in thin beds; no fossils are seen	60	
3 to 7. Ash-gray and light-drab limestones interstratified, both slightly bituminous and crowded with *Stricklanida lirata* (near the top)	157	9
8. Measures concealed, with 1 foot of light-drab argillaceous, slightly bituminous limestone in the middle	51	
9. Light-drab argillaceous limestone, slightly bituminous, in beds of from half an inch to 3 inches	87	6
10. Measures concealed at the bight of the cove, north of Southwest Point	157	6
	540	9

4.

	Ft.	in.
1 to 3. Yellowish-white granular limestone, in beds of from 3 to 18 inches thick; often separated by thin partings of green argillo-calcareous shale, which is also disseminated in small patches through the bed	57	3
4. Yellowish-white granular limestone, in beds of from 6 to 18 inches thick; consisting of masses of organic remains, of which crinoidal columns constitute the larger part; some of them being three-fourths of an inch in diameter	16	
	69	3

This is the highest series of strata met with on the island, and its lithological characters are so well marked that it is scarcely possible to mistake it for any of those which precede.

For the sequence of faunal zones, according to which these lithologically similar beds of argillaceous limestone and shale are distinguished by Logan, his original account should be consulted. The general faunal relationships and correlation were thus summed up by Billings: [82a]

MIDDLE SILURIAN—ANTICOSTI GROUP.

Division 1.—The rocks of division 1 rest directly and conformably upon those of the Lower Silurian, above noticed, with no apparent physical gap between them, although there is a paleontological break. It has been already stated that 41 of the species of the lower fauna pass this break. They are here joined by 45 additional species, making the whole fauna of this division to consist of 86 species, so far as is yet known. Of these, 18 pass upward into division 2, 13 into division 3, and 11 into division 4.

Of the 41 species which are received from the Lower Silurian the following are known to occur in Canada West and New York and are variously distributed throughout all the formations from the base of the Quebec group to the top of the Hudson River formation.

Stenopora fibrosa.
Halysites catenulatus.
Beatricea undulata.
Lingula quadrata.
Strophomena alternata.
S. planumbona.
Leptæna sericea.
Orthis porcata.
O. lynx.
Orthisina verneulli.
Ambonychia radiata.
Subulites elongata.
Murchisonia gracilis.
M. ventricosa.
Bellerophon bilobatus.
Pterotheca transversa.
Orthoceras formosum.
Ascoceras newberryi.
Asaphus megistos.
Calymene blumenbachi.
Cheirurus pleurexanthemus.

Among the 45 species which here made their first appearance in the rocks of Anticosti we find *Strophomena rhomboidalis*, *S. pecten*, and *Atrypa marginalis*, all three very characteristic of the Middle and Upper Silurian. The new species include *Atrypa umbonata* and *A. prinstana*, members of the group of which *A. tumida* may be regarded as the central form, a type almost unknown in the Lower but very prolific of species in the Middle and Upper Silurian. This group becomes extinct in the Devonian. The genera Favosites, Heliolites, and Helopora, which here first appear in force, are more characteristic of the upper than of the lower half of the Silurian series. Most of the other new species belong to the ordinary Silurian genera.

The fauna of this division is partly Lower and partly Middle Silurian but is more strongly tinged with the former than the latter.

Division 2.—From this division we have only 39 species, of which 18 are received from division 1 and 21 here first made their appearance. Out of the whole fauna 23, or more than one-half, pass into division 3 and 16 into division 4. As before stated, the only species very characteristic of the Lower Silurian are *Strophomena alternata* and *Murchisonia gracilis*. The most prominent fossil is *Pentamerus barrandi*, which occurs in vast numbers. Owing to the inaccessible character of the coast in bad weather, it was not practicable to make a thorough search for fossils in this division.

Division 3.—In this division there are 53 species, of which 23 are received from division 1, and 26 pass upward. We here meet for the first time with *Pentamerus oblongus*, *Stricklandinia lens*, *S. lirata*, *S. brevis*, and *Laptocœlia hemispherica*. These are all strongly characteristic of the Middle Silurian and occur in this division and also in division 4 in great abundance.

Division 4.—There are 70 species from this division, of which 26 are received from below.

CONCLUSION.

The great abundance of such species as *Strophomena rhomboidalis*, *S. pecten*, *S. antiquata*, *Leptæna transversalis*, *Orthis davidsoni*, *Pentamerus oblongus*, *Stricklandinia lens*, *S. lirata*, *S. brevis*, *Cyrtia myrtea*, *Spirifer plicatella*, and *Leptocœlia hemispherica*, together with the general aspect of the whole fauna of divisions 3 and 4, render it quite certain that this part of the series represents the Upper Llandovery rocks of England and, perhaps, the Lower Llandovery also. They may not be exactly synchronous, for it seems to be now pretty conclusively demonstrated that a fauna may appear somewhat earlier in one region than in another. But, so far as we can at present decide the question by fossil evidence, these rocks are of the same age. I use the word fauna in a purely zoological sense, with no reference to geographical distribution. With regard to the Llandovery formation, Mr. Salter[a] makes the following remarks: "The Lower Llandovery, or, as I prefer to call it, with Prof. Phillips, the Llandovery rocks, are intimately united with the Caradoc, and pass up from them with a great admixture of Lower Silurian, not Upper Silurian, forms. The May Hill sandstone, on the contrary, as Sedgwick showed in 1853, is unequivocally the base of the Upper Silurian, and contains scarcely any true Lower types." Now, the only deposit, as yet known in America, which exhibits such an admixture, is division 1 of the Anticosti group. If, then, the extinction of the Lower Silurian fauna occurred in the ancient British seas at the same time that it did in the American waters, it follows that division 1 is Lower Llandovery; and that the Hudson River is Caradoc.

It is, however, very difficult to correlate all the divisions of the English Middle and Lower Silurian with those of America, and I shall take this occasion to make a few observations on the other members of the series not found in Anticosti. From what we know of the origin and mode of accumulation of sedimentary strata, it is highly improbable that each of the minor formations of one country should have its exact equivalent in another land several thousands of miles away, although the larger groups, of which these smaller ones are the component parts, may be well represented, and paralleled in a general way. Everywhere we find a number of breaks or gaps, and the probabilities are vastly against these breaks having been all occasioned at the same time in distant localities. It is more consistent with the nature of things that many of the breaks in America should stand opposite—so to speak—the formations in England, and vice versa. Perfect parallelism of the minor groups may be looked for as the exception, not the rule.[b]

M-N 13-14. LAKE WINNIPEG, MANITOBA, AND SASKATCHEWAN.

The Silurian of northwestern Manitoba is a thin-bedded limestone, which varies in character from bed to bed. The lower portion, well exposed at Grand Rapids,

[a] Geol. Mag., vol. 3, p. 240.

[b] Prof. A. C. Ramsey (Anniversary address to the Geological Society, 1863: Jour. Geol. Soc., vol. 19) gives the following account of the breaks in the English series from the Lingula flags up to the Wenlock shale:

Lingula flags.
  Break very nearly complete both in genera and species, and probable unconformity.
Tremadoc slate.
  Break very nearly complete, both in genera and species, and probable unconformity.
Llandeilo and Caradoc beds.
  Large break, especially in species, and probable unconformity.
Lower Llandovery beds.
  Break and decided unconformity.
Upper Llandovery beds.
  Break and strong unconformity.
Wenlock shale, etc.

on the Saskatchewan, consists of 54 feet of white or yellow limestone, partly magnesian, partly chalky, and partly ripple-marked and containing impressions of salt crystals. The base is not seen, but limestone of Trenton age lies not far below. Fossils are lacking in the lower 10 feet but numerous above, and the strata are compared by Tyrrell[817a] with the lower part of the Niagara of Wisconsin. Above the lower portion is a considerable thickness, "possibly a few hundred feet," of dolomites and dolomitic limestones of upper Niagara age. The beds exhibit impressions of salt crystals and are in some places "fragmental." Tyrrell gives a list of 41 species of fossils determined chiefly by Whiteaves. Near Lake St. Martin (latitude 51° 45′) the strata of Niagara age rest on granite of an island in the rocks of Trenton age, which elsewhere underlie them. Gypsum occurs not far away. Near by, on the eastern shore of Lake Manitoba, "the thin-bedded upper Niagara dolomites are overlain by a few feet of a thick-bedded massive stromatoporoid magnesian limestone, which yielded a few corals, including *Pycnostylus guelphensis*."

N-O 8. SOUTHEASTERN ALASKA.

The Wales "series" of southeastern Alaska comprises argillites, of great thickness but unknown age, and younger limestone, 2,000 feet or more thick, from which Kindle [496] lists Silurian fossils. He says:

> Two horizons of the Silurian have been recognized. The older of these is represented by a small fauna which has been found on the northwest coast of Kuiu Island. In the limestones northeast of Mead Point the following fauna occurs:
>
> Diphyphyllum? sp.
> Conchidium knighti (Sow.).
> Whitfieldella sp.
> Holopea cf. servus Barr.
> Murchisonia sp.
>
> None of the species are abundant, with the exception of *C. knighti*, which is represented by great numbers of large shells in one thin bed of limestone.
>
> *C. knighti* is one of the characteristic fossils of the Aymestry limestone of the Ludlow group of England. It is known also from Russia and Bohemia. There appear to be no authentic records of its occurrence in the Silurian faunas of the United States. The nearest equivalent of this fauna in eastern America is the Niagara fauna. While none of the species collected are identical with Niagara species, *Conchidium knighti* is very closely related to *C. nysius* of the Niagaran fauna.
>
> The Kuiu Island fauna occurs in the midst of a limestone series which appears to be 2,000 feet or more in thickness. Other portions of the series which were examined appeared to be barren. Upward these limestones seem to terminate with volcanic breccias, while below they pass into cherts and argillites of undetermined age.
>
> The later Silurian horizon does not appear to be present in the Kuiu Island section. It occurs at Freshwater Bay, where more than a thousand feet of gray limestones, which precede the beds carrying Devonian fossils, outcrop along the south side of Freshwater Bay. The lower two-thirds of this series comprises dark-gray, thinly laminated limestones. Leperditias of an undetermined species occur abundantly in certain beds in the lower part of the series. A few fragments of another and larger crustacean, probably a Ceratiacaris, are associated with them. These crustaceans comprise the fauna of the lower 700 feet of the section, so far as discovered.
>
> In the upper 300 feet of the limestones of the section a crustacean fauna predominates, but the types represented are unlike those of the preceding division. One of the conspicuous forms in this fauna is a largely undescribed ostracod provisionally referred to Isochilina by

E. O. Ulrich, having a length of 1¼ inches. Fragmentary specimens indicate the presence of one or more other species of large ostracods, which together with a new species of Ceratiacaris are associated with the large Isochilina. Other forms occurring in this portion of the section are Zaphrentis ? sp., represented by a single specimen, *Meristella tumida* Dalm. ?, and Megalomus sp. undt. The Megalomus is a large and very thick shelled bivalve comparable in this respect with *Megalomus canadensis* of the Guelph and identical with a species occurring in the limestone at Glacier Bay.

While none of the forms occurring in the two lowest divisions of this section have been identified with known species, the dominance of the large ostracods and the massive-shelled Megalomus and thick-shelled Murchisonias point to a late Silurian age of the fauna. The horizon represented is apparently about that of the Guelph.

The Silurian fauna of Freshwater Bay is found also at Glacier Bay, to the northwest. A small collection in the National Museum made by Cushman and a much larger collection by Mr. F. E. Wright show the faunas of the two localities to bear the closest resemblance.

The horizon represented by the fauna at Freshwater and Glacier bays is not known as yet elsewhere in Alaska. The Kuiu Island Silurian fauna differs very materially in its facies from other known Silurian faunas of Alaska, but the same horizon appears to be represented by the Silurian found by the writer on the Porcupine River, in northeastern Alaska, during the last summer.

N-O 10. FINLAY AND OMENICA RIVERS.

Beneath the "Devono-Carboniferous" Banff limestone, in the Peace River pass, British Columbia, McConnell [562b] observed beds containing Halysites, which may represent the Silurian. They apparently correspond with the strata holding a similar stratigraphic position and also containing Halysites, which occur east of Columbia River on the main line of the Canadian Pacific Railway and immediately overlie graptolite-bearing slates of Black River to Trenton age (Normans Kill fauna). (See p. 191.)

N-O 15-17. SOUTHWEST COAST OF HUDSON BAY.

The mapping of Silurian rocks on the southwest coast of Hudson Bay rests upon collections of fossils from a few isolated localities, which do not suffice to delimit the formation in relation to the Ordovician rocks of the same district. The most noteworthy of these occurrences is at Port Churchill, where fragments of a white limestone yielded fossils related to the Silurian of the Saskatchewan and of Anticosti.[818] Farther south the limestones have been observed and fossils collected, especially on Ekwan and Attawapiskat rivers. Dowling [291a] states:

> The valleys of all the streams entering the western side of James Bay are cut down through the drift deposits to a flat-lying limestone, which forms a wide belt around the west shore of the bay and along the southern shore of Hudson Bay. On the Albany River the upper part of the series is proved to be of Devonian age, and beneath, at a greater distance from sea, Silurian limestones are exposed. These beds probably overlap any older ones that may be beneath and rest directly on the Archean.

Descriptions and lists of fossils may be consulted.[291, 924]

P 6-7. SOUTHERN ALASKA, COOK INLET TO YAKUTAT BAY.

Metamorphic rocks of sedimentary origin constitute in southern Alaska a great and extensively exposed series, the Valdez group, which is probably chiefly Paleozoic and includes Silurian, but no definite section can be thus correlated. (See note on metamorphic Paleozoic in Alaska, Chapter VII, p. 353.)

P 19. UNGAVA BAY.

Akpatok Island, in Ungava Bay, is described by Robert Bell [68a, 69] as consisting of a great thickness of "Cambro-Silurian" rocks. The fossils which he collected are stated to represent the "Hudson River" terrane.

According to Low,[550b] the fossils of Akpatok Island range from "Lower Galena-Trenton to Lower Helderberg."

P-R 9-10. BEAR RIVER AND MACKENZIE VALLEY.

Bear River, the outlet of Great Bear Lake, passes from Cretaceous to Paleozoic rocks in cutting through a ridge of which Mount Charles is the highest point in the vicinity. J. M. Bell [64a] ascended the mountain in 1899 and reports:

> Ordovician or possibly Silurian rocks occur at "The Rapid" on the Bear River where the mountain range crosses it. Mount Charles, the most prominent part of these mountains, is a hill of about 1,500 feet in height and consists of a large anticline, embracing subordinate folds. The rocks are interstratified conglomerates, quartzites, and magnesian limestones, the latter of great thickness. I found thin layers of gypsum in several places, interstratified with dark-gray shaly dolomite.

Bell does not cite any fossils. Dawson [257c] quotes Meek on the Devonian age of the limestones of the Mackenzie Valley, which were earlier referred to the Silurian by Isbister and others. "Amongst all the collections under examination from various localities along Mackenzie River and its tributaries, between Clearwater River and the Arctic Ocean, a distance by course of the valley of more than 1,000 miles, there are no Carboniferous or characteristic Silurian forms." If Bell and Meek are both correct, the anticline crossed by Bear River brings up Silurian strata not generally exposed along the Mackenzie.

P-S 10-17. ARCTIC REGION.

The southern islands of the Arctic Archipelago are extensively covered by Silurian strata, probably in most places underlain by the late Ordovician, with which they constitute the base of the stratified sediments that dip gently northward from the "Laurentian" gneisses of the mainland. These Silurian deposits are by their fossils so related to the strata occurring near Lake Winnipeg and in the Mississippi Valley as to demonstrate the extent of the sea over northern central North America. Waters affording the same habitat and supporting the same faunas were continuous to the northern shores of Russia and spread widely over Siberia.[804, 876]

Dawson's comments on the views formerly held and now deemed reasonable as to the presence of Ordovician strata in the Arctic have already been quoted (p. 222). The following account of the Silurian rocks is Haughton's description as given by Dawson.[257f]

> The Silurian rocks of the Arctic Archipelago rest everywhere directly on the granitoid rocks, with a remarkable red sandstone, passing into a coarse grit, for their base. This sandstone is succeeded by a ferruginous limestone containing rounded particles of quartz, which rapidly passes into a fine grayish-green earthy limestone abounding in fossils, and occasionally into a chalky limestone, of a cream color, for the most part devoid of fossils. The average dip of the Silurian limestone varies from 0° to 5° NNW., and it forms occasionally high cliffs and occasionally low flat plains, terraced by the action of the ice as the ground rose from

beneath the sea. The general appearance of the rocks is similar to the Dudley limestone and would strike even an observer who was not a geologist. This resemblance to the Upper Silurian beds extends to the structure of the rocks on a large scale. Alternations of hard limestone and soft shale, so characteristic of the Upper Silurian beds of England and America, arranged in horizontal layers, give to the cliffs around Port Leopold (northeast part of North Somerset) the peculiar appearance which has been described by different polar navigators as "buttress-like," "castellated;" this appearance is produced by the unequal weathering of the cliff, which causes the hard limestone to stand out in bands.

A few fossils procured by Hall on the west shore of Kennedy Channel, at Cape Leidy, Cape Frazer, and other points, were examined by Meek,[584] who reported 12 species and commented:

From the foregoing list, it is believed that geologists will agree that the rocks at this highest northern locality at which fossils have ever been collected belong to the Upper Silurian era. The most remarkable fact, however, is that they are nearly all very closely allied to and some of them apparently in all respects undistinguishable from species found in the Catskill shaly limestone of the New York Lower Helderberg group.

Authorities for the distribution of Silurian strata throughout the Arctic region are given by Dawson[257e] in his detailed account of the scattered data gleaned by him from the writings of many explorers. The localities noted are named below. Dawson also gives a list of localities at which fossils have been obtained.

P–Q 16–17	Southampton Island.
Q 18–19	Baffin Land.
R 10	Cape Parry; Baring or Banks Land.
R 14–15	King William Land and Boothia Peninsula.
R 17	Melville Peninsula.
R–S 11–13	Mainland Coast, Wollaston and Victoria lands.
R–S 14	Prince of Wales Island.
R–S 15–16	Gulf of Boothia.
S 15	North Somerset.

Jones,[472a] Salter,[692] and Schuchert[712] may also be consulted.

Low[550a] describes an area of Ordovician and Silurian limestones covering all but the northeast coast of Southampton Island, most of Coats Island, and all of Mansfield Island and reappearing on Akpatok Island, in Ungava Bay, though not seen on the intervening southern shore of Hudson Strait. The fossils from the south shore of Southampton Island constitute "a fauna closely resembling that of the Lake Winnipeg basin, and extend over a period from the Galena-Trenton to the Guelph and Niagara."

Q 3. SEWARD PENINSULA.

The Nome group of Seward Peninsula comprises mica schists and probably three massive limestones, which, according to P. S. Smith,[767] range in age from Cambrian to probably post-Ordovician. The Port Clarence limestone is the oldest division of the Nome group which is known to contain fossils. The faunas of this limestone have been listed by Kindle,[503] who states [a] that a magnesian limestone on Fish River yielded a heavy-shelled lamellibranch comparable with *Megalomus canadensis* and identical with a species which occurs in the limestone of late Silurian age at Glacier Bay and at Freshwater Bay in southeastern Alaska. (See p. 262.)

[a] Personal communication, January, 1910.

On the map the Silurian is not distinguished, being included in the unaltered and probably also in the metamorphosed Paleozoic rocks.

Q 5-6. YUKON-TANANA REGION.

The Fortymile group of crystalline limestone and quartzite with some graphitic schist was provisionally correlated by Brooks [101a] with the Nome group and the Skajit formation of northwestern Alaska. Later investigations by Brooks and Kindle on Porcupine River have resulted in more definite determination of the Silurian age of a massive limestone which may be equivalent to that of the Fortymile group.

With regard to the Porcupine section, Brooks [102] says: "The Silurian is represented by at least 2,500 feet of magnesian limestone with some quartzites and slates, which are probably conformable to the Ordovician. Its correlation with the Fortymile series of Spurr is suggested but not proven."

Kindle [498a] gives a list of 37 species collected from this limestone and comments:

The Porcupine River fauna contains species which link it with the Silurian faunas of both Europe and America. Of these *Rhynchotreta cuneata*, *Spirifer nobilis*, and *Pentamerus oblongus* have long been known in both European and American faunas. The peculiar little twisted brachiopod *Streptis greyi* has been recognized at but one other American locality, however. Williams has reported it from the St. Clair limestone fauna of Arkansas. In Europe it occurs in the Silurian of Bohemia, in England, and at the island of Gotland.

The Silurian fauna of the type represented by the species listed here is known to have a wide distribution throughout the world. It is well known in various parts of Europe and has been recognized in regions as remote as China, New Zealand, and Australia. This fauna occurs in a magnesian limestone of considerable thickness—probably 2,000 feet. It is preceded in the section by Ordovician limestones containing Maclureas. It is followed by a somewhat later phase of the Silurian and by the Devonian.

Q-R 5. ENDICOTT RANGE.

The Skajit formation of the Endicott Range, northern Alaska, consists of heavy-bedded crystalline limestone and mica schist, in which a few obscure fossils, apparently Silurian, were found by Schrader.[708]

T 16-17. ELLESMERE LAND.

A thick section of Ordovician, Silurian, and Devonian strata occurs on the north shore of Jones Sound, southern Ellesmere Land, and has been described in detail by Schei,[550d] as follows:

There are at Havnefjord, in Jones Sound, above some layers of quartz sandstone, which entirely cover the gneiss granite there, a series of limestone conglomerates with marly schists and pure limestones of a thickness of 1,200 to 1,500 feet. These are again overlain by a series of beds at least 2,000 feet thick, of hard, impure limestones, brown or yellowish gray in color and often remarkably heavy.

At South Cape, which is entirely composed of this brown limestone, are found in the lower parts Maclurea sp., and Halysites sp., referable to the Middle Silurian [probably Ordovician], while west of it, at Bjorneborg, the upper parts of the series contain badly preserved remains of Orthocerata, corals, and *Pentamerus* cfr. *tenuistriatus*. Hereafter the upper part of the limestone seems to be equivalent to the older Upper Silurian (Landovery). This brown limestone occurs from South Cape westward to Kobbebugten, in Hell Gate, and is broken at Lille Sandor, tectonic disturbance bringing up the underlying conglomerate series and even the Archean. * * *

On the south side of Rendalen appears the brown limestone of the capes, series A, with a flat dip to the north-northwest; but on the north side of the valley is a division of dark schist [shale], series B, lying conformably above the beds of brown limestone. Associated with these schists, particularly in their lower and upper parts, are numerous layers of pure dark limestone, frequently fossiliferous. In Rendalen and in Kobbebugten, where this same division also appears, a quantity of material was collected, of which 15 species are provisionally determined, among them being Favosites sp., *Strophomena* cfr. *euglypha,* Neristella in numbers, *Rhynchonella* cfr. *borealis, Pentamerus* cfr. *galeatus, Spirifer* cfr. *elevatus.* The period of this division in series B is Wenlock.

The upper part of series B appears, among other places, at the headland north of Tunneldalen, in Hvalrosfjord. Above a black shale containing Monograptus sp. and *Leperditia* cfr. *phaseolus* is a bed of fragmentary limestone with Favosites, *Strophomena* cfr. *pecten, Atrypa reticularis, Pterinea* cfr. *sowerbyi.* From a locality in Gaasefjord, on the same horizon, were taken *Favosites* cfr. *hisingeri, Favosites gothlandicus, Thecia swinderenana, Spirifer elevatus, Spirifer* cfr. *crispus, Strophomena corrugatella* Dav., Pterinea sp. According to these, the period of this upper part of series B should be Ludlow. The thickness of the series is about 1,000 feet.

In Hell Gate, as well as in Gaasefjord, these strata are overlain by series C, in its lower parts consisting of interstratified light and dark marl schists, which are somewhat sandy, while in its upper part appear pure quartz sandstone beds and argillaceous sandstone. The collective thickness of these strata is about 1,000 feet in Gaasefjord, while in Hell Gate it is probably somewhat greater. No fossils were found in this series.

At the base of the high cliffs at Indra Eide and Borgen appears series C. In both these places it is overlain by a dark limestone and black shale, partially fossiliferous. This dark limestone and shale are the lowest layers in a series of strata at least 1,500 feet in thickness, series D, which appears in the profiles on both sides of Gaasefjord, from Borgen to the foot of Vargtoppen (Wolf Top), and from Indra Eide to Skrabdalen.

In series Da occurs *Atrypa reticularis* in great quantities, but little else. On the other hand, there are preliminarily determined in Db about 55 species, of which may be mentioned Favosites sp. div., Columnaria sp., *Cyathophyllum* sp. cfr. *hexagonum,* Receptaculites sp., Fenestella sp., Homalonotus sp., Burmeisteria sp., Dechenella sp., Proetus sp., *Orthis striatula,* Leptæna sp., Strophomena, Streptorhyncus, *Atrypa reticularis aspera, Rhynchonella* (*Pugnax*) cfr. *reniformis pugnus, Productus* cfr. *prolongus,* Spirifer of the *verneuilli* Murch. type, a peculiar Pentameride, Terebratula cfr. Dielasma, Pterinea sp., Modiolopsis sp., Lucina sp. div., Bellerophon sp., Platyceras sp., Orthoceras sp., Gomphoceras, gigantic nautilus, and ganoid scales.

The fauna in Dc is merely a repetition and, in the case of certain species, a further development of the forms found in Db. It will thus be seen that there is a spring in regard to the fauna between the upper layers in series B and the lower ones in series D, which more particularly resemble Lower or Middle Devonian. The concordantly embedded(?) series C might, therefore, be thought to represent uppermost Silurian as well as lowest Devonian.

Divisions Dd and Df are poor in fossils and are partly shale divisions. In the impure limestone of Dg occur again numerous fossils, among which are *Atrypa reticularis, Rhynchonella* cfr. *cuboides, Spirifer* cfr. *undifera,* Productus sp., Terebratula cfr. Dielasma, Pterinea sp., Avicula sp., Modiolopsis sp., Pleurotomaria sp., Proetus sp. Traces of placoderm fish are also met with. Above these strata are beds of pure limestone, Dh, and above these again some less pure, Di. The uppermost strata of Di alternate with strata of light-gray quartz sandstone terminating in a clay sandstone, which in places is richly fossiliferous, though the fossils are in a bad state of preservation. Among these are Lamellibranchiata, Dechenella sp., remains of Holoptychius, etc.

This argillaceous sandstone is simultaneously the last link in series D and the first in series E. This is a huge collection of quartz sandstone strata building up the mountains on both sides of the inner part of Gaasefjord. The lowest part, which is 900 to 1,200 feet in thickness, consists almost exclusively of quartz sandstone. On the north side of Skrabdalen in the sandstone profile, occur conglomerate strata, half an inch to an inch in thickness. In these were found considerable remains of Coccosteus sp., Holoptychius sp., and *Modolia angusta.* In the same strata with these were also seen indeterminable plant fossils. Slightly higher up in the profile, however, in a black shale which occurred in two lentiform masses, 18 inches and 6 feet in thickness, were found numerous plant fossils.

Prof. Nathorst, of Stockholm, who has kindly undertaken the examination of these, says that among others are *Archæopteris fissilis* Schmalh. and *Arch. archetypus* Schmalh., both characteristic of Upper Devonian. In examining the material collected, Prof. Nathorst also found with the plant remains some remains of fishes.

Low,[550e] who quotes the foregoing description from Schei, comments on it as follows:

From the above it will be seen that on the southern side of Ellesmere there is a complete succession of strata, bearing fossils from Middle Silurian age up to the Upper Devonian. These strata have an aggregate thickness of 8,000 feet and form the thickest and most carefully measured section of the Silurian and Devonian beds of the Arctics.

The southern shore of Jones Sound presents a different section, which is thus described by Low: [550f]

On the southern and southwestern parts of North Devon the Silurian strata are much thinner than those described by Schei. At Cuming Creek the Archean gneisses were found overlain unconformably by red and purple arenaceous shales and thin-bedded sandstones having an aggregate thickness of 50 to 100 feet. These in turn were succeeded by beds of impure limestone of light-gray or creamy color. The beds are usually under 2 feet in thickness and separated by thinner beds containing a considerable amount of clay. These light-colored limestones have a thickness of over 1,000 feet in the cliffs on both sides of the creek. The sides of the cliffs are covered with broken limestone, so that it was impossible to measure a section up them, but in two or three places a darker-colored limestone conglomerate was found, made up of small pebbles cemented by a dark shaly matrix. Fossils are only found in the beds immediately overlying the dark shales and sandstones of the base. These show that the lower limestone is of Silurian age, about the horizon of the Niagara.

Similar conditions prevail in the cliffs at Beechey Island, where a large collection of fossils was obtained from the lower limestone beds, while others, picked up loose but evidently fallen from the cliffs above, showed that the upper beds passed close to if not into the Devonian.

Similar Silurian limestones constitute the island of Cornwallis, to the westward of North Devon, while in the remaining Parry Islands farther west the Silurian strata are lost beneath the Devonian and Carboniferous rocks of those islands.

CHAPTER VI.

DEVONIAN.

Color, dark blue.

Symbol, 15.

Distribution: Eastern-central United States, eastern Canada, northwestern Canada, and Cordillera of the United States, Canada, and Alaska.

Content: Devonian as commonly defined through the Appalachians, including Helderberg at the base and higher formations to Chemung and Catskill, inclusive; in the northeast, from Gaspe to New York, Helderberg is included with the Silurian in mapping; in the Appalachian zone south of latitude 38°, the Devonian color on the map includes Silurian; throughout the Cordillera from Mexico to Alaska the Devonian where present is mapped with Carboniferous undivided (14), except that it is distinguished in the Klamath Mountains, California.

Devonian areas.

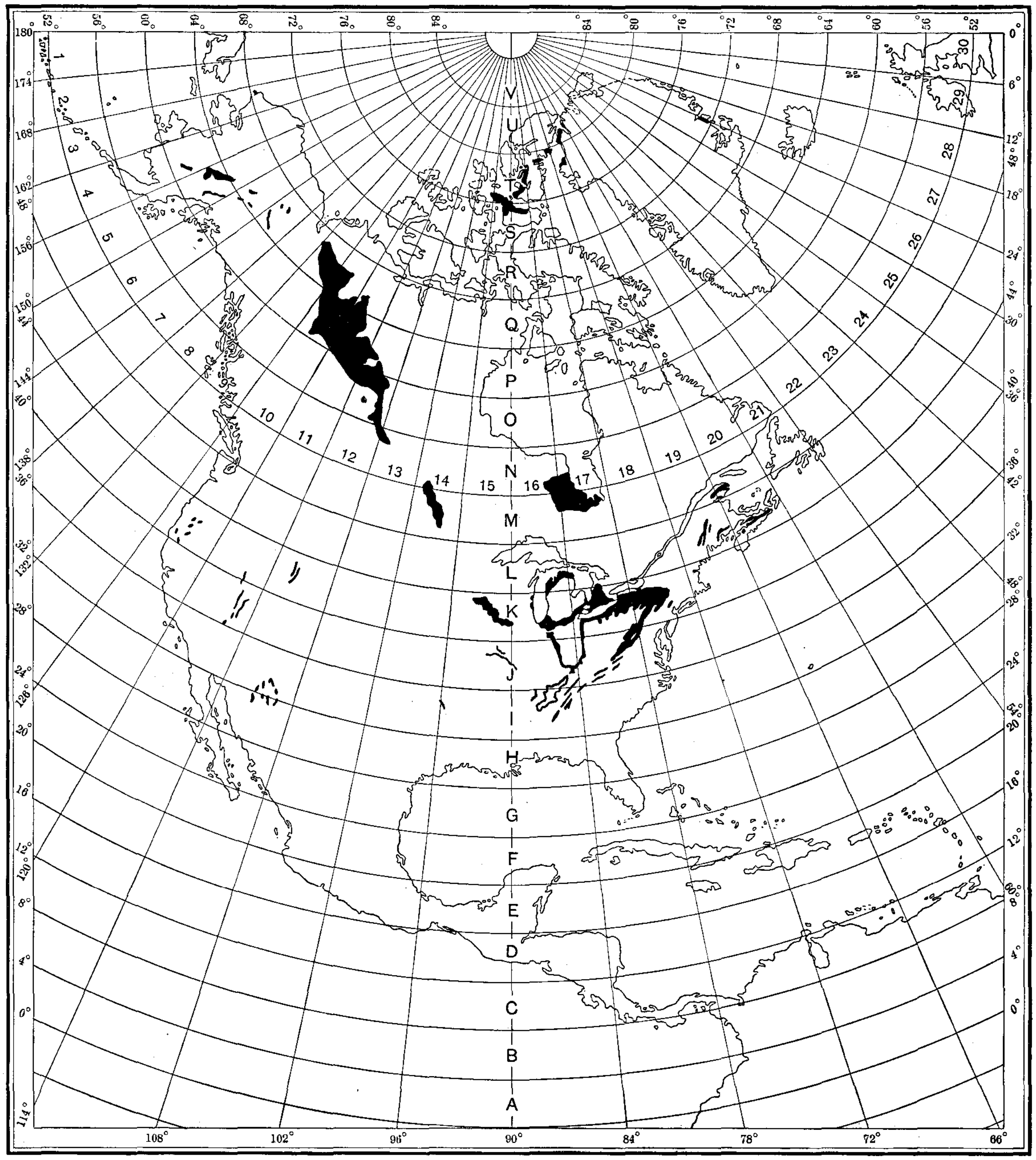

FIGURE 8.—Sketch map showing the distribution of Devonian rocks represented on the geologic map of North America and the key to references in the text.

H-I 12. SOUTHERN ARIZONA AND NORTHERN SONORA.

The sections at Globe and Bisbee, described by Ransome,[657a, 659] include limestone which contains late Middle or Upper Devonian fossils. At Globe the formation is continuous upward with Carboniferous (Mississippian) limestone, as are the Ouray limestone of Colorado and the limestones described by Dumble.[296]

At Bisbee the Martin limestone (Devonian), 340 feet thick in the type section, is distinguished from the Abrigo limestone (Cambrian) below and the Escabrosa limestone (Mississippian) above it. The fauna is described and correlated by Williams,[658b] who concludes that its affinities are with the Neo-Devonian of New York but that in Meso-Devonian time the fauna occupied the Arizona province in migration from Russia.

Williams comments on the fauna as follows:

The species *Atrypa reticularis* is present in 25 of the 30 faunules. Some one or more of the corals are found in 11 of the faunules. [Six of] the faunules * * * contain several species of the reef-building corals and probably represent a common fauna.

Associated with these corals are species[a] which indicate distinctly the fauna so well developed in the Devonian rocks at Rockford, Iowa. On the supposition that *Spirifer hungerfordi* and *Spirifer whitneyi* are characteristic species of that fauna, the following species, associated with them in the Bisbee quadrangle, are now added to it—that is, *Dielasma calvini*, *Productella speciosa*, *Spirifer* cf. *jeremejevi*. These twelve species, at least, are therefore probably present in a common fauna of this Arizona region, which is also represented in Iowa, and is certainly of Devonian age.

Its comparison with New York and northern Appalachian faunas indicates close affinity with a fauna occurring at the base of the Chemung formation of New York, above the typical Ithaca formation. In the High Point zone of Naples, Livingston County, N. Y., the species of the genus Strophonella reported is *S. reversa*. The form reported in the above list is *S. cælata*, which occurs in the *Stropheodonta cayuta* fauna of the southern counties of New York and across the border in Tioga and Bradford counties, Pa., but not, so far as I have observed, in the High Point fauna. In this southern extension it is associated with typical *Spirifer disjunctus*. The Productella of the Arizona region is also of the same type as that represented in this upper (Chemung) zone rather than in the underlying typical Ithaca zone of *Productella speciosa*. The evidence is therefore confirmatory of the opinion that this western American fauna did not reach the upper Appalachian region, in its full complement, until after the deposition of the zone of the Ithaca formation.

It is to be observed, however, that in Russia the fauna with which this Arizona fauna shows closest affinity is classed by Tschernyschew as middle Devonian rather than upper Devonian and occurs below the Cuboides fauna. It is also regarded by him as equivalent to the Stringocephalus fauna, which in western Europe is strictly Mesodevonic. This is further correlated by Tschernyschew with the Hamilton group of North America.

* * * * * * * * *

There can be little doubt as to the close affinity of the Arizona and Russian faunas here referred to. Comparison of *Spirifier hungerfordi*, as it occurs both in Iowa and Arizona, with Russian specimens of *Spirifier anossofi* demonstrates the two to be closely related, as Tschernyschew maintained; but the rounded cardinal angle as well as coarser radiating striæ mark the figures of *S. anossofi* of Tschernyschew (as well as actual specimens seen by me), from the *Sp. hungerfordi* as it is seen both in Iowa and Arizona. There are figures in the original

[a] For list see the work cited.—B. W.

description of De Verneuil, which have the angular terminations of the cardinal area. Also some young specimens from Iowa in my collections show distinctly rounded cardinal angles.

Associated with that species are *Productus hallanus* and Rhynchonellas of the Pugnax type (*R. acuminata*), which distinctly belong to this fauna as developed in America.

As I have reported in other places, this *Pugnax pugnus* fauna occurs in the New York section, both in Ithaca and High Point zones, which are both above the representative of the Cuboides zone (Tully limestone) of that region, and before the appearance there of the typical *Spirifer disjunctus* fauna. But in New York the species which dominates in the Iowa, Arizona, and Russian faunas (*Spirifer hungerfordi* and *Spirifier anossofi*) is entirely absent, or certainly very rare even if eventually it should be discovered. From this and other similar peculiarities presented by the New York faunas, I am inclined to think that the horizon at which the Pugnax fauna enters the New York sections is later chronologically than that of the formations holding the fauna in Russia, and possibly also appreciably later than the zone marked by it in Iowa and Arizona.

Although *Spirifer whitneyi* presents many characters of the general *Spirifer disjunctus* type, its range in the Russian and also in the west European Devonian confirms this same view. The Arizona fauna does not present any very close affinity with the distinctly Chemung (*Spirifer disjunctus*) fauna of New York.

This earlier age for the *Spirifer hungerfordi* fauna is also indicated by the development of Productus. All the representatives of that genus reported from Arizona and from the same fauna as expressed in Iowa indicate an earlier stage of its development than that exhibited by the Productellas of the Chemung formation of New York.

From these and other considerations it seems reasonable to adopt Tschernyschew's view that the zone in Russia containing the *anossofi* fauna is the equivalent of the Stringocephalus zone of western Europe as well as of the Hamilton formation of North America; and therefore that the fauna is properly a Mesodevonian rather than Neodevonian fauna. On these grounds we should place the formation bearing this fauna in Arizona in the Mesodevonian, although its representatives do not appear in the New York fauna until the opening of Neodevonian time.

The stratigraphic relations of the limestones at Globe and Bisbee exhibit a hiatus from Cambrian to Devonian but the strata are apparently conformable throughout to the close of the Carboniferous.

In the Clifton-Morenci district Lindgren [541] found a formation, the Morenci, which consists of 75 feet of compact fine-grained argillaceous limestone below and 100 feet of clay shale above. The strata are conformable to the Ordovician and Carboniferous. They have yielded a meager fauna, which indicates a Devonian horizon, though it might be Silurian or Carboniferous.

I 12. ARIZONA.

Reagan [663] states in regard to the Devonian of the Fort Apache region, in Arizona:

Immediately overlying the Silurian on the periphery are alternating chert and flint strata followed by massive, very fossiliferous light-colored fine-grained marble limestone, which in turn is followed by a grit. This formation, like the Silurian, is exposed as a narrow strip encircling the Ellison dome from the Nantan Mountains on the southeast around by the northeast to the Tonto Basin, where it forms one of the "rim" series of that basin. The strip thus formed is sometimes more than 3 miles wide, though it is usually much less. Besides this belted strip several of the buttes of the Tonto region belong to this formation, one of which is situated 3 miles northeast of Ellison. This butte is called Juniper Butte on the Government maps, but among the settlers it is called Shell Mound, because of its numerous shell fossils. The formation is Devonian, as is indicated by the fossils obtained, *Orthis livia, Spirifer fornacula,* and *Acervularia davidsoni,* and corresponds very much to the Devonian formation at the falls of the Ohio.

I 12-13. SOUTHWESTERN NEW MEXICO.

At Kingston, N. Mex., in the southwestern part of the Territory, Gordon and Graton [372] observed the occurrence of Devonian limestone similar to the Ouray limestone of Colorado. The fauna of the Ouray has recently been figured and described by Kindle.[501] Lindgren [542c] states:

The Devonian is present in an area extending from the Mimbres Mountains westward to the Arizona line and everywhere appears as a thin formation of dark clay shales, usually calcareous in the upper portion. The maximum thickness (465 feet) was noted at Silver City. In the Mimbres Range, where Gordon has given the name Percha shale to the formation, it is only 200 feet thick and its upper part contains a rich and characteristic Devonian fauna. The Devonian is not present in the Franklin Mountains of Texas but appears with a thickness of 200 feet at Clifton, Ariz. The Devonian shale is believed by Gordon to overlie the Ordovician limestone with an unconformity of erosion, but the shale and underlying limestone are conformable at Georgetown, Lone Mountain, and Silver City, and also at Clifton, Ariz. At any rate the Devonian period in southern New Mexico was characterized by shallow muddy deposits, uniform over a large area.

I 14-15. SOUTHERN OKLAHOMA.

Taff and Ulrich [808c] distinguished "Siluro-Devonian" and late Devonian and early Carboniferous strata in the Arbuckle Mountains. The "Siluro-Devonian" rocks were mapped as the "Hunton limestone" and include strata which carry faunas ranging from Clinton to Oriskany. (See pp. 228–230, Chapter V.) The late Devonian and early Carboniferous strata are the Woodford chert, which is described as follows:

Excepting the flinty Oriskany limestone occurring locally at the top of the Hunton limestone and possibly the Helderberg member of the latter, Devonian rocks in the Arbuckle region are limited to a single formation of chert and black shale, known as the Woodford chert. While this chert is apparently conformable with the limestone below in any single locality, it appears that this is not true in a broad sense. The Oriskany beds at the top of the Hunton limestone, consisting of several feet of cherty limestones, are present in one place but do not occur in another. In the northeastern part of the uplift, notably near Franks, cherty limestones are present at the top of the Hunton. Near the western end of the uplift, on the southern side of the Washita Valley, this upper member of hard limestone is absent and the thickness of the entire formation is reduced to a little over 100 feet. In all places there is an abrupt change in sedimentation from the top of the Hunton limestone to the chert or shale of the Woodford formation.

The Woodford chert has an estimated average thickness of 650 feet. It varies somewhat in lithologic character. In places massive chert rests upon the limestone; in other places black shale occurs at the base of the formation. As a rule, however, the formation becomes less cherty from the base upward. It is usually even bedded, occurring in layers from a few inches thick to thin laminæ. In places, especially in the northeast side of the uplift, the formation is composed almost entirely of thin, fissile siliceous and distinctly bituminous black shale. In this part of the region, a few miles west of Hunton, lentils of almost pure flints were noted interstratified with the black shale near the base. In the western part of the region bluish shales were seen interstratified with the black shale in the upper part of the formation. At various positions in the section, especially in the more cherty beds, are small, rounded, marble-like concretions of a calcareous nature. In places there are large segregations of a similar character, concentrically banded, which occur intersecting several layers of cherty shale.

* * * * * * * * *

Fossils are very rare in the Woodford chert, and those found are not well preserved. In the lower part of the formation in the western part of the region a small Lingula of the type *L. spatulata* Hall and a few conodonts have been observed. In the shales of the upper part the only recognizable fossils seen are two concentrically plicated species of Productella, one of which seems referable to *P. concentrica* Hall.

* * * * * * * * *

This formation is believed to be of the age of the Chattanooga formation of Tennessee, the Ohio shale of Ohio, and the Portage and Chemung of New York. At the top it doubtless includes strata corresponding in age with the Noel shale of northern Arkansas and the basal shale of the Tullahoma formation of Tennessee, which are believed to be of Kinderhook age, or, according to the present classification, earliest Carboniferous.

At present it is not possible to determine the exact parting between the Devonian and Carboniferous, since there is no clear stratigraphic distinction in the shales, and fossils are rare.

I 15. ARKANSAS.

The Chattanooga shale (Devonian) is represented in northern Arkansas [6, 656] together with a local basal member known as the Sylamore sandstone. The formation consists of a persistent black shale, with locally a dark phosphatic sandstone or conglomerate (Sylamore member) at the base, and represents a late stage of advance of the sea upon the Ozark land. In places it reaches a maximum thickness of 150 feet, but the areas are too small to be shown on the map.

I 16, J 17. THE APPALACHIAN VALLEY (ALABAMA, GEORGIA, TENNESSEE, THE VIRGINIAS, AND MARYLAND).

Along the trend of the Appalachian Valley and Mountains the Devonian formations exhibit a very marked change. In Maryland their sequence is still complete from the Helderberg limestone up and their thickness in Allegany County is 7,875 to 10,200 feet; but they thin out toward the south, the lower formations appear only locally or not at all, and in Georgia and Alabama the Upper Devonian (Chattanooga shale) overlaps unconformably upon older strata and is reduced to a thickness of 10 or 15 feet only.

The Maryland section is typical for adjacent areas of Pennsylvania and Virginia. Prosser [646a] in 1901 summed up the results of investigations carried on by the Maryland Survey. He describes the Helderberg limestone (upper part of the Lewistown limestone), as thin-bedded bluish-gray ringing limestone, more or less shaly, 400 feet thick, followed by massive darker-blue limestone to a total thickness of 750 to 900 feet. The strata are fossiliferous and according to Prosser comprise representatives of the Manlius, Coeymans, New Scotland, and Becraft limestones of the New York section. The Cayugan strata (Manlius of Prosser) are now separated from the Helderberg in Maryland.

The Oriskany sandstone Prosser describes as bluish-black cherty limestone, 75 to 100 feet in thickness, above which comes a white calcareous sandstone

350 feet thick, the whole the equivalent of the New York Oriskany and the same as "the Monterey sandstone of the Piedmont folio."

The Romney shale is described by Prosser as consisting of thin black shales, sharply distinguished from the Oriskany, followed by drab and bluish argillaceous to arenaceous shales and thin sandstones, the whole 1,600 to 1,650 feet thick, and as representing the Marcellus and Hamilton of New York. Kindle [502] has since differentiated the Onondaga in Maryland at the base of the Romney.

Of the Jennings formation, the lower part is composed of thin black argillaceous shales, regarded by Prosser as the equivalent of the Genesee shale of New York; followed by olive to bluish argillaceous shales, regarded by Prosser as representing the Naples of the Portage of New York, and green arenaceous shales, containing a Chemung fauna; the total thickness is 3,800 to 4,000 feet.

The Hampshire formation is described by Prosser as consisting of alternating red, flaggy, and massive sandstones and arenaceous or argillaceous shales, 2,000 feet thick, equivalent to part of the Catskill of New York.

An important description of the Lower Devonian and Silurian of Maryland is given by Schuchert,[714] who lists the species of each horizon and correlates the strata with the New York section.

I-J 16. TENNESSEE, KENTUCKY, AND NORTHWESTERN ALABAMA.

The Devonian formations of Ohio and Indiana thin toward the south where they lap unconformably upon the low land surface of Silurian limestones. Kindle [493a] states:

> The Devonian formations below the New Albany shale are frequently entirely absent in the Kentucky sections, and where present they are usually represented by only a few feet of strata. The Sellersburg beds have not been seen south of Louisville. The attenuated character of the lower Devonian beds in Kentucky has been generally explained as due to thinning out. Prof. N. S. Shaler did not recognize any stratigraphic break at the base of the New Albany shale and regarded it as the equivalent of the New York Devonian formations down to the Oriskany, where the Corniferous was wanting in the Kentucky section. The writer has found sections which show unconformity between the New Albany shale and the beds below in Kentucky. This interval of erosion which has been detected at the base of the Black shale explains the entire absence of the Devonian limestone at many localities and its extreme thinness where present.

According to Schuchert [711d] and Foerste [340b] the Devonian formations in western Tennessee represent, where present, Helderberg, Oriskany, Onondaga, and later Devonian time, the highest strata being the black Chattanooga shale. The distribution of these strata is very irregular. In many places they are absent and locally they are represented only by beds from 1 foot to a few feet in thickness. Their normal sequence is as follows: Linden formation (basal Helderbergian age), Camden chert (lower Oriskany age), limestone of Onondaga age, and Chattanooga shale, with phosphatic beds at its base and Hardin sandstone member and shales above.

The following notes on the Linden are abstracted from the article by Foerste:

> The Linden at Perryville, Tenn., immediately succeeds the Brownsport (Silurian). It consists of "fairly solid crinoidal rock," 10½ feet, at the base, with comparatively few fossils (*Orthothetes worthanus, Rhipidomella oblata,* and *Striatopora issa*); softer, partly crinoidal, partly fine-grained rock more or less interbedded with clay, 11½ feet, richly fossiliferous (*Stropheodonta*

beckei, *Strophonella punctulifera*, and *Orthothetes woolworthanus*, common; *Dalmanites micrurus*, not rare; *Uncinulus schucherti*, very scarce); fossiliferous clay, 15 feet; overlain by thin limestone layers, $1\frac{1}{2}$ feet, full of bryozoans. Upon these lies a sandy bed, which may be the Hardin sandstone member, the Camden chert being absent.

In other local sections noted by Foerste the Linden varies in thickness, being 101 feet at Pyburn Landing, on the Tennessee, and thinning rapidly eastward. It is succeeded in some places by the Camden chert, in others by the Hardin sandstone member.

The Camden chert was first distinguished by Safford, who recognized the Oriskany facies of its fauna. It is 60 feet thick at Camden, Benton County; is strongly developed west of Tennessee River in Henry, Benton, and Decatur counties; and thins toward the east. The Camden fauna was collected and studied by Schuchert,[711e] who states:

The fossils of this formation are, as a rule, natural casts both of the interior and exterior of the organism, and preserve in detail the finest markings. This fauna is closely related to that described by Meek and Worthen[a] from the "Clear Creek limestone" of southern Illinois, in Alexander, Jackson, and Union counties. From this region are known but 11 species, and 8 of these are also found in Tennessee. They are *Anoplia nucleata*, *Anoplotheca flabellites*, *Eatonia pecularis*, *Spirifer worthenanus*, *S. hemicyclus*, *Megalanteris condoni*, *Amphigenia curta*, and *Strophostylus cancellatus*.

The "Clear Creek limestone" of Illinois is intimately connected with the Helderbergian below and is not less than 200 feet thick, being followed by a "quartzose sandstone" from 40 to 60 feet in depth. The latter is probably equivalent to the Upper or typical Oriskany of New York and does not appear to be present in western Tennessee. From Prof. Safford's description of the Camden chert, it is evident that the Lower Oriskany thins rapidly southward. In Tennessee it is about 60 feet in thickness, while it is not less than 200 feet thick in Illinois, exclusive of the Upper Oriskany, which is entirely absent in the former State.

The Camden chert fauna contains 32 species, and 6 of these are restricted to southern Illinois and western Tennessee. Of the entire fauna, 24 species are found either in the Helderbergian or in the Lower Oriskany of other regions, and 20 occur in the Upper Oriskany, or Onondaga. After removing the 13 species common to both the Lower and Upper Oriskany and the 2 restricted forms, 17 remain. Of these 10 occur either in Helderbergian or Lower Oriskany rocks of other regions, while 6 are found in higher beds. This evidence, therefore, indicates clearly a Lower Oriskany age for the Camden chert of Tennessee and the "Clear Creek limestone" of Illinois, which indication is the more marked because of the absence of such characteristic Upper Oriskany species as *Hipparionyx proximus*, *Chonostrophia complanata*, *Spirifer arenosus*, *Rensselaeria ovoides*, *Meristella lata*, *Camarotœchia pleiopleura*, *C. barrandei*, or *C. speciosa*.

Concerning the representative of the Onondaga in western Tennessee, Foerste[340c] says in part:

On the western flank of the Cincinnati geanticline, along Harpeth River, between Newsom and the bridge west of Pegram, the Silurian is directly overlain by a thin bed of Devonian limestone, varying in thickness from 12 feet at the west to 3 feet at the most eastern point of outcrop. * * * *Nucleocrinus* (*Olivanites*) *verneuili* is a characteristic species. *Stropheodonta demissa*, *Stropheodonta perplana*, *Rhipodomella penelope*, and *Nucleospira concinna* are also found. This white and comparatively pure limestome is overlain by a darker and more sandy limestone.

[a] Geol. Survey Illinois, vols. 1, 2, and 3.

Foerste notes another occurrence, 4 miles north of Bakerville, where a limestone 3 feet thick has yielded Heliophyllum and Blothrophyllum, closely resembling forms in the "Corniferous at the Falls of the Ohio, Louisville, Ky." Several species of Cystiphyllum, Cyathophyllum, and Cladopora, a very large form of *Atrypa reticularis*, and *Reticularia fimbriata* were found. These occurrences he correlates with the Jeffersonville limestone of Kentucky and Indiana, regarded as the equivalent of the Onondaga limestone of the East.

The Chattanooga shale and its members, the Hardin sandstone and the Maury green shale of Safford, in western Tennessee are described by Hayes and Ulrich [431c] as follows:

Excepting the bottom and top, which will be described separately, the mass of this formation is a nearly black, rather tough bituminous shale, splitting generally into thin plates. It is the well-known and sharply defined formation so often called the Black shale. The formation as a whole is remarkably persistent in its distribution, being found nearly everywhere in Tennessee and adjoining States to the south, west, and north, where its proper horizon is exposed. Its occasional absence is due either to nondeposition or to erosion preceding Carboniferous deposition. Generally throughout middle Tennessee there is at the base of the formation a thin bed which is entirely different in character from the black shale above. In the western part of the Columbia quadrangle, particularly in the valley of Swan Creek, this bed consists largely of calcium phosphate and forms the source of the Tennessee black phosphate. Its appearance varies somewhat from place to place, as well as its chemical composition. It may be gray, bluish black, or black in color, and it may be composed of grains large enough to be seen by the naked eye or may have a dense, fine-grained structure. When examined with the glass small oval grains are generally found to be more or less abundant, sometimes making up the mass of the rock. These have polished surfaces and a brown or amber color. In many cases they are the casts of minute coiled shells. The phosphate bed passes by gradations laterally into a bed of coarse sandstone or conglomerate containing varying amounts of phosphate. The grains are in part phosphatic ovules and in part quartz, with less abundant waterworn fragments of other rocks and fish bones.

The phosphate bed is also replaced, particularly toward the southwest, in Hardin, Wayne, and Perry counties, by a fine-grained gray or black sandstone, which reaches a maximum thickness of 12 feet in Hardin County, where it has been called the Hardin sandstone by Safford. It may consist of a single massive bed or may have a shaly structure, and is generally more or less phosphatic.

It is evident that the black phosphate, the conglomerate, and the fine sandstone are merely three phases of the same member of the Chattanooga formation and represent deposition during approximately the same time, their difference in composition being due to differences in the sources from which their materials were derived. Occasionally, and this is particularly true of areas in which the Chattanooga formation rests on the Clifton and Fernvale formations, the conglomeratic phosphate layer is replaced or represented by black shale like that making up the body of the formation. Except in these cases the basal bed everywhere follows a more or less easily determined unconformity, and was deposited over a nearly submerged land surface. This subsidence began in the Oriskany and, continuing through the Onondaga and Hamilton ages, resulted finally in the submergence of the whole of the middle Tennessee dome. This submergence occurred in the Portage and continued through the Chemung, these late Devonian ages being represented by the Chattanooga shale.

At the top of the formation there is very generally a thin stratum of greenish shale and earthy sandstone, which has recently received the designation "Maury green shale" from Prof. Safford. He says it ranges "from a few inches to 4 or 5 feet in thickness;" but so far as our observation is concerned, it does not exceed 2 feet in this area and usually varies between 12 and 18 inches. Nearly always this green shale has embedded in it smooth dark nodules or concretions of lime phosphate. The nodules vary greatly in size, shape, and relative abundance. Some are spherical and from a half to several inches in diameter; others are flattened or irregular ellipsoids, sometimes as much as 2 feet in length and over 6 inches thick; and they may be loosely disposed in the shale, or closely packed. The green color is due to the presence of glauconite or greensand, a silicate of iron and potash. Rarely, as in the upper part of East Fork of South Harpeth Creek, the green shale is absent or not distinguishable, and in these cases the black shale seems to pass very gradually into overlying green shale, which constitutes the base of the full Tullahoma section.

Fossils are almost if not entirely restricted to the lower member of the Chattanooga formation. In the dark-gray variety of phosphatic rock, which is really a conglomerate, casts of minute coiled and bivalve molluscan shells, washed out of the Ordovician rocks forming the surface of the land that was being gradually submerged, are very abundant. Waterworn bones of large fishes not infrequently occur with them. In the basal shale and fine-grained sandstone a species of Lingula, probably *L. spatulata,* is frequently seen, while the shiny teeth, jaws, and cephalic plates of conodonts, supposed to be small fishes related to myxinoids, are often found, sometimes in great numbers.

In the table of correlations of the Columbia folio [431a] the Chattanooga shale of western Tennessee is placed as the equivalent of the Portage and Chemung of New York.

J 15-16. MISSOURI AND ILLINOIS.

A narrow belt of thin Devonian strata extends from southern Illinois northwestward into Missouri as far as Jefferson City. Keyes [491] distinguished the Grand Tower limestone, 100 feet, and the Callaway limestone, 70 feet thick, the latter overlain by Kinderhook (Carboniferous) strata. The Grand Tower he referred to the Oriskany and Onondaga epochs, and the Calloway to the Hamilton epoch. The Onondaga fauna was also recognized by Weller [879] near Grand Tower, Ill. Buckley,[106] in a recent paper, describes the Devonian of southeastern Missouri as composed of Clear Creek limestone (Oriskany age), at the base, overlain by Grand Tower limestone (Hamilton and Onondaga age), with the Sulphur Springs formation, composed of several members, at the top. Weller [882] and Ulrich [a] regard the Sulphur Springs formation as being of Mississippian age and a part of the Kinderhook.

The relations of the Devonian strata of northeastern Missouri to those of Iowa, the significance of the unconformity between the Silurian and Carboniferous in central Missouri, and the correlation of the Devonian of southern sections are considered by Keyes [492] in a general paper.

The Devonian of Illinois has been discussed by Weller [875, 883] and Savage.[703b]

Weller's article in 1897 is a detailed study of the zones which may be recognized in the "Bake Oven" section, near Grand Tower, on Mississippi River. He distinguished seven conspicuous divisions comprising 26 faunal zones, from each of which he gives a list of fossils. He concludes:[875a]

It is believed that the facts here set forth satisfactorily demonstrate that the Devonian faunas in southern Illinois are not related to the Iowan Devonian faunas, as has sometimes been suggested, but are a western extension of the faunas of the New York province. At the "Bake Oven" section the fauna of the lowest beds is of an age corresponding to the lower portion of the Upper Helderberg period, while the uppermost faunas are of Hamilton age. The line of demarcation between the Upper Helderberg and Hamilton faunas can not be exactly drawn.

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[a] Personal communication.

The discussion by Savage [703b] is in part as follows:

The rocks of Helderbergian age in Illinois correspond with the New Scotland formation of New York. They succeed the Clinton after an exceedingly long land interval, represented by all of the Silurian after the Clinton, and the Coeymans of the Lower Devonian.

* * * * * * * * *

The New Scotland formation in Union and Jackson counties has an aggregate thickness of more than 160 feet. The lower portion, for a thickness of 100 feet, consists of shaly limestone with interbedded bands of chert. * * * In the cut made by the Frisco Railroad Co. a short distance south and west of Tower Rock 10 species were collected. * * *

The upper 58 feet of the New Scotland formation is composed of light-gray, heavy-bedded, coarsely crystalline limestone. * * * The beds furnished 17 species.

The Clear Creek formation consists of light-gray to yellowish colored cherts that are usually in thin layers, but which in the lower part are sometimes 3 to 5 feet in thickness. * * *

This formation rests, with erosional unconformity, upon the New Scotland beds at the south end of the Back Bone Ridge. It corresponds in age to the Camden cherts of western Tennessee. The beds represent deposits of the Upper Oriskany time, as is indicated by the interwedging of the upper chert layers with those of the basal portion of the succeeding Onondaga. The chert formation has a thickness, in Illinois, of about 327 feet. Fossils are somewhat rare in the lower portion, but in the middle and especially in the upper portion there is a rich fauna.[a] * * *

The sedimentation of the Upper Oriskany time continued without a break into the Onondaga or Corniferous. The latter period was initiated by disturbances to the westward, in Ozarkia, which increased mechanical sedimentation in the Illinois area. These resulted for a time in the deposition, along the eastern shore of Ozarkia, of layers of sand containing Onondaga fossils alternating with the return of the Oriskanian limestone conditions. Eventually sand deposition prevailed and there was spread over the basin the basal sandstone of the Onondaga formation, containing [10 species].

Early in the Onondaga time an elevation in the southern portion of Union and in Alexander County put a stop to further deposition in these regions, while farther north, in Jackson County, sedimentation was uninterrupted.

At the cut through the Back Bone and at the Bake Oven, a short distance north of Grand Tower, there is exposed a continuous section of the Onondaga formation showing a thickness of 115 feet. The beds consist largely of light-colored, regularly bedded, more or less crystalline limestone, which becomes arenaceous in the lower part. Fossils are abundant throughout the section.[a] * * *

During the Onondaga and the succeeding Hamilton time the warm waters from the Gulf region, with their successive faunas, spread toward the northeast across Illinois and Indiana, passing around the north end of the Cincinnati axis, and mingled with those of the eastern embayment in western New York. Such water connections permitted continued migrations within this sea and account for the close correspondence between the various Middle Devonian faunas of southwestern Illinois and those of western Ontario and New York.

Throughout Hamilton time the Kankakee barrier, or peninsula, extending from Ozarkia toward the northeast across Illinois, was largely effective in preventing the waters of the Interior or Mississippian sea from uniting with those of the northwestern or Dakotan basin toward the northwest. As a result of this separation the deposits and the faunas of Hamilton time, in Illinois, belong to two distinct provinces. The phase of the Hamilton in the vicinity of Rock Island and in Jersey and Calhoun counties belongs to the northwestern or Dakotan province; while that of southwest Illinois belongs to the New York province.

The New York faunal phase of the Hamilton is well developed in the south part of Union County, in the N. ½ sec. 34, T. 13 S., R. 2 W.; and farther north in the NE. ¼ sec. 34, T. 11 S., R. 2 W. The formation is also represented in the upper beds near the north end of Back Bone Ridge, in Jackson County.

[a] For list of fossils see the work cited.—B. W.

At the first-mentioned exposure there is at the base of the Hamilton 28 feet of yellowish-blue shale, which contains *Leiorhynchus limitare*. Both the character of the sediment and the fossils remind [one] decidedly of the Marcellus shale of New York. This shale rests unconformably (erosional) upon the basal sandstone member of the Onondaga. It is succeeded by a few feet of limestone, which in places is much leached and very fossiliferous, *Athyris spiriferoides, Delthyris sculptilis, Rhipidomella penelope, Spirifer granulosus,* and *Stropheodonta concava* being very common. At points farther north the lower beds of the Hamilton consist of dark-colored impure limestone which succeeds the Onondaga without any apparent break. The characteristic fossils of these layers are *Microcyclus discus, Athyris vittata, Eunella attenuata, Spirifer fornacula, Conocardium cuneus,* and *Onychodus sigmoides.*

The middle portion of the Hamilton limestone is dark colored and evenly bedded and contains *Ambocœlia umbonata, Chonetes yandellanus, C. pusillus, Cranæna romingeri, Parazyga hirsuta, Pholidops oblata,* and *Spirifer pennatus.* Above this horizon occurs about 25 feet of yellowish-brown impure siliceous limestone with few fossils. Near the top of the formation come in a few feet of hard gray limestone containing *Chonetes coronatus, Rhipidomella vanuxemi, Spirifer audaculus, S. pennatus, Tropidoleptus carinatus,* and *Vitulina pustulosa.*

During Upper Devonian time the Mississippian sea continued to expand, spreading the materials of this formation more widely than the preceding. In the NE. ¼ sec. 34, T. 11 S., R. 2 W., the lower deposits of the Upper Devonian are conformable upon the Hamilton. There is here exposed a thickness of 33 feet of yellowish-brown (black where unweathered) siliceous shale or shaly limestone, cherty near the top, and marked by *Leiorhynchus globuliformis, L. mesacostalis, Reticularia lævis,* and *Spirifer pennatus.* At other points the upper cherty phase is succeeded by 50 or more feet of greenish to black, almost barren shales. These siliceous and dark-colored shales are probably the equivalent of the "calico rock," a mottled and leached siliceous shale, present farther south in Union and Alexander counties. They doubtless correspond with the Chattanooga black shale, Ohio black shale, New Albany black shale, and the Lower Portage beds of other States.

Generalized section of the pre-Mississippian strata in southwestern Illinois.

System.		Correlations.	Location of sections.	Descriptions of horizons.	Feet.
Devonian.	Upper Devonian.	New Albany black shale=Chattanooga black shale=Ohio black shale=Lower Portage, 86 feet.	NE. ¼ sec. 34, T. 11 S., R. 2 W., and SE. ¼ sec. 1, T. 13 S., R. 2 W.	Greenish-blue shale, fossils almost none	29
				Black shale with few fossils, but carrying numerous very small balls of iron pyrite from ⅛ to ½ inch in diameter	21
				Brown to black, siliceous shale or shaly limestone with *Leiorhynchus globuliformis* and *Reticularia lævis*	36½
	Late Middle Devonian.	Hamilton, 70 feet.	NE. ¼ sec. 34, T. 11 S., R. 2 W., Union County. Section at Back Bone near Grand Tower.	Light-gray siliceous limestone, in part oolitic, characterized by *Chonetes coronatus, Cranæna romingeri, Spirifer pennatus, S. audaculus, Tropidoleptus carinatus,* and *Vitulina pustulosa*	7
				Yellowish-brown siliceous or shaly limestone with few fossils	25
				In the north are dark-colored, fine-grained limestones with *Microcyclus discus, Chonetes yandellanus, Eunella attenuata, Parazyga hirsuta, Spirifer fornacula,* and *S. pennatus.* In the south are gray or leached limestones with *Athyris spiriferoides, Delthyris sculptilis, Spirifer granulosus, Rhipidomella penelope*	38
		Marcellus, 28 feet.	N. ½ sec. 34, T. 13 S., R. 2 W. Union County.	Rather soft shale weathering to a yellowish-brown color, with *Leiorhynchus limitare*	28
				This horizon is not present at the north, in Jackson County.	

Generalized section of the pre-Mississippian strata in southwestern Illinois—Continued.

System.		Correlations.	Location of sections.	Descriptions of horizons.	Feet.
Devonian.	Early Middle Devonian.	Onondaga, $156\frac{2}{3}$ feet.	Back Bone, Jackson County. Bake Oven, Jackson County.	The Onondaga is well developed in Jackson County, where it passes without a break into the Hamilton. In the southern part of Union County there is a break and the Onondaga is represented only by the basal sandstone.	
				Heavy layers of very hard gray, coarsely crystalline limestone, containing corals, *Chonetes konickianus*, *Pholidostrophia iowensis*, *Productella spinulicosta*, and *Stropheodonta concava*. *Strophalosia truncata* is abundant in the lower half, while *Productella spinulicosta* is common in the upper part	26
				Layer of dark-colored limestone largely composed of *Chonetes konickianus* var	$3\frac{5}{6}$
				Thin-bedded hard gray limestone, layers 2 to 10 inches thick. Fossils rare: *Chonetes konickianus* var. present in the upper part and *C. pusillus* and *Stropheodonta concava* in the lower	15
				Hard gray impure limestone with few fossils	21
				Dark-gray impure limestone with thin chert bands near the top. Fossils numerous, *Nucleocrinus verneuili*, *Rhynchonella gainesi*, *Meristella barrisi*, *Spirifer acuminatus*, *Stropheodonta patersoni*, etc	$8\frac{1}{3}$
				Dark-gray impure fine-grained limestone. *Chonetes mucronatus* abundant in a zone near the middle. Other fossils are *Rhipidomella vanuxemi*, *Spirifer grieri*, *Stropheodonta patersoni*, *S. perplana*, and *Phacops cristata*	11
				Heavy layers of light-gray subcrystalline limestone. Fossils abundant. *Coscinium cribriformis*, *Centronella glansfagea*, *Spirifer duodenarius*, *S. macrothyris*, and *Odontocephalus ægeria* present throughout	38
				Alternating layers of light-gray arenaceous subcrystalline limestone and coarse-grained sandstone, containing *Centronella glansfagea*, *Meristella* near *lentiformis*, *Rhipidomella musculosa*, *Spirifer duodenarius* and *S. macrothyris*	$15\frac{1}{2}$
			NW. $\frac{1}{4}$ sec. 26, T. 12 S., R. 2 W., also SW. $\frac{1}{4}$ sec. 26, T. 13 S., R. 2 W., Union County.	Bed of more or less iron-stained sandstone, in places soft and friable, at other points cemented by a deposit of iron or silica, containing *Michelinia stylopora*, Aulacophyllum sp., *Centronella glansfagea*, *Spirifer duodenarius*, *S. macrothyris* and *Odontocephalus arenarius*	18
	Oriskanian.	Upper Oriskany—Clear Creek chert, Camden chert, 237 feet.	Schaffer's branch, 2 miles west of Jonesboro; NW. $\frac{1}{4}$ sec. 26, T. 12 S., R. 2 W., Union County.	Bed of light-gray chert in layers 3 to 9 inches thick. *Amphigenia curta*, *Chonostrophia reversa*, *Eodevonaria melonica*, *Schuchertella pandora*, and *Spirifer worthenanus* abundant	$5\frac{1}{2}$
				Reddish-brown friable sandstone with *Michelinia stylopora*, Zaphrentis sp., *Amphigenia curta*, and *Spirifer duodenarius*	$2\frac{5}{6}$
				Layers of light chert, 4 to 8 inches thick. *Anoplia nucleata*, *Chonostrophia reversa*, *Eodevonaria melonica*, *Schuchertella pandora*, and *Spirifer worthenanus*	$1\frac{1}{2}$
				Reddish-brown friable sandstone	2
			NW. $\frac{1}{4}$ sec. 10, T. 12 S., R. 2 W.; NE. $\frac{1}{4}$ sec. 12, T. 12 S., R. 3 W., Union County. NE. $\frac{1}{4}$ sec. 36, T. 14 S., R. 2 W., Alexander County.	Bed of light-colored chert layers, in places alternating with impure siliceous limestone and at other points composed wholly of chert bands. Fossils most abundant in the upper part. *Amphigenia curta*, *Anoplotheca flabellites*, *Eatonia peculiaris*, *Eodevonaria melonica*, *Chonostrophia reversa*, *Schuchertella pandora*, *Spirifer worthenanus*, and *S. hemicyclus* common in the upper part	225
				In the southern part of Union County the lower chert layers are massive and contain but few fossils. In the pit worked by the M. & O. Railroad, $1\frac{1}{2}$ miles north of Tamms, in Alexander County, may be seen an exposure of more than 100 feet in which few fossils were found.	

Generalized section of the pre-Mississippian strata in southwestern Illinois—Continued.

System.		Correlations.	Location of sections.	Descriptions of horizons.	Feet.
Devonian.				A short break in sedimentation.	
Devonian.	Helderbergian.	New Scotland, about 158 feet.	South end of Back Bone, Grand Tower, Jackson County and Bald Rock, SE. ¼ sec. 23, T. 11 S., R. 3 W., Jackson County. Grand Tower Rock, and Frisco Railroad cut a few rods farther west in Missouri.	Heavy-bedded, light-colored, coarsely crystalline limestone with *Eatonia singularis*, *Spirifer macropleura*, *S. perlamellosus*, *Stropheodonta beckii*, and *Strophonella punctulifera*, about	58
				Bed of impure shaly limestone with bands and nodules of chert in the upper portion. *Dalmanella subcarinata*, *Meristella lævis*, *Spirifer cyclopterus*, *S. perlamellosus* and *Strophonella punctulifera*, about	100
				This horizon appears to belong immediately below the one above. It is doubtless present at Bald Rock and in the river bluff farther south, but the fossils were not found at the latter points.	
				A long break in sedimentation.	
Upper Silurian or Silurian.	Niagaran.	Clinton — Dayton, Ohio Clinton, Interior or western Clinton, 75 feet.	2 miles northeast of Gale, NW. ¼ sec. 27, T. 14 S., R. 3 W., and ¼ mile south and southeast of Gale, Alexander County.	Pink mottled limestone in layers 10 to 45 inches thick, containing many small immature brachiopods, with which occur *Plectambonites transversalis*, *Rafinesquina mesacosta*, and *Spirifer* near *sulcata*	23
				Layers of gray to drab-colored limestone, 2 to 6 inches thick, alternating with thin bands of chert and characterized by such typical Clinton fossils as *Stricklandinia triplesiana* and *Triplecia ortoni*	6
				Bed of tough gray limestone in layers 3 to 8 inches thick, which are imperfectly separated by 2 to 4 inch partings of chert. Fossils rare	0–46
				This horizon is wanting at some points in this area.	

J–K 11–12. GREAT BASIN, NEVADA AND UTAH.

In the Eureka section, Nevada, the Lone Mountain limestone (Ordovician) passes by imperceptible gradations upward into the Nevada limestone, which is followed by the White Pine shale, both assigned to the Devonian by Hague and measuring about 8,000 feet. Hague[391b] describes the relations as follows:

The Lone Mountain and Nevada limestones taken together present an immense thickness of beds, lying between the Eureka quartzite and the White Pine shale. Together they measure about 7,800 feet in their broadest development. The division into Silurian and Devonian is based mainly upon paleontological grounds. The transition in sedimentation from characteristic Silurian to unmistakable Devonian is so imperceptible that a boundary between them is impossible to establish, and, as is usually the case where the beds form a continuous, conformable limestone series, a line of separation based upon faunal changes must always remain more or less arbitrary. Lithologically, in their broader features, the Silurian and Devonian limestones are quite distinct; it is only in the intermediate beds that no line can be drawn. The light-gray and white siliceous beds that form the mass of the Lone Mountain present a wide vertical range, and in these beds are occasionally seen obscure impressions of Niagara corals, and in other localities, in similar rocks not much higher up in the series, occur *Atrypa reticularis* and other forms foreshadowing the Devonian. It is known that the characteristic Lone Mountain beds carrying *Halysites catenulatus* extend for nearly 1,500 feet above the Eureka quartzite, and that beds easily identified by their organic remains bring the Devonian down to about 6,000 feet below the summit of the great limestone belt lying between the Eureka quartzite and the White Pine shale. Halysites and *Atrypa reticularis* were never found associated together, although it can not be definitely stated that the former fossil does not appear as low down in the limestone as the highest occurrences of the characteristic coral.

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Conformably overlying the Nevada limestone occurs a heavy body of black shale, which has been designated as above, it having been first recognized as a distinct horizon in the White Pine mining district to the southeast of Eureka. It occupies a clearly defined stratigraphic position with a marked change of sedimentation and a fauna distinct from both the underlying and overlying horizons.

* * * * * * * * *

Impressions of plants, which are exceedingly rare in Paleozoic rocks of the Great Basin, are very abundant and form a distinctive feature of this epoch, notwithstanding that everything which has been collected has been of a fragmentary nature. The most promising specimens for identification were submitted to Sir William Dawson, who, in his report, called attention to the poor state of preservation of the plants. Under date of Montreal, June 11, 1889, he writes:

"One slab contains a small ribbed stem referable to Goeppert's Anarthrocanna, a doubtful Calamitean plant. The specimen is not unlike those found at Perry, in Maine, and Bay de Chaleur. On the large slab is also a slender branch stem which I suppose may be the stipe of a fern, and from its character and angle of ramification probably belongs to the genus Aneimites, but no trace of the pinnæ can be seen. The evidence, so far as it goes, would indicate the Upper Devonian (or Erian, as I prefer to call it), rather than the Middle Devonian or the Lower Carboniferous."

It will be seen that this determination as to the age of the plants is quite in accord with the geological position of the beds above the Nevada limestone of the Devonian and directly below the Diamond Peak quartzite of the Carboniferous.

Girty[363c] in 1905 tentatively placed the White Pine shale in the Carboniferous and correlated it with the Caney shale of Arkansas. He says:

In the White Pine district of Nevada the beds called "Lower Carboniferous" by Mr. Walcott, which are suggested to be of Pottsville age, are underlain by a black shale—the White Pine shale—which he assigned to the "Upper Devonian." I have long been of opinion, however, that the age of this bed is not Devonian, but Carboniferous. The White Pine fauna, however, is not without forms suggestive of the Devonian, to which period it was also tentatively assigned by Meek. One of the most striking of these is a Leiorhynchus resembling *L. quadricostatum*. *Productus hirsutiformis* and a Posidonomya (Posidoniella?) also lend it a Devonian aspect. A Leiorhynchus like *L. quadricostatum*, a Productus like *P. hirsutiformis*, similar Goniatites, and similar Posidoniellas, are found near the base of the Caney shale in Indian Territory, and in the Spring Creek limestone and Fayetteville shale of Arkansas. These facts, together with a similarity in lithologic character and an identity in stratigraphic position, in point of which each occurrence is immediately beneath beds supposed to represent about the same horizon, while not sufficient to demonstrate stratigraphic equivalence, for which a thorough comparison of the entire faunas would be necessary, lend a strong color of probability to it.

Eastward from Nevada the Devonian thins notably. It was supposed to be represented in the Wasatch section by the Ogden quartzite of King,[505a] but the formation has since been determined to be the Middle Cambrian quartzite repeated by an overthrust. Blackwelder[84e] says:

Kindle[a] has recently shown that the Jefferson limestone of Montana, with a sufficient Devonian fauna, extends southward into the mountains of Utah, and he has traced it along the east side of Cache Valley, in the Bear River Range. He has also identified in the same locality a limestone containing Silurian fossils conformable beneath the Jefferson formation.

[a] Kindle, E. M., Bull. Am. Paleontology No. 20, Ithaca, N. Y., 1908.

It was to be expected that the same formations would soon be found also on the west side of Cache Valley, in the Wasatch Range proper. As exposed on the crest of the range, there is, between the Ordovician quartzite and the identifiable part of the Mississippian limestone, a succession of dark limestones, with some ash-gray brittle dolomites having a thickness of 1,000 to 1,500 feet. In the lowest beds there are corals such as Halysites and Favosites. At a slightly higher horizon there are abundant shells, which Kindle thinks are the same as his Pentamerus fauna of the Bear River Range. All the specimens, however, are poorly preserved, and show best upon the weathered surfaces. Between the Silurian horizon and the fossiliferous Mississippian there is a thick, dark limestone which corresponds satisfactorily with Kindle's Devonian Jefferson formation east of Cache Valley. Further search may be expected to reveal the Jefferson fauna in these beds.

Kindle[498b, 499b] examined the sections in several canyons south of Logan Canyon, in the northern part of the Wasatch Mountains. He distinguishes 1,000 to 1,200 feet of dark magnesian limestones as Devonian, the equivalent of the Jefferson limestone of Montana. The formation lies between Silurian and Mississippian limestones. (See p. 320.)

In the Uinta Range the Devonian is not present, the Ordovician quartzite being immediately overlain by limestones of lower Mississippian age.

In the Grand Canyon section, Arizona, a limestone 94 feet thick is classed as Devonian by Walcott.[852] It rests on Cambrian rocks, as does the Ouray limestone in some areas in Colorado, and is overlain by the Redwall limestone (Carboniferous), 962 feet thick. In Gilbert's original account[360a] of the Redwall he says: "The base of the system is arbitrarily assumed at the first marked lithological change, and it is not impossible that it has been placed so low as to include Devonian, or even Upper Silurian, if those formations are represented in the series."

B. S. Butler[a] has recently found Devonian underlying Mississippian limestone in the Star Range, Beaver County, Utah.

J-K 12-13. WYOMING AND COLORADO.

In western Wyoming the Devonian is represented by the Jefferson limestone. It is not present in the Bighorn Range, according to Darton, and does not occur near Rawlins, according to Kindle. Blackwelder says that it probably occurs in the Teton and Gros Ventre mountains and perhaps in the northwestern part of the Wind River Range.

In southwestern Colorado the Devonian is represented by the Elbert formation and the lower part of the Ouray limestone. The Elbert consists of calcareous shales, thin limestones, and local quartzite beds, characterized in many places where shaly by casts of salt crystals and carrying at several horizons fish remains of Upper Devonian age (Bothriolepis and Holoptychius). It usually rests unconformably upon the Cambrian (Ignacio quartzite). It is conformable to the overlying Ouray limestone, the division between the two being marked by a band of red shale, the top of the Elbert. The Ouray limestone is in greater part dense and compact, yellowish, somewhat sandy in the lower layers, and in places coarsely crystalline in the upper ledge. It is 100 to 250 feet thick. The lower part contains a Devonian fauna and the upper part a Mississippian (lower Carboniferous) fauna.

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[a] Personal communication.

No line of division can be traced between the two, however, and therefore all the beds are included in one formation.

Girty [194] states:

In general the Devonian fauna of the Ouray belongs to upper Devonian time. It is but distantly related to the Devonian faunas of New York, and its relation to those of the Mississippi Valley, or even to other known western Devonian faunas, is not close. It shows many points of approximation to the Athabascan fauna described by Whiteaves and is somewhat strikingly similar to the Devonian of Russia.

J–K 17–18. SOUTHEASTERN PENNSYLVANIA, MARYLAND, AND VIRGINIA.

Until recently the Onondaga has been supposed to be absent from the Allegheny region south of northeastern Pennsylvania. In regard to the occurrence of the Onondaga Kindle [a] says:

This fauna, in a slightly modified form, extends southward from New York through the Allegheny region as far as the northern boundary of Tennessee. The Onondaga fauna occurs throughout this region in the lower part of what has been called the Marcellus shale in the Pennsylvania reports, the Romney shale in Maryland and northern Virginia, and the base of the Chattanooga shale in southwestern Virginia. The beds holding this fauna in the Allegheny region represent an argillaceous facies of the Onondaga. They are chiefly drab or olive-green shales with more or less argillaceous limestone interbedded. This set of beds is separated from the Hamilton above by fissile black shales differing in no important features from the Marcellus shale of New York.

Swartz [805] has identified the Portage and Chemung in western Maryland. He describes local sections, gives extended lists of faunas, and concludes:

It is very difficult to determine [the Portage-Chemung boundary] when the brachiopod facies of the Portage immediately underlies the Chemung. Of the New York section Clarke remarks: "It is extraordinarily difficult to fix on a division plane between the Ithaca and the overlying Chemung faunas." If this be true in New York, it must be still more true when an attempt is made to correlate that section with those of other States, and the results attained must be open to revision as fuller investigations give increased data. Nevertheless, it seems reasonably probable from the preceding studies that the horizon in question is to be placed between the strata bearing the *Spirifer disjunctus* and *Spirifer mesacostalis* faunas, giving the following succession:

Chemung, *Spirifer disjunctus* fauna.
Portage { *Spirifer mesacostalis* fauna.
Spirifer pennatus var. *posterus* fauna.
Naples fauna. }
Genesee, Black shales with Buchiola fauna.

Lithologically the horizon is not well defined, the conditions varying at different localities. In general the Portage is characterized by smooth fissile shales and interbedded sandstones and the Chemung by a larger percentage of sandstones, while its shales are softer and break with a hackly fracture. The transition from Portage to Chemung is, however, not sharply defined by any lithological features.

Certain facts seem to harmonize with those of New York.

1. The general succession of forms seems to be that of New York. At the base occurs the Genesee, thinning eastward, followed by the Naples fauna of the Portage. Above the latter is found *Spirifer pennatus* var. *posterus*, succeeded by *Spirifer mesacostalis*, and finally by *Spirifer disjunctus*.

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[a] Comment on manuscript.

2. There is a greater development of the Naples fauna in the west and of the Ithaca fauna in the east.

3. The shore line was probably eastward, as indicated by the fact that there is a marked development of conglomerates eastward, as at Millstone. These diminish toward the west, where the lower Jennings is largely composed of argillaceous shales, as at Allegany Grove.

The thinning of these formations southward through the Virginias may be traced in general stratigraphic terms in folios of the Geologic Atlas of the United States by Darton[226, 228, 229, 231] and Campbell;[121, 123, 124, 125] also in other papers by Darton,[221] Campbell,[122] and Prosser.[650]

Devonian formations in Piedmont, Franklin, Staunton, and Monterey quadrangles.

System.	Formation.	Thickness (feet).[a]				General character.
		Piedmont.	Franklin.	Staunton.	Monterey.	
Carboniferous (Mississippian).	Pocono sandstone.	30–80	85–700	700	70–90	Conglomerate and sandstone.
Devonian.	Hampshire formation.	2,000–2,300	1,600–2,200	1,000–1,400	1,500–1,800	More or less thinly bedded sandstone and shady shale, generally red, with gray and greenish-gray beds.
	Jennings formation.	3,300	2,100–3,800	2,800–3,400	3,000–3,800	Gray to buff sandstone interbedded with gray, olive, and buff shale.
	Romney shale.	1,100–1,300	1,100–1,300	600–1,000	1,000–1,300	Shale, black and fissile below, with thin limestone layer, lighter colored and more sandy above.
				Unconformity.	Unconformity.	
	Monterey sandstone.	215–300	200–300	0–300	50–200	Calcareous sandstone, weathering to brown porous sandstone.
Silurian.	Lewistown limestone.	[In part equivalent to Helderbergian (Devonian). See Chapter V, p. 239.]				

[a] The measurements range south through the Piedmont, Franklin, and Staunton quadrangles from latitude 39° 30′ to 38° and west from the Staunton to the Monterey, longitude 79°–80°, in West Virginia and Virginia.

Two quadrangles which lie southwest of the Monterey quadrangle, between 80° and 81° west and 37° 30′ and 38° north, have not been surveyed. Next southwest come the Pocahontas and Tazewell quadrangles (81°–82° west, 37°–37° 30′ north), which have been mapped by Campbell.[123,124] In the interval the distinction between the Jennings and Hampshire is lost, as shown in the following section from the Pocahontas and Tazewell folios:

Devonian formations in Pocahontas and Tazewell quadrangles.

System.	Formation.	Thickness (feet).		General character.
		Pocahontas.	Tazewell.	
Carboniferous.	Price sandstone.			
				(Transition; no distinct boundary.)
Devonian.	Kimberling shale. [Approximate equivalent of Jennings and Hampshire.]	3,000–3,250	2,000?–3,000	Green, sandy shale and thin sandstone containing one or more beds of quartz conglomerate near the top.
				(Transition; no distinct boundary.)
Devonian.	Romney shale.	400–600	300–500	Black carbonaceous shale.
Devonian / Silurian.	Giles formation (Oriskany and Lower Helderberg).	30–200	100–200	Coarse yellow sandstone. Cherty limestone. Coarse reddish sandstone. Blue limestone.
Silurian.	Rockwood formation (Clinton).			

Kindle's collections from southwestern Virginia have shown that the typical Chemung fauna extends southwestward as far as Bland County and that the greater part of the Kimberling shale is the equivalent of the Chemung of New York.[938a]

The portions of the Pocahontas and Tazewell quadrangles in which the preceding sections were observed lie in southwestern Virginia. In the extreme southwestern part of the State, 30 miles beyond them, is the Estillville quadrangle, which presents the following section north of Clinch River according to Campbell:[121]

Devonian formations in Estillville quadrangle.

System.	Formation.	Thickness (feet).	General character.
Carboniferous.	Newman limestone.	700–930	Pure blue limestone in the lower part; cherty toward the base.
Devonian.	Grainger shale.	420–500	Calcareous sandstone above sandy shale, merging into black shale below.
Devonian.	Chattanooga black shale.	530–1,000	Chiefly black carbonaceous shale; with ash-colored sandy member in the middle.
Silurian.	Hancock limestone. [a]	180–275	Blue fossiliferous limestone, very sandy at the top and bottom.

[a] According to Kindle (personal communication) the Hancock limestone is of Silurian age in lower part and of Devonian age in upper part.—B. W.

The change of names from the Tazewell to the Estillville quadrangle indicates the uncertainty attending the selection of formational and also of systemic boundaries in the two sections. The relations of the Kimberling shale to the Grainger shale and of the Romney shale to the Chattanooga shale have not been traced across an unsurveyed gap of a few miles. The Grainger may include part of the basal Mississippian.

The Grainger shale has been mapped by Keith through the Morristown and Maynardville quadrangles, Tennessee, to the vicinity of Knoxville (longitude 84° west, latitude 36° north), and it is accompanied by the Chattanooga shale, which extends beyond to Georgia and Alabama.

Along the base of the Cumberland escarpment across Tennessee, from the Briceville through the Kingston and Chattanooga quadrangles, into Georgia, the Devonian is represented only by the Chattanooga shale, which ranges in thickness from 80 feet in the northeast to as little as 10 feet in the south. In its occurrences in Georgia and Alabama the Chattanooga shale is remarkable for the persistency with which it retains its character, although everywhere very thin.

In the Coosa Valley of Georgia and Alabama the Frog Mountain sandstone (of Oriskany age) lies unconformably upon Ordovician rocks. Hayes [418] described the occurrence as follows:

There are between Indian and Weisner mountains several small areas occupied by a formation which comes in contact with all the older formations thus far described. It consists of coarse ferruginous sandstone, in some places white, resembling quartzite, and in others yellow or gray and weathering to incoherent beds of sand. Beneath this sandstone and usually deeply covered by its débris are shales, also variable in composition and appearance. No satisfactory measurement has been made of their thickness, but this is probably as variable as their physical appearance.

Schuchert [711f] determined the following Oriskany forms from this sandstone:

Orthis (Rhipidomella) musculosa Hall.
Stropheodonta magnifica Hall.
Anoplotheca fimbriata Hall.
Spirifer tribulis Hall.
Meristella cf. walcotti Hall and Clarke.
Ambocœlia umbonata Conrad.

K 10. KLAMATH MOUNTAINS, NORTHERN CALIFORNIA.

Among the Paleozoic strata of the northern Sierra the Devonian is recognized by an Onondaga fauna. The fossils are corals, which in places form reefs, and the terrane itself consists of limestone, 50 to 70 feet or more thick, which is associated with schists and eruptive rocks.[283]

Diller has brought together the available information regarding the Devonian of northern California. He distinguishes the southwestern and northeastern belts, which may be recognized on the map. Concerning the former he says: [276c] "In the southwestern belt there is a line of Devonian limestone lentils (formerly doubtfully referred to Jura-Trias) which may be traced with many interruptions for over 100 miles parallel with the South Fork of Trinity River." In the detailed descriptions of several localities, the intimate association of the limestone with more or less vesicular igneous rocks that break through it, inclose it, and form the greater mass of the material is repeatedly mentioned. The fossils from one locality (near White Rock) were determined by Schuchert as Upper Devonian, those obtained at six other localities as Middle Devonian.

Concerning the northeastern belt Diller [276d] states:

The northeastern belt of Devonian limestones and shales lies chiefly in the Sacramento drainage, extending northward into the Klamath and Rogue River region. The southern part, lying within the Redding quadrangle, and as far north as Gazelle, has already received much attention. The principal limestone bodies rich in fossils occur near Klamath and on Hazel Creek. Smaller masses outcrop near Horsetown and at a number of points 6, 8, and 11 miles northeast of Redding, where they lie close to the Carboniferous in line with a larger mass 2 miles northwest of Baird.

One of the best sections of these rocks, but not including the whole Devonian series, may be obtained on Backbone Creek 3½ miles north of Kennett, where nearly 900 feet of sediments are quite fully exposed.

[Top.]	Feet.
1. Conglomerate; many quartz pebbles and numerous holes from dissolved limestone fragments, some of which contain fossils like those of the limestones below. Unconformable on 2. Possibly Carboniferous	30
2. Shales, mostly dark, with some thin sandy beds	140
3. Limestone, rather massive, light colored; little chert but full of corals, etc. (locality 6242)	100
4. Thin-bedded sandstones and shales which are cherty and gray below. Near middle part is limestone lens 10 to 15 feet thick	300
5. Limestone, thin bedded and crowded with massive, branching, and cup corals (6244). Cherty nodules and bands in bluish limestone becoming whitish and without chert below	250
6. Siliceous shales; 10 feet of banded chert at top, with sandy shales, black shale, and fine shaly sandstone, very thin bedded, resting on the igneous rocks below	75

A large number of fossils were collected from the Devonian of the Redding quadrangle, and these may in large part be referred to the section given, although but few of the fossils were actually collected at the point where the section was measured. After enumerating a number of the species found at various localities, Mr. Schuchert concludes as follows:

"The section of locality 6242 given me by Mr. Diller, the thickness of which he estimates to be about 900 feet, has one general fauna indicative of the Middle Devonian. The general age has been known for some years, but the collections of 1902 have given us a definite section and also species that are known to occur in other American localities. This is especially true of the fossils of the lower shale zone, which repeats the fauna of the Eureka and White Pine districts of Nevada and the Middle Devonian of Iowa. The species that are common to at least two of these regions are *Schizophoria striatula, Stropheodonta canace, Gypidula lotis, Pugnax altus, Atrypa missouriensis*, and *Cyrtina missouriensis*?"

Taking these species in connection with the corals of the limestones, as *Heliolites porosa*, Endophyllum or Spongophyllum, and Phillipsastræa, one sees plainly that the California Middle Devonian belongs to the "Euro-Asiatic province." This province extends east in North America as far as central Missouri, eastern Iowa, Milwaukee, Wis., and Petosky, Mich. East of these places occur the Middle Devonian faunas of the "North American type."

These Devonian strata are described as the Kennett formation, their stratigraphy, details of occurrence, and paleontology are presented, and their conformable relations to older volcanic rocks are stated in the Redding folio.[279]

K 15. IOWA.

The following section of the Devonian of Iowa was compiled by Chamberlin[1346] from the Iowa Survey reports:

Generalized section of the Devonian for Iowa.

Formation.	Thickness (feet).	Characteristics.
Lime Creek formation	80	Dark-colored argillaceous shales, highly fossiliferous, and locally calcareous.
State quarry beds	20–40	Light gray; good building stone. Fish teeth.
Sweetland Creek shales	20–40	Black and greenish; Upper Devonian fossils.
Unconformity.		
Cedar Valley limestone	250–300	Pure to argillaceous limestone and dolomite; sometimes massive, sometimes finely laminated, frequently brecciated.
Wapsipinicon formation (Independence, Fayette, Davenport).	100–150	Carbonaceous shales with bands of impure concretionary limestone; brecciated limestone.

These strata represent Middle and Upper Devonian, a local unconformity or change in fauna distinguishing the two. The Middle Devonian beds overlap northward as they rise in the series and rest in part on Silurian, in part on Ordovician. Calvin[117] states with reference to strata in the extreme northern part of the State:

The lowest beds seen in Howard County belong to a horizon far above what has been recognized as the base of the Devonian in the southern part of the area of its distribution. The beds which rest directly on the Maquoketa contain *Stropheodonta demissa* Conrad, *Productella subalata* Hall, *Atrypa aspera* Schlot., *Spirifer pennatus* Owen, and *Cyrtina hamiltonensis* Hall. The fauna indicates a horizon equivalent to that represented about the middle of the quarries at Independence, in Buchanan County. In this zone in Howard County, Productella is the most abundant and most characteristic fossil, and it is convenient to refer to the horizon as the Productella beds. This zone belongs to the Upper Davenport beds of Norton, below which, before reaching the base of the Devonian in Linn, Cedar, and Scott counties, there are divisions of the Wapsipinicon stage which have been described as Lower Davenport, Independence, Otis, and Coggan.

With reference to the distinction of Devonian and Carboniferous Weller[877] concludes:

The succession of faunas exhibits a somewhat gradual transition from the earlier faunas with quite marked Devonian characters to the later ones which are typically Carboniferous in aspect. The Devonian element in the faunas is for the most part exhibited by the pelecypods, while the brachiopods are usually Carboniferous in aspect. This overlapping and intermingling of Devonian and Carboniferous faunal elements makes it impossible to draw a sharp line separating the Devonian and Carboniferous systems such as is recognized in the continental interior between the Ordovician and Silurian in the Medina formation, and between the Silurian and Devonian in the Waterlime formation. The Devonian-Carboniferous dividing line is more nearly analogous with the Cambro-Ordovician division.

K 16. WISCONSIN.

In the vicinity of Milwaukee the Devonian is represented by the Milwaukee formation (of Hamilton age). According to Alden,[11] as nearly as can be determined from partial exposures and drilled wells the order and maximum thickness of the members of the formation are as follows:

Generalized section of the Devonian beds of Milwaukee, Wis.

	Feet.
Black shale	15
Soft bluish "soapy clay" or shale	80
Bluish magnesian limestone, "cement rock"	12
Bluish limestone and softer bluish "soapy clay"	31

These beds, with the exception of the upper black shale, are highly fossiliferous, showing a great variety of invertebrate forms as well as plates and teeth of armor-plated fishes. * * * Beneath this group of beds is the brownish limestone provisionally referred to the Cayuga group [Waubakee formation, Silurian].

K 17. ONTARIO.

In Ontario the Devonian formations, as determined by boring, are listed by Brummel [105a] as follows:

	Feet.
Devonian:	
Portage and Chemung	25–200
Hamilton, about	350
Corniferous	160–300
Oriskany	6–25
Silurian:	
Lower Helderberg Onondaga	300–1,000

These formations, their distribution, and their relations to the New York equivalents as then understood were described in detail by Logan.[544p] Concerning the Oriskany he states that it enters Canada at Waterloo, on the Niagara.

In its lithological characters it does not seem to differ materially from the same rock in New York. The lower beds appear in several places to be composed of chert or hornstone, frequently containing large quantities of iron pyrites, and occasionally beautiful specimens of purple fluorspar. * * * Resting on these beds there is a sandstone, which is somewhat different in different localities. In the township of Dunn, near Haldimand, it is frequently made up of large angular pieces of hornstone; which, with the numerous large corallines and other fossils present, render it almost useless as a building stone. In the townships of Oneida and North Cayuga * * * there are large exposures of the rock. It is composed of fine grains of white quartz, in some parts so closely cemented as to assume the characters of a white compact quartzite. In other parts it is made up of coarser grains of quartz, some of them being an eighth of an inch in diameter and pretty well rounded. With these there are occasionally grains of feldspar. The rock in these cases, being sometimes slightly calcareous, disintegrates by exposure to the weather. The beds are massive and from 6 inches to 6 feet thick. * * * The sandstone in some parts very much resembles the white beds of the Potsdam formation; but it passes from white to light gray and, in some places, through yellowish to brown. * * * The greatest thickness of the mass may be about 25 feet; but though now and then attaining 10 feet, it seldom exceeds about 6, and it is frequently wanting between the Waterlime series and the overlying Corniferous formation.

The rock abounds in organic remains.[a]

Concerning the "Corniferous" Logan states:

In western Canada we find that many of the fossils of the Corniferous limestone pass up from the Oriskany sandstone; and the intermediate Onondaga limestone, with its encrinites, can no longer be recognized as a distinct formation. We therefore unite the two limestones under the name of the Corniferous formation.

[a] For list of species see the work cited.—B. W.

The surface occupied by this formation in western Canada is probably between 6,000 and 7,000 square miles. A great part of this however is deeply covered by drift, so that the exposures are comparatively few. * * *

The generally small dip of the strata and the frequent occurrence of slight undulations render it very difficult to find the succession of the beds, or to determine with accuracy the whole thickness of the Corniferous formation. The great extent occupied by it in western Canada, however, makes it probable that it must be much more considerable here than in New York. In the townships of Woodhouse and Townsend, where there are frequent exposures, the breadth at right angles to the strike is upward of 10 miles. The fall of the surface, in that distance, is estimated at 140 feet; so that if the average slope does not exceed 30 feet in a mile, there would here be a thickness of about 160 feet of the Corniferous limestone. The strata which in Michigan are considered as the equivalents of this formation have, according to Prof. Winchell, a thickness of about 350 feet; so that it would appear that the thickness gradually augments to the westward.

The formation enters Canada from New York, nearly opposite Buffalo, and is traceable in a narrow belt along the shore of Lake Erie, resting on the Oriskany sandstone, or, where this is wanting, on the Waterlime series. * * * Some portions abound in chert, which forms beds of from 1 to 4 inches or exists in nodules like flints in the limestone. Many of the beds contain silicified organic remains. These in some localities, as in North Cayuga and at Port Colborne, are found weathered out and loose, in great abundance, at the surface of the ground. Some of the beds are little more than an aggregate of silicified organic remains, with so little calcareous matter that the whole mass coheres, after the carbonate of lime has been dissolved out. * * *

To the west of the Grand River, in the counties of Haldimand and Norfolk, the Corniferous limestones are often seen resting on the Oriskany formation and forming small eminences, which present escarpments, with the sandstone at their base. These limestones are here of a drab color and abound in chert. * * *

Higher in the series, along the same line of country, blue limestones, sometimes to the amount of 20 feet, with gray beds in less volume, are associated with cherty layers, and interstratified with bands of a drab-colored limestone. * * *

The limestones of this formation are all more or less bituminous, and bitumen exists in many of them in a liquid form, as petroleum or rock oil, filling the cells of the corals and other fossils. The corals often prevail in distinct bands, some of which will be saturated with the oil while those above and below will have little or none. In working Mr. Horn's quarry, which has already been mentioned, on the thirteenth lot of the second range of Bertie, the oil is seen to impregnate particular beds, which are in great part made up of the remains of a species of Heliophyllum. These corals, in various attitudes, are arranged in bands varying in breadth from 3 to 6 inches; and in their open cells the petroleum is lodged. The intermediate parts of the rock, which contain no oil, are composed of a mass of broken organic remains, chiefly encrinites, while in the coral-bearing beds these comminuted crinoids serve as a paste to fill up the interstices among the corals.

Logan defines the stratigraphic limits of the Hamilton formation of Ontario as follows:

In the western part of Canada we have not been able to distinguish either the Marcellus shales or the Tully limestones from the Hamilton group, and we shall therefore, in describing the rocks of that region, include under the name of the Hamilton formation all the strata between the Corniferous limestones and the Genesee shales. This formation occupies the lowest portion of the saddle-shaped depression noticed in the previous chapter as crossing the peninsula from Lake Erie to Lake Huron and separating the Corniferous formation into two areas. The space thus occupied is very much covered by drift and the contact between the Corniferous and Hamilton formations has not yet been seen, so that it is not easy to assign their precise stratigraphical place to the exposures which are met with.

The strata comprised in this interval are described as gray calcareous shale, gray limestone composed of remains of encrinites, and soft shales. There are also black shales which may indicate the passage from the Marcellus to the Hamilton. Logan cites several partial sections, and Brummel[105] gives well records which include the Hamilton.

Under the name "Portage and Chemung group" Logan[544q] cites the occurrence of black bituminous shales, which may represent the Genesee and which occupy a small area at Kettle Point, on Lake Huron. He says:

Here, in a low cliff, on the west side of the cape, is a section of between 12 and 14 feet of very fissile black bituminous shales, weathering to a leaden-gray, and often stained brown by oxide of iron. A yellow earthy coating of oxalate of iron is sometimes found in the surfaces of the shales, which also contain nodules and crystals of iron pyrites, besides peculiar spheroidal concretions, whose fancied resemblance to inverted kettles has probably given its name to the point. They vary in size from 3 inches to as many feet in diameter, and are sometimes nearly spherical and at others somewhat flattened, generally on the under side. Occasionally a smaller spheroidal mass is implanted on the top of a larger one. These concretions are readily broken and are then seen to be composed of brown crystalline carbonate of lime, which is confusedly aggregated in the center and sometimes contains blende. Around this are arranged slender prismatic crystals, which extend from the nucleus to the circumference, the whole having a radiated columnar structure, which, not less than the terminations of the prisms at the surface of the spheroidal masses, gives them very much the aspect of fossil corals.

On the east side of the point the upper beds of the section are concealed, but the lower ones come from beneath the bank at a little above the water's level and cover an area of several acres, the whole surface being studded with these spheroidal concretions, which remain when the softer shale around them has been partially worn away.

This black shale is fossiliferous and contains a fucoid resembling a variety of the *Fucoides cauda-galli* of Vanuxem, which is very abundant in the lower beds. Flattened stems of *Calamites inornatus* (Dawson), which are sometimes 7 or 8 feet long, and 3 inches wide, occur about the middle of the section and are occasionally converted into coal. Besides these, according to Dr. Dawson, there occurs here a stem which belongs to *Sagenaria veltheimiana* (Goeppert). An undetermined Lingula is found with these plants, together with numbers of what appear to be microscopic orbicular shells.

The fauna of the Oriskany of Ontario has been carefully studied by Schuchert,[710] and that of the Hamilton by Whiteaves.[915,921] Shimer and Grabau[740] have published measurements of local sections at Thedford, Ontario, and lists of fossils from the several divisions, together with a discussion of correlation and faunal migration.

K 17-18. PENNSYLVANIA AND NEW JERSEY.

The Devonian formations of New York can be traced southward into Pennsylvania and New Jersey, as was shown by Williams[930] in 1884, by the work of the respective State surveys, and by recent studies of several observers. Some of these formations, however, notably the Tully limestone, are exceptionally limited and are not known to occur south or west of northeastern Pennsylvania and northern New Jersey. The Ithaca fauna, which is lacking in western New York, extends across Pennsylvania in a belt that passes southeast of Altoona. The contemporaneous fauna of the Portage of western New York occurs at Altoona, the two faunas being inshore and offshore, as brought out by Williams and Kindle.[938]

The section near Altoona, as determined by Butts,[112] is as follows:

Section of Devonian rocks near Altoona, Pa.

Formation.	Thickness (feet).	Character.
Pocono sandstone (Carboniferous).		
Catskill formation	2,000	Red shale and red or brown sandstone, with some gray or green shale or sandstone. Unfossiliferous.
Chemung formation	2,500	Lower 1,400 feet gray or green sandy or clay shale; upper 1,000 feet large proportion chocolate shale and thin layers of chocolate sandstone; fossiliferous; conformable with Nunda.
Nunda (Portage) formation	1,400	Base soft pale-brown clay shale, splitting easily into thin, smooth plates; above, change to greenish-gray sandy shale with some layers of hard bluish fine-grained sandstone. Fossiliferous.
Genesee shale	80	Black clay shale, very fissile, containing plentiful calcareous concretions; conformable with both Nunda and Hamilton.
Hamilton formation Marcellus shale	3,100	Very dark green, olive-green, and gray shale and dark-green sandy, slightly micaceous shale; infrequent bands of fine-grained bluish sandstone.
Oriskany sandstone	20-50	Thick-bedded, generally coarse-grained gray or buff siliceous rock.

Kindle [495] comments in detail, with faunal lists, on the faunas of the Altoona section.

The Devonian formations in New Jersey present different characters in two districts, the Delaware Valley and Green Pond Mountain. Kümmel [513c] states:

The Devonian formations of the upper Delaware Valley are of marine origin and are chiefly fossiliferous calcareous shales and limestones having a thickness of about 1,000 feet. Those of the Green Pond Mountain region are chiefly arenaceous shales, sandstones, and conglomerates, carrying comparatively few fossils and aggregating over 4,000 feet in thickness.

The Helderbergian or lowermost Devonian faunas in New Jersey are essentially the same as those in New York, and the same faunal zones are recognized. The first formation carrying these faunas is the Coeymans limestone.

Coeymans limestone.—In the Nearpass section the Coeymans limestone has an estimated thickness of 40 feet, though only the lower beds are exposed. It rests conformably upon the Manlius limestone, from which it differs lithologically in its coarser and more crystalline texture and lighter color. Frequently more or less chert is mingled with the limestone. The Coeymans fauna is far more prolific than that of the Manlius and differs markedly in composition, the most characteristic species being *Gypidula galeata*. A coral bed carrying more or less completely silicified masses of *Favosites helderbergiæ* and a concentrically laminated stromatoporoid occurs in the base of the formation.

Stormville sandstone.—In the southern half of the Wallpack Ridge in New Jersey, a thin sandy layer occurs at the top of the Coeymans limestone. It is in general an inconspicuous formation, owing to its thinness and heavy deposits of glacial drift. It becomes more conspicuous toward the south and according to White [a] it gradually replaces the overlying calcareous and shaly strata until it occupies the entire interval between the Coeymans limestone and the Oriskany sandstone. It has not been recognized in the Nearpass section near Tristates nor at any point north of Hainesville, N. J.

New Scotland beds.—The New Scotland beds, which overlie the Coeymans limestone in the Nearpass section, consist of about 20 feet of a very hard cherty limestone followed by a series of calcareous shales, having an estimated thickness of 140 feet. Nowhere in the State is there exposed a continuous section of these beds as is the case with several of the lower formations. The fauna is a prolific one and is especially characterized by the abundant representation of the genus Spirifer. Its differences from the Coeymans fauna are of such an essential

[a] Second Geol. Survey Pennsylvania, Rept. G6, 1882, pp. 132, 133.

character as to indicate a separate immigration from the exterior into this region.[a] As indicated above, south of Hainesville a thin sandy bed intervenes between the Coeymans limestone and the New Scotland beds and gradually replaces the latter. At Flatbrookville, where these strata cross the Delaware into Pennsylvania, the lower cherty limestone member of the New Scotland beds has disappeared and the Stormville sandstone contains a fauna characterized by *Spirifer macropleurus*.

Becraft limestone.—A hard gray cherty limestone overlies the shaly layers of the New Scotland beds, forming a resistant layer which outcrops frequently along Wallpack Ridge. Its entire thickness has never been observed, but it is estimated to be about 20 feet. Its fauna is closely allied to that of the New Scotland beds, a few new forms appearing and a few old ones disappearing. There is also some difference in the proportionate number of individuals of some species, notably of *Leptæna rhomboidalis*, which becomes especially abundant. The bed is correlated with the Becraft limestone of New York.

Kingston or Port Ewen beds.—A series of strata, nowhere exposed, occupies the interval between the Becraft limestone and the base of the Oriskany. They are probably shaly beds which easily disintegrate and thus become covered with débris. Their thickness is roughly estimated as 80 feet. The only basis for their correlation is their position, which corresponds to that of the Port Ewen (Kingston) beds of New York. In Pennsylvania, the same beds have been called the Stormville shales by White.[b]

Oriskany formation.—A series of strata, aggregating about 170 feet in thickness, succeed the Port Ewen beds and are referred to the Oriskany. They are for the most part siliceous limestones, but the summit of the formation along the southern half of the Wallpack Ridge becomes a sandstone. The arenaceous facies is said to become more marked to the southwest in Pennsylvania and to embrace lower and lower beds until all the strata to the top of the Coeymans limestone are sandstones. The fauna of the Oriskany beds in New Jersey comprises three well-defined faunal zones, the lowest characterized by *Dalmanites dentatus*, the second by *Orbiculoidea jervensis*, and the third by the great abundance of *Spirifer murchisoni*.

In the Nearpass section the beds bearing the *Dalmanites dentatus* fauna are about 30 feet thick and form the crest of a high ridge which is the southern extension of the "trilobite ridge"[c] east of Tristates. There is a mingling of Helderbergian and Oriskanian forms in this fauna, and there has been some difference of opinion as to whether these beds should be placed in the Port Ewen or Oriskany, but recent workers[d] unite in referring them to the Oriskany.

Esopus grit.—The Esopus grit which overlies the sandstones and siliceous limestones of the Oriskany forms the crest of Wallpack Ridge for the greater part of its extent in the State. It is a nearly black gritty rock with well-developed cleavage, which obscures the bedding planes. The fucoid "cauda galli" markings can frequently be recognized on the bedding planes when the latter can be distinguished. Apart from these markings fossils are very rare. The average thickness of the formation in New Jersey is estimated to be 375 feet.

Onondaga limestone.—The Onondaga limestone overlies the Esopus grit along the northwestern slope of Wallpack Ridge. Toward its base the formation is somewhat shaly and there is apparently a rather gradual transition from the grit to the limestone. The latter is hard, cherty, and regularly bedded in layers ranging from 3 inches to 1 foot in thickness. The beds are assigned to the Onondaga on the basis of their position and lithology rather than faunal evidence, since the recognizable forms are not sufficiently characteristic for close correlation.

Marcellus shale.—Fissile black shale, referable to the Marcellus, has been reported to occur in New Jersey along the bed of the Delaware River a few miles below Port Jervis, but in recent years the exposures have apparently been buried by silting up of the channel. This is the highest of the Devonian beds exposed in the State along the Delaware River, but in the Green Pond Mountain area still younger beds occur.

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[a] Weller, Stuart, New Jersey Geol. Survey, Paleontology, vol. 3, 1903, p. 90.
[b] Second Geol. Survey Pennsylvania, Rept. G6, 1882, p. 131.
[c] Shimer, H. W., Bull. New York State Mus. No. 80, 1905, p. 175.
[d] Weller, Stuart, op. cit., p. 96. Shimer, H. W., op. cit., p. 184.

DEVONIAN FORMATIONS IN THE GREEN POND MOUNTAIN AREA.

Kanouse sandstone.—The Kanouse sandstone, the lowest Devonian formation of the Green Pond Mountain region, is a thick-bedded, fine-grained conglomerate below and a greenish sandstone above, having a thickness of about 215 feet. Although fossils are not rare, yet as a rule they are obscure and many of them are so greatly distorted that their identification is impossible. So far as recognized they indicate an Onondaga fauna, and these beds may be interpreted as the shoreward correlatives of the Onondaga limestone. It is the formation which in the New Jersey Geological Survey reports has been called the Newfoundland grit.

Its outcrops form a narrow belt parallel to the Decker Ferry limestone but separated from it by a narrow interval. In the upper Delaware Valley, as noted above, there are seven formations aggregating nearly 900 feet in thickness between the Decker Ferry and the Onondaga. In the Green Pond Mountain region none of these has been recognized and, if present at all, it can be only in very attenuated form.

Pequanac shale.—The Kanouse sandstone apparently grades upward into a black and dark-gray thick-bedded slaty shale (the "Monroe" shale of Darton and others). Cleavage is usually strongly developed so that the bedding planes are not always readily discernible. The thickness is estimated at 1,000 feet. This formation is probably conformable upon the Kanouse sandstone, but the contact has nowhere been observed. It contains a somewhat meager fauna, among which, however, is the characteristic Hamilton species *Tropidoleptus carinatus*, so that its reference to this period is beyond question.

Bellvale sandstone.—The Bellvale sandstone is scarcely more than a continuation of the Pequanac shale, but the beds are coarser and more sandy. The average thickness is estimated at 1,800 feet. The few fossils found are all Hamilton species.

Skunnemunk conglomerate.—The Bellvale sandstones grade upward into a coarse purple-red massive conglomerate, the white quartz pebbles of which are sometimes 6 or 7 inches in diameter. Beds of red quartzitic sandstone alternate more or less frequently with the conglomerate and there are many gradations between the two. It forms the great mass of Bearfort Mountain in New Jersey and of Bellvale and Skunnemunk mountains in New York. It is the youngest Devonian formation in New Jersey and rests upon beds known by their fossils to be of Hamilton age. Whether it is the exact equivalent of the Chemung-Catskill can not be determined.

K 17-18. NEW YORK.

According to the nomenclature of the present New York State Survey, the classification of the Devonian of that State is as follows:[302]

Summary of classification of the New York Devonic.

[According to John M. Clarke. Descending order.]

System.	Group.		Stage.
Carbonic.	Pennsylvanian.		Olean conglomerate.
	Mississippian.		Knapp beds. Oswayo beds (Panama conglomerate). Cattaraugus beds, including Wolf Creek conglomerate.
Devonic.	Neodevonic.	Chautauquan.	Chemung beds (Catskill sandstone, local facies).
		Senecan.	Portage beds (Naples, Ithaca, Oneonta, Sherburne beds, local facies). Genesee shale. Tully limestone.
	Mesodevonic.	Erian.	Moscow shale. Ludlowville shale. } Hamilton. Skaneateles shale. Cardiff shale. Marcellus shale.
		Ulsterian.	Onondaga limestone. Schoharie grit.
	Paleodevonic.	Oriskanian.	Esopus grit. Oriskany beds.
		Helderbergian.	Port Ewen limestone. Becraft limestone. New Scotland beds. Coeymans limestone.

These formations vary greatly in thickness from east to west and north to south. The Helderbergian strata do not occur in the western part of the State. The Oriskany sandstone overlaps westward into Ontario; but the Schoharie and Esopus are of local distribution only. The Onondaga limestone and the Hamilton and Marcellus shales are relatively widespread, as is the Genesee, or its equivalent; but the Tully and Portage are more restricted. The Chemung and particularly the Catskill are very thick near-shore and the latter in part continental deposits of the Bay of New York and its southern extension into Virginia, and they are represented farther west by the Upper Devonian shales.

Hall [397] described the "Lower Helderberg" as follows:

The Lower Helderberg group, which constitutes the more important portion of the strata from which are derived the fossils of the present volume, has been so termed from its very complete development along the base of the Helderberg Mountains, constituting, in this part of New York, an important fossiliferous group. In some parts of the Helderberg Mountains and along the Hudson River at Rondout and at Schoharie and elsewhere the lowermost beds of this group rest directly upon the Waterlime beds, which we regard as the uppermost member of the Onondaga salt group, indicated as a separate formation by reason of its economical importance and likewise characterized by certain peculiar fossils, while the marls of the Salt group are usually nonfossiliferous.

The lowest member of the Lower Helderberg series is a thin-bedded, often thinly laminated dark-blue limestone, which, from the abundance of its tentaculites, has been termed the Tentaculite limestone. Its color, texture, and composition contrast strongly with the rock below.

The second member of this group is a thin mass of limestone, consisting almost entirely of the coral Stromatopora, and constitutes a very persistent member of the group; to this succeeds a limestone charged with great numbers of the broken shells of *Pentamerus galeatus* and known as the Pentamerus limestone. This graduates above into a shaly formation, which was designated in the New York reports as the Delthyris shaly limestone, from the abundance of this genus of fossils. It is the most fossiliferous member of the group. * * * This shaly limestone, in physical character and composition, corresponds nearly with the shaly member of the Niagara group and contains numerous similar or representative forms.

To this succeeds a compact crinoidal limestone, and above this is a mass of bluish-gray limestone, charged with Brachiopoda, among which a Pentamerus similar to *P. galeatus* is so abundant that the rock has been termed Upper Pentamerus limestone.

A comparison of the species shows that the fossils of the Lower Helderberg rocks are analogous to those of the Niagara group and contain among them certain species which we regard as representative forms of the Silurian species in Europe; and we can not do otherwise than retain this series as a member of the Silurian system.

In 1874 Hall [398] published a detailed description of the distribution of the "Lower Helderberg" and its relations to the Niagara and the intervening "Onondaga salt group," with a map of the eastern United States illustrating the occurrence of the three terranes.

Schuchert [711b] quotes Hall's description and gives an account of the representatives of the Helderbergian in several States and Canada, together with an extended discussion of the faunas, from which he concludes:

With these facts there is presented a great paleontological break between the Siluric and Devonic at the top of the Cayugan group. The succumbing of the normal marine faunas of the Niagaran group is undoubtedly associated with the red gypsiferous and saliferous sediments of the Cayugan group. If the latter had a normal marine fauna instead of one of peculiar Crustacea, the continuity of life from the Niagaran to the Helderbergian would be probably complete. However, in most areas outside of New York and Ohio, there is a great hiatus between the Niagaran and the Helderbergian, which tends to make a clear and easily discoverable line for field geologists in separating the Siluric from the Lower Devonic.

* * * * * * * * *

From the foregoing summary of the Helderbergian fauna it is evident that most of the characteristic Siluric genera of trilobites, brachiopods, and crinoids are there absent. This might be expected, for, as has been seen in the previous chapter, about 2 per cent of the Helderbergian fauna are derived from the Siluric. On the other hand, in some of the trilobites, Bryozoa, and pelecypods, many of the gastropods, but more particularly in the diversified brachiopods, are met organic groups which in their culmination are characteristic of the Devonic. It can not be denied that the Helderbergian fauna has a Siluric facies, yet these types either have greater differentiation in species or the forms attain a larger size. The fact that 9 per cent of the Helderbergian fauna pass into a generally accepted Devonic horizon, the Oriskany, outweighs the evidence of a Siluric facies and specific derivatives. The writer therefore concludes that the Helderbergian has a fauna unlike the Siluric, but one in harmony with the Devonic and its position near the base of that system.

Neither of the Helderbergian zones can be regarded as the deeper-water facies of the littoral Oriskany, not only because the fauna of the latter has a more decided Devonic aspect, but also for the fact that wherever the two formations are present the Oriskany always overlies the Helderbergian. As far as known, there is no interlamination, and in New York, where the stratification is simple, there is a regular sequence. Where the older Oriskany is absent there is a slight unconformity between the Helderberg and the later Oriskany. This unconformity becomes a decided one in going from eastern to central New York, because the later Oriskany gradually comes to overlie successively the various members of the Helderbergian and finally the Cayugan.

The Oriskany sandstone is thus described by Hall:[397a]

The Oriskany sandstone everywhere succeeds to the upper members of the Lower Helderberg group and at several points extends beyond the known geographical limits of the latter. In the greater number of localities within the State of New York the transition from the upper calcareous beds of one group to the siliceous or sandy beds of the other is very abrupt, while in other instances there is an intermingling of calcareous matter in the lower beds of the sandstone. In these instances, however, as well as in others, the siliceous material appears to have been to a considerable degree in the condition of gelatinous silex, producing a rock approaching in character to hornstone; while other examples present an appearance as if the grains of silex had been softened, or agglutinated by a siliceous paste. In its more fossiliferous parts the rock is a mixture of silica and carbonate of lime, and the action of the weather, dissolving and removing the latter, leaves a grayish-brown porous mass, embracing the casts of the interior and molds of the exterior of the fossil shells. In many places the rock consists of a sandstone of nearly pure white, or graduating from white to buff-colored; in more southern localities it often presents the aspect of a siliceous limestone, not differing greatly from the succeeding limestones.

Schuchert [711c] gives the following account of the character of the Oriskany in New York:

In a general way it may be said that the Oriskany formation extends with many interruptions along the eastern and northern flanks of the Helderberg Mountains of New York. Along the northern side the Upper Oriskany only is known to be present, exceedingly variable in thickness but never more than 30 feet, diminishing in volume and resting westwardly upon the successive lower horizons of the Helderbergian and finally on the Siluric. In the region of Cayuga Lake it is sparingly present, and is practically absent west of Ontario County, the Corniferous or Onondaga then resting directly on the Salina or Waterlime. Beyond the Niagara River, to the northwest of Cayuga, in Ontario, the Oriskany reappears irregularly over a very limited area, again overlying the Salina, and is from 6 to 25 feet thick. Southerly, along the western side of the Hudson River, the Upper Oriskany is very intermittent and often but 2 or 3 feet thick. On Becraft Mountain there is an outlier of Oriskany. In Orange County the Oriskany again appears to thicken, and in the Neversink Valley the thickness is about 125 feet, and at this point it is intimately connected with the Helderbergian. In New Jersey, and particularly in the eastern Appalachian folds of Pennsylvania, the Oriskany in its lithologic character is ever changing from sandy shales, sandstones, and chert beds to coarse conglomerates. Its thickness also increases from north to south; in northeastern Pennsylvania it is from 50 to 125 feet thick, and on the Lehigh River, below Bowmans, it is fully 200 feet.

Clarke [157a] has thus stated the distribution and relations of the Helderbergian and Oriskany:

In New York the deposits constituting the earliest members of the Devonic series are, at the bottom, (1) the Helderbergian and, overlying, (2) the Oriskanian. There is a demonstrated gradation of the sediments and the faunas of the lower into the higher, and those at the summit of the Helderberg series—Port Ewen beds—carry so large a representation of Oriskany species, as shown by recent analyses, that they may be wisely regarded as indicating the passage of the earlier into the later fauna.

The Helderbergian rocks (in the Helderberg Mountain region comprising the following divisions from below upward: (1) Coeymans limestone, (2) New Scotland limestone and shale, (3) Becraft limestone) enter New York from the southeast along the New York-New Jersey line and end northward in an abrupt escarpment facing east and north in the southern angle of the present Hudson and Mohawk rivers. Of this heavy sheet of calcareous strata there is no trace in New York east of the Hudson River save two small synclinal outliers in Columbia County, Becraft Mountain and Mount Bob. As the formation progresses northward from its entry into the State its thickness increases to where it is abruptly cut off in an erect wall. The Helderberg escarpment carries in its very topography the evidence of a former wide extension on toward the east and northeast. The continuation of this formation westward in New York is notable for its rapid thinning and quick disappearance. The subdivision at the Helderberg Mountain is soon lost westward. The lower division or Coeymans limestone appears to be that extending farthest, as far as the eastern limits of Onondaga County, but the narrow east and west extent of the Helderberg sea is shown by the entire absence of the higher divisions far west of Schoharie Creek.

The Oriskany period succeeding was a time of transgression over the Helderberg deposits beneath. Then the northern coast line in western New York was broken and embayed. While calcareous deposits were formed in the deeper water of the southern reaches, the shore deposits of sand extended westward to Buffalo, in part over eroded surfaces of Siluric limestones to which the Helderbergian sediments had not extended. We have had occasion to show that from the Helderberg westward the sandy shoal-water deposits of this Oriskany time are lenses and thin sheets, often disconnected, in some places rising to considerable thicknesses of friable quartz shore sand into which the waters have rolled the organic remains of the outer sea. These lenses we conceive were separated by tongues of land dividing the embayments of the shore line. The Oriskany in our view presents in New York a twofold facies, that of the deeper littoral represented by the calcareous deposits from the Helderberg southward to Port Jervis and that of the shallow littoral from Schoharie westward; yet it is quite possible that the latter deposits are of later date than most of the former and represent the final transgression of shore sands over the sinking land of Helderbergian time.

The Oriskany sandstone is succeeded by the Esopus shale, which is described by Darton.[227a] The Esopus is said to be "in greater part a fine-grained arenaceous deposit of dark-gray color."

About Schoharie and westward to its termination it is a moderately hard sandy shale varying in color from dark gray or buff to light olive, but east and south with increasing thickness the color becomes darker, the texture of the rock is harder, and slaty cleavage is general. * * * The formation has a thickness of 110 feet at Clarksville.

The Ulsterian of the New York State Survey comprises, in addition to the Esopus shale, a locally developed but not extensive formation known as the Schoharie grit and the widespread Onondaga limestone.

Darton [227] describes these formations, together with others of the Helderberg Mountains.

The Schoharie grit is a local deposit which is characteristically developed near Schoharie and extends through Schoharie and Albany counties to Ulster County. It is a very arenaceous limestone which merges into the Onondaga above but is more sharply separated from the underlying formation. It is locally absent and the Onondaga then rests on the Esopus shale.

The Onondaga limestone, as the term has been applied since 1894, comprises a lower and an upper member called by Hall[396a] "Onondaga" and "Corniferous," respectively, and covers the original application of the descriptive name "Corniferous" of Eaton. The extension of the geographic term Onondaga to the whole was made by Hall.[399] In 1843 Hall[396] described the lower member thus:

Throughout the greater part of the Fourth district the impure limestone terminating the Onondaga salt group is succeeded by the Onondaga limestone, with usually the intervention of a few inches of sandstone before noticed, which in ordinary observations might be entirely overlooked. There is also sometimes a thin band of nonfossiliferous bluish-gray limestone. The range of this formation is in an undulating line having a general east and west direction throughout the district, extending eastward to the Hudson River and westward far beyond the Niagara into Canada. Its northern outline is everywhere well marked, forming together with the next succeeding rock the second great limestone terrace, which rises to the south of the valley marking the range of the Onondaga salt group.

* * * * * * * * *

This rock is subordinate in thickness and continuation to the next succeeding mass, and was not separated from that by Prof. Eaton. Indeed for all practical purposes they may be regarded as one formation, the lower part, where fully developed, being marked by an assemblage of fossils which sufficiently distinguish it.

Its usual characters in the Fourth district are a light-gray color often approaching to white, more or less crystalline in structure, and containing numerous fossils. In many instances this mass, like the encrinal limestone at Lockport, seems almost entirely composed of broken and comminuted fragments of crinoidea and corals, sometimes extremely attenuated, and at other times fragments of large size are preserved.

* * * * * * * * *

Sometimes the mass is fine grained, more compact in texture, and of a darker color; when it has this character, few fossil remains are detected in it. The layers are usually separated by thin seams of greenish shale, which often divide blocks of the stone into wedge-form and irregular laminæ.

* * * * * * * * *

The Onondaga limestone in many places contains nodules or thin interrupted layers of chert or hornstone (usually called flint), and sometimes the Favosites are partially dissolved and the cavities lined with silex in the form of chert, chalcedony, or crystals of quartz. The alimentary canal of the crinoidal columns is frequently lined with crystals of quartz, and the chambers of Orthocera, as well as the cavities of other shells, often present the same appearances.

Its characteristic features, when well developed, and which are always much more prominent than the lithological or mineral characters, are the presence of Cyathophylli, Favosites, and fragments of crinoidal columns. These always accompany it in situations where it is sufficiently developed to be of much importance either in economical consideration or geological interest.

Regarding the upper member of the Onondaga limestone Hall[396b] says:

This rock is one of the most persistent of any in the series, and at the same time maintains a uniformity in lithological character and in the occurrence of certain fossils scarcely possessed by any other. It is known to extend from the Helderberg Mountains, on the Hudson River, to the Niagara River, and thence far into Canada.

* * * * * * * * *

Under the Corniferous limerock of Prof. Eaton were included this rock and the Onondaga limestone of the reports, the latter constituting his "Ceratial rock," so named from the abundance of Cyathophylli which it contains. The name Corniferous is continued as being peculiarly applicable to this rock, though the other limestones contain the same mineral. This is the highest limestone of importance in the series, which continues throughout the district.

In lithological character this rock varies to a considerable degree in its range through the district, being at the eastern extremity a fine-grained, compact limestone, scarcely presenting any crystalline grains. Its color varies from a light grayish blue to dark blue or black, and it is sometimes even of a light-gray or drab color. It contains numerous nodules of hornstone and the strata are sometimes separated by irregular layers of the same. In other localities these layers of hornstone increase in number and thickness to the almost entire exclusion of calcareous matter, and they then present a very harsh outline. * * *

At the eastern end of the district the hornstone is intermingled and interstratified with the calcareous strata, the whole very dark colored.

* * * * * * * * *

The rock for the greater part seems to have been composed of finely levigated calcareous mud, probably derived from the destruction of corals at distinct points, while at the same time siliceous matter often formed no inferior part in its production. The characters which distinguish the last rock, viz, the presence of corals and Crinoidea, are rare in this and form no essential feature. Fossils are generally few and for the most part consist of shells. Some portions, it is true, though of small extent, appear as if they may have resulted from the destruction of corals.

A later account of the Onondaga is given by Grabau.[381]

The Erian of the New York State Survey, which comprises the Marcellus and Hamilton shales, has been the object of extensive investigations. Hall[396c] thus described the Marcellus:

This rock admits of two divisions. The lower is very black, slaty, and bituminous and contains iron pyrites in great profusion; some portions are calcareous, and it is always marked by one or more courses of concretions or septaria, which are often very large. This division terminates upward by a thin band of limestone, above which the shale is more fissile, and gradually passes from black to an olive or dark-slate color.

In general characters the lower part resembles the Utica slate and is not distinguishable from the Genesee slate in its general aspect; it is, therefore, more properly a slate than a shale, if the distinction is to be continued. For practical purposes there is little advantage in separating the upper division of this shale from the Hamilton group. The line of separation is nowhere well marked, the change in lithological character being gradual, while some of the fossils continue from one to the other.

The finely levigated mud composing this rock indicates a period of great tranquillity in the waters, moved probably only by currents sufficient to transport the materials over the wide extent we find them. The nature and condition of the fossils also indicate a quiescent period, for their forms are among the most delicate and their parts are usually preserved in the greatest perfection. In some instances, however, from their great numbers, they are packed closely together and fracture on the separation of the laminæ.

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In many places this rock contains so much bitumen as to give out flame when thrown into a fire of hot coals.

Under the title "Hamilton group" Hall[396d] describes the middle Devonian:

This group consists of several members which may be considered distinct, but which, when viewed in connection, present so many features in common that they are all recognized as the products of one period, and thus constitute one great group. In the Fourth district, the only changes recognized in lithological products are from shaly to calcareous, with occasional thin beds of limestone, and more rarely of sandy shale.

The group, as a whole, presents an immense development of dull olive or bluish-gray calcareous shales, which, on weathering, assume a light-gray or ashen tint; some portions become brownish on exposure, but these are of small thickness in this district. At a few points the shale becomes darker or black and exhibits a tendency to slaty structure, but as a general character the cleavage is irregular and oblique to the planes of stratification. On weathering, where the edges are exposed, there is manifested a slight tendency to slaty cleavage.

From the wide and even distribution of the materials of this group, it was evidently produced during a period of great tranquillity, when the finely levigated mud was transported over wide areas by gentle oceanic currents. The great profusion and variety of organic forms proves also the quiescent condition of the ocean, which, together with the slightly calcareous nature of the mud, favored the growth and distribution of the Testacea.

The upper part of this group, in the Fourth district, bears a very close analogy in its lithological nature to the shale of the Niagara group, and in abundance of organic remains it is even more prolific. The forms of the latter are, however, of entirely different species, though corals and shells of similar genera abound, and trilobites of the same and different genera.

Concretions or septaria, in well-defined and often fantastic forms, are common in every part of this group. In many instances the calcareous matter has concreted around some organic body, or a nodule of iron pyrites seems to have been the center of attraction. In such instances we often find numerous fossils embedded in them or attached to their outer surface. The greater number, however, are well-defined spheroidal masses, with or without seams of crystalline matter and not containing any organic body. Others, and particularly in the lower part of the shale, are small, spherical or elongated, and with a small perforation through their center, in the manner of the common nodules or other concretionary forms in recent clay beds.

Organic forms abound throughout the group, but they vary somewhat in the different parts. In the lower division the most abundant are those of Orthis, Atrypa, and Strophomena, with some spiral univalves; while above this portion great numbers of Avicula, Cypricardia, Nucula, and other similar forms abound, with fewer of the genera Orthis, Delthyris, etc. In the next division Delthyris, Strophomena, and Atrypa abound, to the almost entire exclusion of the forms before mentioned. In the same situation with these we find numerous species of corals; Cyathophylli, Favosites, and other forms are abundant, while fragments of crinoidal columns are everywhere scattered through the mass or, spread evenly over the surface, form thin layers of themselves. Many of the species of this division are discontinued and their place supplied by others of the same genera in the higher part of the group. * * *

Although this group is so widely spread and evenly distributed and of uniform character over the western part of the State, still at its eastern extremity the lithological character is widely different. The shales are more or less arenaceous and some parts are well-marked sandstone. The proportion of siliceous and argillaceous earth is nearly reversed from what it is in the same rocks farther west. The mass varies from sandy shale to shaly sandstone and even tolerably pure sandstone. This character gradually changes to the westward, the sand diminishing and the clay increasing. The features presented by this group at its two extremes and along its whole length offer one of the most instructive exhibitions of the varying character of mechanical deposits. The facts prove the origin of the materials to have been at the east or southeast. The force of the current which drifted them into the ocean was sufficient only to carry onward the coarser particles to a certain distance, where they were deposited. The finely levigated mud was carried beyond this point, being floated by less force than the sand. Some portion of the clay was deposited with the sand toward the central part of the State, and but little of the latter extended beyond this point. Finally the current became more gentle and the clay was deposited to a certain extent, beyond which the power of the current was insufficient to carry even this material, and the deposit consequently thinned out in that direction. * * *

This change in the nature of the materials is accompanied by an equally marked change in the fossils embedded in the different parts of the group. In the eastern part of the State Avicula and Cypricardia, with Nucula, etc., prevail in immense numbers, while at the extreme western margin, though in precisely the same position, they are of the rarest occurrence, while numerous forms of Delthyris and Atrypa abound.

The above-quoted descriptions by Hall apply particularly to the Fourth district of the early Geological Survey of the State—that is. the region south of Lake

Ontario and west of Cayuga Lake. Similar accounts with local variations are given in the reports of Vanuxem [829] and Mather.[578]

With reference to the Hamilton as exposed on the southeastern shore of Lake Erie, Grabau [376] may be consulted. He gave the following classification:

> The following formations are exhibited in the sections:
>
> Chemung group (Portage stage):
> - Naples shales.
> - Genesee slate.
>
> Hamilton group:
> - Hamilton stage:
>   - Moscow or upper shales.
>   - Encrinal limestone.
>   - Hamilton or lower shales.
> - Marcellus stage:
>   - Transition shales.
>   - Marcellus shales.

The Hamilton of Cayuga Lake, New York, was made the subject of a special study with reference to its fauna by Cleland,[160] who states:

> The Hamilton formation, including the Marcellus shales, is in this region, as shown by the Ithaca well section, 1,224 feet thick. It is bounded above by the Tully and below by the Onondaga (Corniferous) limestone.

Cleland divided the Hamilton of the Cayuga section into 25 faunal zones, each of which is described in detail in his report, together with the composition of the faunules.

Williams's later studies in classification[935, 935a] led him to the following arrangement of the Ithaca section:

Revised classification and nomenclature of the section passing through Ithaca, N. Y.

Series.	Formation.	Members and lentils.	Thickness (feet).
Erie division or series of Vanuxem.	Chemung (shale and sandstone)	Fall Creek conglomerate lentil Wellsburg sandstone member Cayuta shale member	0–10 600–650 600
	Nunda (shale and flagstone).	Enfield shale member Ithaca shale member Sherburne flagstone member	550–800 [a] 80–460 188–260
	Genesee shale.		125
	Tully limestone.		10–30
	Hamilton shale.		1,035
	Marcellus shale.		125
	Onondaga limestone.		125
	Oriskany sandstone.		0–4

[a] In the chart as published in Science (vol. 24, p. 366) this figure is 300 feet.

It is difficult to follow any description of the Middle and Upper Devonian of New York without a knowledge of the conditions which have led to different classifications by several geologists for sections occurring in the eastern or western parts of the State. The strata are chiefly shale, sandy shale, shaly sandstone, or sandstone, which in any one section may present distinctly recognizable differences but which do not retain the same characters or distinctions from place to place. The faunas also vary in vertical and horizontal distribution and are to some extent recurrent. The divisions particularly involved in this vaguely classified series are those above the Hamilton, namely, the Tully limestone, Genesee shale, Portage group, and Chemung formation.

The Tully limestone was well described by Hall[396e] and has been made the subject of a special paleontologic and correlative study by Williams,[931] who states:

The Tully limestone is a zone of argillaceous limestone, ranging from a few feet to over 50 feet in thickness, the outcrop of which crosses the middle counties of New York State from Ontario to Chenango counties but is not clearly recognized in the sections south of New York. In New York the outcrop is lost to the eastward and to the westward, not so much by thinning out as by a decrease, until unrecognizable, of the calcareous elements, and a failure of the peculiar species. In the central part of its outcrop this limestone appears at the top of the Hamilton formation, which consists of a series several hundred feet thick of soft shales, with a few more or less calcareous zones; and it is followed immediately by a black shale which gradually loses itself by alternate oscillation in a gray, more or less arenaceous shale and argillaceous sandstone, known in New York as the Genesee shale and the Ithaca group, and the more sandy portion above as the Portage group. In the region where the Tully limestone is well developed the black shales contain a fauna corresponding to that of the *Cardiola retrostriata* zone of Europe, and there is in the sandy shales above a fauna rich in Goniatites where best developed. * * *

For this study the more important species in the Tully limestone of New York are the brachiopods.[a] * * * Besides these are species belonging to other orders.[a]

* * * * * * * * *

I have examined a large amount of material from genuine Tully limestone, and also considerable more doubtfully referred to that horizon. In most places the Hamilton rocks are richly fossiliferous immediately under the Tully limestone. These former, though mainly shales, contain limestone beds which in hand specimens are rarely distinguishable from the genuine Tully above; but the characteristic species of the Tully are wanting and characteristic Hamilton species are abundant in them. Much confusion has thus arisen, and the Tully fauna, as reported in lists,[b] is very imperfect by the inclusion of many species which do not belong in the limestone.

There are about 50 genuine Tully limestone species. Of these less than 25 are at all common, and the other 25 are Hamilton species which do not appear above the Tully, or are unique forms of Hamilton types. Of the more or less common Tully forms fully one-half are also clearly Hamilton species or their descendants, or are unique forms.

The change in fauna which begins with the Tully limestone and makes the characteristic upper Devonian fauna includes the appearance in New York of at least ten or a dozen species which have closer affinities with species of the middle Devonian in Europe than with any previous species in the New York series.

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[a] For lists see the work cited.—B. W.

[b] See list furnished by S. G. Williams (Sixth Ann. Rept. State Geologist, Albany, 1887, p. 26). A considerable number of the species reported in this list I have examined in the collection made by the author of the list and find them and the rock containing them indistinguishable from specimens obtained at the same locality below the Tully limestone layers filled with Hamilton species but never in the Tully limestone itself.

Regarding the strata above the Tully limestone, Hall's remarks[396f] "preliminary to the following rocks and groups" may still be read to advantage:

In the Fourth district the Tully limestone terminates all those deposits in which calcareous matter forms an essential part. In all the higher rocks this material, when existing, is the result of the destruction of organic bodies; and in the few instances where it appears the origin is unquestionable, for the fossils still retain so much of their original form as to be readily recognized. This rock forms a strong line of demarcation not only in this respect, but also as regards fossils, very few forms which are known below continuing into the rocks above. The lithological character of the products above this rock are throughout more or less similar, while they differ from those below; and, with a single exception, lithological character is a sufficient guide for distinguishing the different strata.

This contrast of character is more marked toward the western extremity of the district than it is farther east, and finally, on its eastern extreme, there is a greater similarity in the lithological features. This change is likewise attended with the occurrence of some of the fossils of the lower group in the rocks of the higher, the nature of the two being very similar, although the Tully limestone is in its greatest force; while at the west, where it does not exist, no such mingling of the fossils is known.

At Ithaca, for example, where we are far above the Tully limestone and where the rocks are well marked by an abundance of fossils peculiar to themselves, still we find the *Microdon bellastriata*, the *Modiola concentrica*, and some others, and I have even detected the *Calymene bufo* and *Dipleura dekayi* in the same association. Still farther east there is a greater mingling of species of the lower rocks with the upper and a nearer approach constantly in materials of composition. These circumstances, in the eastern portion of the State, render it difficult to point out the line of demarcation between the lower and higher rocks of this division.

At the eastern extremity of the State, also, the Tully limestone does not exist, and therefore that guide to the line of division between the lower and higher groups is wanting. The absence of this rock and the similarity of lithological products, as well as the mingling of the organic remains of the lower rocks, render it impossible to make a distinction in groups with the same degree of satisfaction as farther west. By reference to the section along the Genesee River it will be seen that the Genesee slate, a black carbonaceous mass, is succeeded by shale of a deep-green color and well defined above. This is succeeded by flagstones, which alternate with shale of a less deep green color and often with black shale. These again are followed by a greater proportion of sandstone, often thick bedded, and presenting far less of the characters of those below.

These rocks are well exposed on the Genesee River, and there can be no possible room for error in their examination. The whole thickness here exposed is scarcely less than 1,000 feet; and throughout this thickness there is as yet no fossil known which occurs in the Chemung group to the south and above these rocks. These circumstances led to the separation of this portion of the system and the adoption of Portage or Nunda as the locality designating the group. Farther east the green shale (Cashaqua shale) is often darker in color and more sandy, becoming largely interstratified with flagstones which have much the character of those which lie above it on the Genesee, except in the absence of a peculiar species of Fucoides. At the same time the small Avicula, which is so abundant in the Genesee slate, is almost equally abundant in the green shale and flagstones at Penn Yan.

Again, when we go westward as far as Lake Erie, we find that instead of the flagstones succeeding the green shale, as on the Genesee, a black shale is the first mass above. This soon gives place to green shale, and we have alternations of green and black shale for many hundred feet, before coming to the thin-bedded sandstones.

Proceeding with the description of the rocks, Hall says regarding the Genesee shale:

Superimposed upon the Tully limestone, or, in its absence, resting upon the Moscow shale, we find a great development of argillaceous fissile black slate. Where its edges only are exposed it withstands the weather for a great length of time and often presents mural banks in the ravines, river courses, and upon the shores of lakes. Where the surface of the strata are exposed it rapidly exfoliates in thin even laminæ. On disintegration, it is often stained with iron, owing to decomposition of pyrites; but in many instances and the greater number of localities it retains its deep black color. In this it is distinguished from some beds of black slate in higher situations, which always become stained with hydrate of iron on their edges and upon the surface of the laminæ.

In color and general characters it greatly resembles the Marcellus shale; and aside from position, it would be difficult to distinguish the two in the absence of fossils. * * *

In lithological character this rock is entirely uniform throughout the district, presenting itself upon the margin of Cayuga Lake and upon Lake Erie, having the same deep black color and laminated slaty structure. Neither is there any change in its organic remains; the same forms, and many of them almost equally abundant, are found throughout its entire extent. The greater portion of this rock is destitute of fossil remains, and it is only toward the upper part that they occur.

Under the heading "Portage or Nunda group" Hall[396g] states:

This group presents an extensive development of shale, shales and flagstones, and finally some thick-bedded sandstone toward its upper part. Like all the other mechanical deposits of the system, as they appear in New York, it is extremely variable in character at different and distant points. * * *

From its superior development along the banks of the Genesee River in the district formerly included in the town of Nunda, now Portage, it has received that name to distinguish it from the higher rocks, which possess some differences in lithological characters but a more striking dissimilarity in organic remains.

Hall distinguished the Cashaqua shale, Gardeau shale and flagstones, and Portage sandstone as formations of his "Portage or Nunda group" and described their characters in detail in the chapter devoted to that group. Clarke[153] has thus summarized Hall's account:

The succession of strata exhibited in a series of beautiful exposures along the course of the Genesee River was described in some detail by Prof. James Hall in the fourth "Annual report of the survey of the fourth geological district of New York" (1840).

The beds which lie directly above what was there termed the "upper black shale" (thus contradistinguished from the "lower black shale," the former now known as the Genesee slate and the latter as the Marcellus shale) were designated as the Cashaqua shales, taking their name from the creek entering the Genesee River from the east at Mount Morris. These are olive-green or gray clay shales alternating with bituminous shaly beds and with interbedded thin shales, sandstones, and flags. Upward in the rock series there is in general a gradual increase in the amount of arenaceous sediment, the sands and flags becoming increasingly predominant and the shale beds themselves more arenaceous. While the transition to these beds from those below is in all respects an easy one, yet there is a possibility of distinguishing them in the mass, and hence the upper beds were termed the "Gardeau or Lower Fucoidal group;" the adjective term referring to the abundance of the so-called *Fucoides graphica* over the lower surfaces of the flags. A thick mass of heavy-bedded greenish or gray feldspathic and quartz sandstones above the Gardeau flags, representing the culmination of arenaceous sedimentation of this cycle, was termed the "Portage or Upper Fucoidal group," many of the layers containing vertical annelidan borings filled with mud, which have commonly passed under the name of *Fucoides verticalis*.

In recognition of the fact that the distinction thus instituted in parts of this series would be difficult of application in actual practice, the same author, in 1843, applied the term "Portage or Nunda group" to the entire series lying between the uppermost beds of the Genesee slate and the upper limit of the heavy beds of Portage sandstones. Since that date not only have the rock strata thus delimited in these western sections of New York been known in geologic literature as the "Portage group," but this term has been also, and properly, applied to all formations in whatever sections of this State and bearing whatever faunas, between the horizon of the Genesee slate beneath and the earliest strata characterized by the incoming Chemung fauna above.

Recent investigations indicate that the historical delimitation of the Portage group in the typical Genesee section does not express the complete upward range of the fauna of this group. In the Genesee Valley the Portage sandstones are overlain by sandy shales and thin sandstones from 100 to 200 feet in thickness and in lithologic character, not unlike the Gardeau layers beneath; and through these beds the Naples or Intumescens fauna ranges, with slight accretions. Strictly speaking, this fauna is mainly confined to the more argillaceous layers, while toward the top a Chemung fauna appears in the more arenaceous strata. But this alternation concerns only the upper portion of these beds. To this series of strata representing the prolonged existence of the Naples fauna the term Wiscoy shales and sands has been applied. In protracting, upon the evidence of the contained fossils, the scope of the Portage group to include these beds, we shall not appear to violate propriety, for they did not escape the observation of Prof. Hall, who at the close of his description of the Portage group says (1843, p. 248): "The Portage sandstone is succeeded by olive shaly sandstone and shale and this by black micaceous slaty shale with septaria; to this follow shales and coarse sandstones with fossils of the Chemung group."

In the pages succeeding this quotation and in the second part of his contribution on the Naples fauna[154] Clarke describes and illustrates with maps the stratigraphy, paleontology, and geography of the later Devonian of New York.

The "Ithaca group" was early distinguished by Hall, but later [396h] included by him in the Chemung in the following terms:

In the annual reports this name was adopted for designating the highly fossiliferous shales and shaly sandstones, so well developed at the inclined plane of the railroad and on the Cascadilla and Fall Creeks, near Ithaca. Subsequently an examination of the highly fossiliferous strata along the Chemung River, and particularly in Chemung County, resulted in the adoption of that name as designating this portion of the system.

Succeeding examinations satisfied me of the identity of the formations at Ithaca with those of Chemung, and this opinion was advanced in the annual report of 1841.

The reasons for merging the two in one were stated to be the impossibility of identifying them as distinct by any characteristic fossils. The same opinion is still entertained, after a full examination of the strata and a comparison of the fossils collected here and elsewhere in well-authenticated localities of the Chemung. There is scarcely a fossil known at Ithaca which is not found at numerous other localities; though it is true, not only of Ithaca but of many other places, that some of the fossils are confined to the single locality in which they occur.

By careful and extended examination the Chemung group may be subdivided locally where it is most perfectly developed, but these divisions will hold good only over small districts of country, position and lithological character having had much effect in producing these distinctions dependent on fossils.

Later work has not sustained the identification of Ithaca with Chemung. Williams [930a] first showed that Ithaca and Portage are equivalent. He said:

Although the faunas [of the Ithaca and Chemung] are very similar, there can be no doubt that along the present meridian they represent two distinct geological stages. That they blended in some measure farther east may be possible, in the same way that it is probable that on going westward the Marcellus and Genesee stages blended.

Although I do not know that the Ithaca fauna is an early stage of the Chemung fauna, I am persuaded that the two may be readily distinguished by their fossils.

That the typical Chemung fauna is thus distinct from that of the Ithaca group and characteristic of a later stage, is shown, paleontologically, by the following considerations:

The genera Spirifera, Orthis, Strophodonta, and Productella are common to both faunas, and are represented by numerous individuals at almost any fossiliferous exposures of either group. But for each genus the species are different. Spirifera is represented in the Ithaca group by *Sp. mesocostalis* var. *acuminata* and the first variety of *Sp. mesostrialis.*

The Chemung group is characterized by *Sp. disjuncta, Sp. mesocostalis* 2d var., a large, coarsely plicated, broad form, and *Sp. mesostrialis* 2d var., the wide mucronate form, neither of which is seen in the Ithaca group.

Orthis, in the Ithaca group, is *O. impressa* of the narrow variety, rarely wider than long.

In the Chemung group *O. impressa* is the second variety; wide form, with broad sinus; also there are *O. tioga* and *O. carinata,* neither of which is known in the Ithaca group.

The Strophodontas of the Ithaca group are *Str. mucronata,* and the closely allied variety of *Str. perplana* var. *nervosa.*

In the Chemung group *Str. cayuta* is the prevailing form, and a coarser, more irregular form of *Str. perplana* var. *nervosa.*

Str. demissa is reported from both groups but is extremely rare in either.

Productella is represented in the Ithaca group by *P. speciosa* and a small form I have identified as *P. speciosa,* small variety. In the Chemung it is *P. lachrymosa* and *P. costatula.*

Besides these genera, Streptorhynchus is common in the Chemung group, and it is extremely rare, if it appear at all, in the Ithaca group.

Ambocœlia umbonata var. *gregaria* is abundant in some stages of the Chemung group but is rarely ever seen at Ithaca. The latter two forms are seen below the Ithaca group, hence their absence there is evidence of modified fauna rather than extinction.

These differences in the prevailing varietal or specific characters of common genera, which (as genera) are known to be common for a considerable range below and above the stages under consideration, I take to be more reliable evidence of actual difference in horizon than would be any number of distinct species of different genera in the two faunas.

In the study of the Devonian of New York to which the bulletin just cited was a first contribution, Williams has developed essential general principles regarding the geographic and chronologic relations of faunas. The principles and the discussion of the evidence do not pertain to this account of stratigraphy, but the application to the relations in New York is appropriate. Under the heading "Faunal dissection of the Devonian," Williams [934] expresses the results of special studies as follows:

Previous work in correlation had been conducted on the fundamental assumption that identity of fossils is sufficient evidence of identity of the formations containing them. In other words, it had been assumed that for purposes of classification in the time scale the formation and the fauna are identical. The way in which fossils have been customarily labeled has prevented a testing of the truth of this assumption. If there be any distinction in time value between the formation and its fauna, it is difficult to demonstrate it so long as the only name and designation of the fauna is that of the formation in which it was originally found.

If the "Chemung formation" be extended below the fossiliferous strata of Ithaca, as it was in the literature before 1880, then the fossils in the "Ithaca group" belong to the Chemung fauna. When the Ithaca fauna was dissected and it was shown that the species were not those of the Chemung fauna above but were rather modified successors of the Hamilton fauna, it became clear that, faunally, the Ithaca group was not a part of the Chemung formation. Nevertheless, the term "Chemung" was still retained in general literature for the "period" which included both the "Ithaca" and "Chemung" epochs, so that the real issue was still obscured by the imperfection of the nomenclature which used "Chemung" with two meanings.

The terms "Portage," "Hamilton," "Trenton," and "Niagara" are also applied in this double sense in the classification of formations, making it almost impossible to frame a statement which will express the thought that formations and faunas are discriminated upon different bases and that their limitations may not be identical.

In order to demonstrate the actual facts in the case, it has been found necessary to collect a large number of statistics regarding the actual faunal contents of each zone in some well-known formation, and also regarding the separate faunules taken from outcrops of the same formation over an extended area.

* * * * * * * * *

It is now possible to state that the Tropidoleptus fauna of the Hamilton formation persists in its integrity above the top of the Hamilton formation; that in eastern New York it occupies a place in the column which is occupied in central New York by the Ithaca formation and in the Genesee Valley by a portion of the Portage formation.

This state of things has been already demonstrated in respect to the position of the Catskill formation in the geological column. But the significance of the facts was obscured in that case by the fact that the Catskill as a pure formation is distinguished by its red sedimentation, which, therefore, was easily discerned in the field by the stratigraphical geologist; but the fossil evidence of the Chemung, though constantly annoying him, had not in his mind the distinct stratigraphical significance which he attached to the color ingredient in the Catskill. The evidence of the Catskill was clear, and if the fossils told another story, so much the worse for the fossils. This was his attitude.

In the present case the faunas are of the same kind, made up of marine invertebrate fossils. They are distinctly marine in all cases, and the demonstration may be expressed in mathematical values. The statistics are sufficient and are gathered from a field that is wide enough to make possible the comparison of the faunules in terms of composition, frequency, and abundance. The variation of species, though not yet demonstrated by the statistics, is strongly indicated by the increasing uncertainty in identification of the species in one direction, while the species are always positively identified in the central region. Great promises of future discoveries in this direction are offered by the facts, and in the future we may expect to see the laws of variation associated with transgression of the faunas clearly demonstrated.

Enough evidence is already in sight to show that at any particular point of time, as represented by a common geological horizon or zone in a given formation, the inhabitants of one sea differed in species within a relatively small distance (50 miles); and within 200 miles the faunas may be entirely different, having not a single species in common

The facts also give clear evidence of the shifting of the fauna with the accumulation of the sediments, so that the center of distribution of each fauna changes as we ascend in the formation. The evidence points to this shifting of the total fauna as the occasion of rapid modification and variation of the species, and the inference is drawn that great changes of conditions were coincident with great shiftings of the fauna. During the prevalence of a fauna in a common center of distribution very little evolution took place for long periods of time, as measured by thickness of sediments, but slight shifting in the geographical position of the fauna is coincident with the appearance of new varieties and, in general, with disturbance of the faunal equilibrium.

The work of dissecting the contents of a fauna into its constituent faunules and then of the analysis of these faunules into their specific composition was begun at Ithaca, in the midst of the abundant Devonian fossils of the formations outcropping in that region. The first attempts to define the separate faunules and to apply names to them were imperfect on account of the absence then of any knowledge as to the range, distribution, and relative abundance or rarity of the component species. These statistics were gathered as the investigations progressed. Although those first attempts at classification on the new basis are now superseded by classification based on the full appreciation of the laws of shifting of faunas, the record of the steps by which the progress has been made will indicate how from the study of conspicuous local phenomena broad general laws have been developed.

Williams enumerates the several classifications developed for the Upper Devonian by the special faunal studies, and finally says:

Revising this classification now in the light of the fuller exhibition of the facts, some of the distinctions made in 1885 are believed to be too refined and local for perpetuation in a general classification, but a few of the points then made may be adopted for general use in discussing the faunas of the whole continent and in comparison with the faunas of the world.

The fauna of the typical Hamilton formation (A) may be appropriately called the *Tropidoleptus carinatus* fauna. That species is more characteristic of the fauna as it appears in its purity in the eastern New York province than is *Spirifer* (*mucronatus*) *pennatus* Atwater.

The second fauna, of the Black shales (B), may be appropriately called the *Lingula spatulata* fauna, as that species is characteristic of it far and wide when in its purity, is rarely entirely absent, and may be found, if diligently searched for, in a typical black Devonian shale almost anywhere in the interior continental basin.

The third fauna, of the Portage shales (C), may be called the *Cardiola speciosa* fauna. Although, as Hall has shown, this is not a Cardiola, as strictly interpreted, and the name Glyptocardia was proposed as a new generic name in 1885 to take its place, the fact that in Europe as well as in this country this generic name has been applied to this species and its European representative makes it not inappropriate as a name for the fauna. As Hall observed in discussing this species (*Glyptocardia* (*Cardiola*) *speciosa* Hall): "It is probably identical with the *Cardiola retrostriata* (von Buch) of various authors, and with *Cardium palmatum* of Goldfuss. Its citation by numerous authors shows its wide distribution in Europe."

The fourth fauna of the list (D)—that of the Chemung formation of the east—is the *Spirifer disjunctus* fauna. The species *Spirifer disjunctus* is undoubtedly identical, specifically, with the form which is more commonly called *Spirifer verneuili* by European geologists. There are several varieties of it which are present in some regions in which the typical form *Sp. disjunctus* is wanting.

Regarding the Chemung, Hall [396i] said in part:

This group consists of a highly fossiliferous series of shales and thin-bedded sandstones, sometimes in well-defined and distinct courses, and an infinite variety resulting from the admixture of the two ingredients. Except in a few localities, there is no very strongly marked line of division between this group and the one below. The distinction consists in the presence of numerous fossils and the coarser-grained sandstones, which are usually more impure from argillaceous admixture than those below. Its lithological characters, however, are variable; and though well marked across a single line of section from north to south, still another at a short distance east or west of this presents considerable variation.

These rocks, however, can everywhere be described as a series of thin-bedded sandstones or flagstones with intervening shales, and frequently beds of impure limestone resulting from the aggregation of organic remains. The whole series weathers to a brownish olive, and even the deeper green of the shales assumes this hue.

The shales vary in color from a deep black to olive and green, with every grade and mixture of these. The sandstones are often brownish gray or olive, and sometimes light gray. More generally, however, there is a tinge of green or olive pervading these strata. Toward the upper part of the group, in many places, there is a tendency to conglomerate; and in a few localities the mass becomes a well-characterized puddingstone, still retaining the fossils of the shales and sandstones. This conglomerate nowhere attains sufficient thickness or importance to merit a distinct description, but in hasty observations it may sometimes lead to erroneous inferences, since it resembles in many respects the distinct and well-defined conglomerate which rests upon this group in the western part of the State, but which is totally distinct from the same.

Many of the shaly sandstones and shales of this group are highly micaceous, and toward the upper part of the whole the shales are reddish, coarse, and fissile, with much mica in small glimmering scales. There is also in these shales a slight change in the character of the prevailing organic forms.

Two observers, Prosser and Williams, have specially studied the Chemung and also the earlier Devonian. Prosser [643,644] described in great detail the sections of the strata in south central and eastern New York, and in his later report he concludes: [644a]

Succeeding the Tully limestone and Genesee slate, or farther east, where these formations have disappeared, the Hamilton formation, is a mass of thin bluish sandstones and smooth shales of Portage age, for which Vanuxem proposed the name "Sherburne flagstone," which has been adopted and used as the name for the formation. It has a thickness of 250 feet in the Chenango Valley and may be readily traced westward to the meridian of Cayuga Lake, west of which Prof. J. M. Clarke has shown that it gradually passes into the Naples beds. Eastward from the Chenango Valley the Sherburne formation crosses Chenango, Otsego, and Schoharie counties, entering Albany County, where it turns south-southwesterly, and apparently extends to the Delaware River crossing Greene, Ulster, Sullivan, and Orange counties. Where the Sherburne formation is separated from the Hamilton by the Tully limestone and Genesee slate, fossils are comparatively rare in it, but to the east of the Chenango Valley, in Otsego and Schoharie counties, they are more common and constitute a modified Hamilton fauna. In eastern New York across Greene and Ulster counties the upper part of the flagstones or "North River blue stone" is apparently in the Sherburne formation but contains scarcely any fossils except occasionally a few species of plants.

Above the Sherburne is the Ithaca formation, which has a thickness of 500 feet in the Chenango Valley and extends from the vicinity of Keuka Lake, where it has been shown by Prof. Clarke that the "Portage or Naples fauna prevails largely to the exclusion of representatives of the Ithaca fauna," [a] eastward across Schuyler, Tompkins, Cortland, Chenango, Otsego, and Schoharie counties. In eastern New York across Albany, Greene, Ulster, and Sullivan counties the physical conditions which existed during the deposition of the Oneonta and Catskill formations appear to have also prevailed during Ithaca time and perhaps they began in the Sherburne, so that there is very little evidence of the Ithaca fauna, the fossiliferous bluish and grayish shales of the more western counties being replaced by the unfossiliferous red and greenish shales and sandstones. In Orange County and northeastern Pennsylvania there is some representation of the Ithaca fauna, the reds appearing later as one follows this series to the southwest. Prof. Clarke has clearly shown that the Ithaca fauna in the Chenango Valley is composed of "a more abundant representation of unmodified Hamilton species" than in the Ithaca region, [b] which is also true to the east of the Chenango Valley, as demonstrated by the numerous lists of fossils given in this report.

From the Chenango Valley eastward the Ithaca is capped by the Oneonta formation, which is composed of red and green shales, reddish sandstones, and coarse-grained grayish to greenish-

[a] Fifteenth Ann. Rept. New York State Geologist, p. 81 and "Geological map showing the distribution of the Portage group."

[b] Idem, pp. 46–63.

gray sandstones. These rocks are nearly unfossiliferous, containing only an occasional specimen of Archæopteris and *Amnigenia catskillensis* (Van.) Hall. The formation has a thickness of 550 feet in the Chenango Valley and as the physical conditions under which the Oneonta was deposited appeared earlier to the eastward, it gradually thickens in that direction till in Albany and Greene counties it completely replaces the Ithaca formation.

The Chemung formation east of the Susquehanna River rapidly thins to the eastward on account of the earlier appearance of the physical conditions which prevailed during the deposition of the Catskill formation, so that the lithologic characters of the Chemung are gradually replaced by those of the Catskill, and as this change takes place the Chemung fauna disappears till the farthest east it was noted was near Spring Lake, northwest of Delhi, where a small Chemung faunule occurs above red shales. Search in the rocks occurring at the horizon of the Chemung formation east of the Delaware River was not rewarded with any fossils, and the lithologic appearance of these rocks is similar to that of those composing the Oneonta and Catskill formations.

In eastern New York in Albany, Greene, Ulster, and Sullivan counties the physical conditions under which the Oneonta and Catskill formations were deposited began as early as Sherburne time and continued throughout the remainder of the Devonian period. The representation of the Ithaca or Chemung faunas is very slight and this great mass of rocks consists mainly of alternations of red and green shales and sandstones and gray to greenish-gray coarse-grained sandstones, with some conglomerates in the Catskill Mountains. In the Delaware Valley the red rocks do not appear as early and there is some representation of the Ithaca fauna, which is more pronounced in northeastern Pennsylvania. As this series of rocks is followed along the Appalachians southwesterly across Pennsylvania, Maryland, and the Virginias it is found that the reds gradually appear later and the Chemung fauna is present. For in western Maryland, succeeding the black shales with a Genesee fauna at the top of the Hamilton, are first nearly barren smooth shales and sandstones like the Portage of western New York, then rougher shales and rather mealy sandstones containing an abundant Chemung fauna with numerous specimens of *Spirifer disjunctus* in Garrett County, and finally the red and grayish shales and sandstones of the Catskill. This change from the Catskill Mountain region to the southwest is found to be quite similar in general characters to the change from these mountains westward across southern New York, the story of which was excellently told some years ago by Prof. Stevenson in his address before the American Association for the Advancement of Science.[a]

K-L 16-17. MICHIGAN, INDIANA, AND OHIO.

The Michigan section of the Devonian comprises the Dundee limestone, Traverse formation, and Antrim shale.

Lane [517] describes the divisions of the Devonian, and from his description the following notes have been derived.

The Dundee limestone is a persistent stratum throughout Michigan, with a general thickness of 200 to 253 feet. "Beginning with a thickness of an even 100 feet in the southeast corner of the State, it thickens slowly to Port Huron. Going west and north it at first thickens until it gets its full thickness of about 250 feet, and then begins to thin." It is nearly the equivalent of the Onondaga ("Corniferous") limestone of New York. "It is very uniformly a high-grade limestone, with only a small percentage of magnesia, not infrequently over 98 per cent $CaCO_3$, light colored, or brown with oily matter * * * and sometimes, not always, cherty."

[a] The Chemung and Catskill (upper Devonian) on the eastern side of the Appalachian basin: Proc. Am. Assoc. Adv. Sci., vol. 40, 1892, pp. 219-248.

The relation of the Dundee to the underlying Monroe formation is one of unconformity, marked by some erosion of the uppermost Monroe. Lane[517a] says:

> At the close of the Monroe the State [Michigan] was so elevated that slight folds which occurred at the same time could be planed off, and the underlying formation in numerous places from Mackinaw to Monroe County, made into a dolomite conglomerate. * * * So far as we know it remained above water during the opening stages of the Devonian Helderbergian. * * * The same disturbance that cut Michigan off once more may have opened up New York to the Helderbergian, so that while the Coeymans and Port Ewen beds were forming in New York, 300 or 400 feet in all, Michigan was mainly out of water, and not until the Schoharie did deposition that has been recognized by its fossils begin in Michigan.

Grabau[382] first described the occurrence of the Schoharie fauna in the Dundee.

Lane uses Traverse to designate a division of the Devonian of Michigan which overlies the Dundee and underlies the Antrim. This is a more restricted use than that of Grabau,[379] who employed "Traverse" to include the Dundee and Traverse of Lane.

In the restricted sense Traverse is classed by Lane[517b] as equivalent to Hamilton and Marcellus, or Erian of Clarke and Schuchert's latest classification of the New York section, and as the representative of the Delaware limestone of Ohio. Of it he says:

> As this group is much thicker and better exposed in the north end of the State and its very existence along the south line of the State has been doubted, we begin our description from the north, where it outcrops on Grand and Little Traverse bays and thence is frequently exposed around to Alpena and Thunder Bay, and is nearly uniform in thickness (600 feet with a basal shale, Bell shale, 80 feet, which corresponds to the Marcellus and is persistent throughout the State.)

Following Grabau, Lane divides the Traverse as follows:

	Feet.
Chert beds; Naples goniatite fauna at top	45–50
Petoskey limestone; Stromatopora and buff magnesian	360
Acervularia beds; Bryozoa beds	110
Bell shales	80
	600

The Antrim shale is described by Lane[517c] as dominantly shale, "black and bituminous at the bottom, then blue, and at the top, where it passes into the Berea grit, or the horizon thereof, red or interstratified with sandstones and gritty." It is regarded by Lane as equivalent to the Senecan of the New York State Survey classification. It may or may not include a representative of the Genesee shale, according to Lane. Of the Ohio divisions it is regarded by him as the equivalent of Huron, Chagrin, Cleveland, and Bedford formations. The thicknesses cited by Lane from well records range from 140+ to 480 feet.

The passage from the Devonian to the Carboniferous in Michigan is not readily placed. Generally the Antrim shale has been regarded as uppermost Devonian and the Berea sandstone as the base of the Carboniferous. The plane at the top of the Antrim is not determinable, however, where the Berea is absent and the Antrim shale is followed by the Coldwater shale, and even where the Berea is present and the lithologic division can be established, the assignment of strata to Devonian or

Carboniferous is subject to question. It has been customary to draw the line theoretically and so far as practicable in fact at the top of the Antrim, on paleontologic grounds. Lane [517c] says:

In order to get consistent results and thickness one must recognize that the transition to the Berea grit is gradual and a great thickness of Berea grit or strata ascribed thereto is at the expense of the Antrim. * * *

To put the base of the Carboniferous at the base of the Bedford we should have to split the Antrim in a very impracticable way, though we could readily enough follow Ulrich's suggestion and place it lower. [Lane states that Ulrich would transfer the Antrim to the Carboniferous.] It is noteworthy that just as the Sylvania is confined to the east side of the basin along the Cincinnati anticlinal, so is the Berea grit, and when the Berea grit does not appear, then the upper strata of the Antrim have a red facies like the Bedford of Ohio, or the Richmond top to the very similar Lorraine. This red facies is, it seems to me, very likely due to exposure to the weather. Where the Berea grit is well developed it is, I believe, never found. It therefore may indicate the uplift generally taken to mark the close of the Devonian and beginning of Carboniferous.

This is the Michigan phase of the Waverly problem. (See also papers by Girty.[361, 363])

In northern Ohio the Cleveland shale is regarded by Prosser [649a] as the uppermost Devonian, whereas the Bedford shale is placed at the base of the Carboniferous. According to Lane both of these formations are represented in the Antrim shale, and thus, to be consistent with the Ohio scale, the line should be drawn in Michigan in the Antrim itself. This Lane regards as impracticable.

Following the general usage we discuss the Berea sandstone and overlying formations as Carboniferous. (See pp. 420–421.)

In 1905 Prosser [651] published a classification of the geologic formations of Ohio, which has since been republished with the New York equivalents by Stauffer.[789] In another paper [790] Stauffer describes the Middle Devonian as follows:

The Middle Devonian of Ohio naturally falls into three divisions, of which the lowermost is known as the Columbus limestone, the middle as the Delaware limestone, and the upper as the Olentangy shale. This division is based on both lithological and faunal differences which in some respects are more apparent in the vicinity of Columbus, although not wanting in any of the belts of the outcrop. The thickness of each of these three formations varies through a considerable range in different parts of the State.

The Columbus limestone presents two rather persistent lithological differences which are excellently illustrated in the outcrops along the Scioto River and are not absent even in the northern sections. These two phases of the formation sometimes blend with each other, but occasionally localities are found where the change is abrupt and the characteristics of each portion decided.

The lower portion of the Columbus limestone consists of a rather porous massive brown limestone, frequently containing a large amount of bituminous matter and very little chert, but generally having numerous cavities or pockets filled with crystals of calcite. At some places near the base it has been observed to have a pitted or honeycombed structure. It sometimes shows a strong oblique jointing and frequently few definite bedding planes. A fresh surface shows a saccharoidal appearance but occasionally glistens with cleavage faces of calcite. There is also a tendency to a banded structure which may be seen in the blocks of most if not all exposures in central Ohio. This banding, frequently of a wavy appearance, seems to be due to the presence of finely divided bituminous matter. The fossils, except in the extreme upper and lower parts, are poorly preserved and rather rare in most localities. Chemically the limestone from this part of the formation is found to be high in its percentage of magnesium. A sample from Dublin yielded 41.07 per cent of magnesium carbonate, while several from Bellefontaine gave even a higher percentage for this constituent.

The upper part of the Columbus limestone, which includes about two-thirds of the formation, consists, in the main, of light-gray limestone in even beds varying from a few inches to several feet in thickness. At places it contains a considerable amount of white or light-gray fossiliferous chert, which is mainly restricted to a few zones, where it occurs in concretionary masses which are arranged in somewhat definite layers. The upper layers of the limestone are the thinner and often of a bluish color. The heavy beds, where long exposed, weather into rather thin irregular layers which break into angular blocks and fall to the base of the cliff, forming the usual talus slope. This portion of the formation always shows a crystalline or subcrystalline structure. It is high in its percentage of calcium carbonate, which ranges from 81.14 to 93.28 per cent in samples taken from Marble Cliff quarries. While all layers seem to contain abundant fossils, many are literally crowded with the remains of the various species which swarmed in the waters of this warm Devonian sea.

The base of the Columbus limestone rests upon the Monroe formation, this contact being that between the two great systems, the Silurian and the Devonian. There is thus a great time gap or unconformity between these two formations, which is strikingly illustrated by the decided change in character and abundance of animal remains. In some localities the lowest layers of the Columbus contain an abundant fauna which in many respects resembles that of the upper part of the same formation, but where these lower layers have been observed in Franklin, Delaware, and Union counties a basal conglomerate is found which consists of large and small waterworn pebbles of the underlying formation embedded in a matrix of Columbus limestone. Where this conglomerate is developed few fossils are found, probably because the organic remains which existed in these localities at the time the layers in question were being deposited were ground to a shapeless mud by the continuous action of the waves among the pebbles of a rocky coast. This conglomerate was formerly supposed to represent the Oriskany sandstone of New York and was so mapped by the geologists who made the first county reports, as well as by Newberry himself; but since this basal conglomerate is not continuous and has not been proved to be Oriskany, it has been customary of later years, and perhaps wisely, to drop the Oriskany sandstone from the Ohio scale and include these deposits with the Columbus limestone, to which they are at least very closely related.

The upper limit of the Columbus is no less interesting, since it terminates in the famous "bone bed" first described by Orton. This layer or bed comprises the upper 6 or 8 inches of the formation and is frequently made up of an "assemblage of millions on millions of generally imperfect but mostly recognizable organs or fragments of the bony structure of the forms of fish life most characteristic of the Devonian age." These teeth and dermal plates are often in an excellent state of preservation, retaining even their original luster. Contrary to what has usually been supposed, this limiting layer of the formation may be traced northward to Sandusky, where it has proved of invaluable assistance in determining the line of division between the Columbus and Delaware limestones.

The Delaware limestone extends from the "bone bed" upward through a thickness of about 36 feet to its contact with the Olentangy shale. It is extremely variable in its appearance, consisting sometimes of thin shaly layers, beds of chert, and fairly massive limestone and again almost entirely of rather massive limestone with very little chert and no shale. Usually it has a deep-blue to slate color, which becomes brown on weathering. The chert which it contains is mostly black and nonfossiliferous, but in sections where little occurs it is often a light bluish white or even pure white and somewhat fossiliferous. In general the Delaware limestone is less fossiliferous than the upper part of the Columbus, but its fauna is by no means small, and frequently layers are found which are very fossiliferous. The variable chemical composition of this formation is easily seen by a reference to the analysis of various samples collected at different localities.

The Olentangy shale extends from the top of the Delaware limestone to the base of the Ohio shale, a vertical distance of about 31 feet in Franklin County. It has been found to be almost invariably present in the central strip from Sandusky southward. In Pickaway County, where the Devonian limestones last appear, this shale occurs, and from thence southward overlaps on the older rocks until at Bainbridge it rests on Niagaran limestones. The Devonian shales cross the Ohio River at Vanceburg, and even near Fox Springs, Fleming County, Ky., the basal shale has the appearance of the Olentangy. As seen in the river bank at Delaware, the Olentangy is a soft bluish shale, with numerous disklike argillaceous limestone concretions near the basal portion and layers of impure limestone in the middle and upper portions. The formation contains few fossils in central Ohio but becomes quite fossiliferous in the Sandusky region, where it includes a limestone member at the top, which has been known as the Prout limestone. The thickness of the formation is there also greatly increased.

Stauffer [788] states that the Columbus limestone is the equivalent of the Dundee limestone of Michigan and the Jeffersonville limestone of Indiana, which are represented in New York by the Onondaga. He places the Delaware limestone of Ohio as equivalent to the Marcellus and correlates the formations of Michigan, Ohio, and New York thus:

Michigan.	Ohio.	New York.
Traverse group.	Olentangy shale. Delaware limestone.	Hamilton beds. Marcellus shale.
Dundee limestone.	Columbus limestone.	Onondaga limestone.

Devonian strata outcrop in three widely separated areas in Indiana—on the Wabash, near Pendleton, and in southern Indiana. The intervening stretches are completely covered by drift. In all sections showing the lower and upper limits of the Devonian in the State the base rests upon Silurian limestones and the top is overlain by Mississippian strata. Kindle [494a] gives the formations present in the northern, central, and southern sections and states the correlation with the New York Devonian as follows:

Devonian formations in Indiana.

Southern Indiana area.	Pendleton area.	Wabash area.
New Albany shale.	Drift covered.	New Albany shale.
	(?)	
Sellersburg beds. Jeffersonville limestone. Geneva limestone.	Pendleton sandstone.	Sellersburg beds. Jeffersonville limestone.

When the first attempts were made to determine the age of the New Albany shale, its known fauna was limited to one or two species of Lingula. Since the discovery of the Lexington fossils by Borden in 1874 [a] the formation has been correlated with the Genesee of the New York scale. The discovery by the writer of a new fauna in the New Albany shale at Delphi throws some additional light on the difficult problem of the true position of this formation in the time scale. Associated with several species which are new or undetermined, we find in this fauna *Spathiocaris emersoni*, a well-known representative of the Naples fauna of New York. This fossil is not known in the Genesee in the New York sections but occurs in the Portage and even as high as the Lower Chemung.[b]

[a] Geol. Survey Indiana, 1874, pp. 112–134.
[b] Clarke, J. M., Bull. U. S. Geol. Survey No. 16, 1885, p. 47.

Of the species which have been previously known in the New Albany shale at least three are characteristic Genesee species; one is common to the Portage and the Genesee. The presence in the New Albany shale of a Genesee fauna and a Portage fauna seems to justify the conclusion that this formation is the western representative of both the Genesee and the Portage.

The *Styliola fissurella* fauna does not bear any stronger evidence of the Genesee age of the New Albany shale than does the *Spathiocaris emersoni* fauna of its Portage age; these two faunas, however, are not intermingled in the New Albany shale. While there is no evidence that either one occupies a higher stratigraphic horizon than the other, they are found in unlike sediments. The *Styliola fissurella* fauna is confined to the fissile black shale, while the *Spathiocaris emersoni* occurs in a soft drab shale which is interbedded with the black shale in northern Indiana. The New Albany shale of northern Indiana contains in its fissile black strata and its drab sandy beds the lithologic elements of both the Genesee and the Portage, but neither these beds nor the elements of the Genesee and Portage faunas which they contain are sharply differentiated, as they are in the eastern Devonian province.

The problem of the correlation of the Devonian limestones with the New York scale is much more difficult for some parts of the Indiana province than for others. In the vicinity of the Falls of the Ohio we find two quite distinct and well-marked faunas. These are the *Spirifer granulosus* and the *Spirifer acuminatus* faunas and represent respectively the Hamilton and Corniferous faunas of New York. Near the Falls of the Ohio the Sellersburg beds and the Jeffersonville limestone which carry these faunas are sharply differentiated lithologically, the Jeffersonville limestone being a nearly pure limestone and representing clear-water conditions during its deposition, while the Sellersburg beds are composed of an impure argillaceous limestone. In the northern part of the southern Indiana area these two formations cease to be sharply differentiated lithologically and merge into each other in a limestone which is neither so pure as the Jeffersonville limestone nor so argillaceous as the Sellersburg beds near the Falls. Associated with the loss of individuality of these two formations occurs a mingling of their two faunas which renders them indistinguishable as separate faunas.

In the Wabash area the faunas of the Devonian limestone are even more distinct than at the Falls of the Ohio. In the lower one *Spirifer acuminatus* is an abundant fossil and the fauna does not differ greatly from that in the Jeffersonville limestone at the Falls of the Ohio. The upper fauna is a distinctly Hamilton fauna, but entirely different from the Hamilton fauna of southern Indiana. Two of the most abundant fossils in it are *Spirifer pennatus* and *Chonetes manitobiensis*. Neither of these species is known in the southern Indiana area.

Hopkins and Foerste [463] follow Kindle's classification, with additional local distinctions, and give the following description of the strata:

In southern Indiana the New Albany black shale is exposed over considerable areas. It is a black to blue-gray fissile shale containing much iron sulphide and a great deal of bituminous matter. The bituminous matter is so plentiful in places that it will burn freely and the volatile gases have been distilled from it. The shale is 104 feet thick at New Albany, and elsewhere it has been reported as much as 140 feet in thickness. The outcrop covers an area from 8 to 15 miles wide, as shown on the map.

The Sellersburg limestone of Kindle includes both the crinoidal and the hydraulic limestones, but Siebenthal limits the term Sellersburg to the upper or crinoidal division and the lower hydraulic limestone he calls the Silver Creek hydraulic limestone. The Sellersburg limestone is a white to gray crystalline limestone that lies between the overlying black shale and the underlying hydraulic limestone. Frequently the basal portions are sandy and sometimes there is a layer of pebbly sandstone separating it from the underlying hydraulic limestone. The shining black pebbles are said to be rich in phosphates.

The Silver Creek hydraulic limestone lies between the overlying Sellersburg limestone and the underlying Jeffersonville limestone. It is a fine-grained, massively bedded argillaceous magnesian limestone, light to dark drab in color, becoming buff on exposure. It is 15 to 16 feet thick at Silver Creek, 8 to 10 feet at Charlestown, and 5 to 6 feet in the vicinity of Lexington.

The Jeffersonville limestone is a white to bluish-gray crystalline fossiliferous flaggy limestone, lying between the Silver Creek hydraulic limestone and the underlying Niagara limestone. It has been correlated with the Corniferous of New York. It is exposed at the Falls of the Ohio River, and from it are obtained many fine coral fossils. In this part of the area there was a great coral reef, not greatly unlike many forming at the present time, except the corals are a different class from the living ones.

The irregular contact representing the unconformity between the Devonian and underlying Silurian has been recognized locally. Kindle has noted it at a point 35 miles south of Indianapolis and in northern Indiana; farther south, according to Kindle,[494] physical evidence of this unconformity between the Devonian and Silurian has not been observed. Along their contact north of Indianapolis later Devonian strata overlap northwestward beyond earlier strata, indicating the gradual submergence of the Wisconsin-Illinois peninsula; and a similar relation is noted on both sides of the Cincinnati arch in Indiana and Ohio.

The Devonian of Ohio (Columbus limestone to Ohio shale, inclusive) comprises the equivalents of the New York section from the Onondaga ("Corniferous") limestone to the somewhat indefinite horizon where the Devonian passes into the Carboniferous.

L 12. SOUTHWESTERN MONTANA.

The type section of the Paleozoic of southwestern Montana is that of Threeforks, near latitude 46°, longitude 111° 30′, originally described by Peale. It includes the Jefferson limestone and Threeforks shale, which lie between the recognized Cambrian and lower Carboniferous strata.

The Jefferson limestone and Threeforks shale were first described by Peale [631, 632] as representing the Devonian and possibly including some Silurian at the base and some Carboniferous at the top. Peale states the occurrence of pebbly limestones of Upper Cambrian or Lower Ordovician age, and in the folio text says: [632a]

DEVONO-SILURIAN.

The pebbly limestones pass imperceptibly into a series of black magnesian limestones which for several hundred feet are, so far as examined, devoid of fossils. It is possible, as the pebbly limestones have every indication of being on or near the border line between the Cambrian and the Silurian [Ordovician], that their upper beds and a part of the overlying black limestones may eventually be referred to the Silurian [Ordovician and Silurian]. There is little doubt that the sedimentation was continuous, and we need not be surprised if sometime in the future this now barren interval should somewhere furnish a mingling of Silurian and Devonian forms.

DEVONIAN.

The black limestones referred to under the head of Devono-Silurian have been provisionally referred to the Jefferson formation, because the fragments of fossils found in the middle and upper part, although few and very indistinct, were recognized to be the same as those occurring in the Threeforks shales, which are, without much doubt, Devonian. The total thickness referred to the Devonian is about 870 feet.

The Jefferson limestone forms the base of the formation, consisting of several hundred feet of black or mud-colored limestone, which is generally crystalline and magnesian from top to bottom. It is well exposed in all parts of the Threeforks region and at most localities is nonfossiliferous, only a few forms having been obtained from near the top of the formation, and these only in the region north of the East Gallatin River.

The Threeforks shales, which rest conformably upon the Jefferson limestone, may be divided into three parts—the lower or orange-colored shales, about 50 feet in thickness; a band of grayish-brown argillaceous limestone, 20 feet thick; and the upper green, black, and argillaceous shales, some 50 feet in thickness, which are crowded with Devonian fossils and capped by a band of yellow laminated sandstone 25 feet thick. These Devonian fossils were found both in the northern and in the southern portion of the district, and doubtless occur wherever the beds are found. A coal-black slate is seen near the upper part of the shales in the vicinity of the head of the Missouri River. In the Jefferson Canyon this has developed into a bed of coal, in which are found limestone nodules containing the same Devonian forms that are elsewhere found in the shales. The shales are near the border line of the Devonian and Carboniferous, and their organic remains contain a mingling of forms of both, but the preponderance of evidence is in favor of their Devonian age.

On examining fossils collected in course of the survey of Yellowstone Park, Girty [393c] confirmed the determination of the Devonian age of the Threeforks shale and noted the relation of the fauna to the Devonian of the White Pine district, Nevada. Fuller collections have been made by Kindle [499] in a special study of the Jefferson limestone and by Raymond [662] from the Threeforks shale. Kindle concludes that the Jefferson is "earlier than Upper Devonian" and probably includes both Lower and Middle Devonian. Raymond describes the fauna of the Threeforks shale as Upper Devonian.

Kindle says, in part:

The Jefferson limestone has a wide distribution in the northern Rocky Mountain region. In Montana its distribution seems generally to coincide with that of the Madison limestone, which immediately follows it in the sections where the highest formation of the Devonian system is absent. Its distinctive composition and color have enabled geologists to identify the Jefferson limestone over a rather wide area in Montana and northwestern Wyoming. The writer has recognized the formation still farther south in western Wyoming and northeastern Utah. [Details follow.]

The evidence now at hand indicates that the eastern edge of the formation lies somewhere near the one hundred and ninth parallel in the States of Montana, Wyoming, and northern Utah. What its southern and western limits may be remains to be determined. The formation has a known east-west extent of about 150 miles in Montana and a north-south extent of about 425 miles. Its actual extent is probably much greater. The paleontologic evidence of the identity of this formation with the Nevada limestone of Nevada is presented elsewhere in this paper.

Sections in Montana.—Some of the stratigraphic evidence on which the extent of the Jefferson limestone as outlined above is based may be shown by consideration of a few typical sections which include this formation and exhibit its relations. The section at Threeforks, Mont., the type locality of the Jefferson, as given by Peale, is as follows:

Section at Threeforks, Mont.

		Feet.
Carboniferous: Madison limestone	Jaspery limestones	575
	Massive limestones	350
	Laminated limestones	325
		1,250
Devonian: Threeforks shales	Upper shale	70
	Limestone bed shown in section.	
	Lower shales	65
		135
Silurian (?) [Devonian of Kindle]: Jefferson limestones	Black limestones	640
Cambrian: Gallatin formation	Pebbly limestones	145
	Dry Creek shales	30
	Mottled limestones	260
	Obolella shales	280
	Trilobite limestone	120
		835

* * * * * * * * *

The Threeforks shales appear to have a much more limited distribution than the Jefferson limestone. They are present, however, in the Melrose section, on Camp Creek, some 30 miles west of Threeforks. The following section is seen along Camp Creek:

Section on Camp Creek, Mont.

		Feet.
K.	Gray nonmagnesian limestone (Madison limestone)	300+
J.	Bluish-gray argillaceous shale, buffish shale in lower part, with limestone bands near middle (Threeforks shale)	200±
I.	Black magnesian limestone, with minor beds of gray limestone distributed through the series (Jefferson limestone)	500±
H.	Buff-gray hard magnesian limestone, with some shaly bands	30
G.	Buffish-gray nonmagnesian limestone, 1-inch to 3-inch laminæ, separated by thin bands of shale	35
F.	Dark-red sandy shales	20
E.	Light-gray magnesian limestone, with some dark bands in lower half	500±
D.	Shale	100
C.	Shale and thin-bedded brownish sandstone	50
B.	Gray shale	40
A.	Quartzite weathering brownish buff	65

The Jefferson limestone seems to reach its maximum thickness in the western part of the State. In the Philipsburg [quadrangle] nearly 1,000 feet of the Paleozoic section is represented by the dark limestones of the Jefferson formation. The following section indicates the relationship of these beds in this region, as seen along Boulder Creek, west of Princeton:

Section along Boulder Creek, Philipsburg quadrangle, Mont.

		Feet.
E.	Dark-gray to white heavy-bedded and flaggy limestone, shaly toward the base (Madison limestone)	500+
D.	Gray to black limestone in alternating beds, the latter predominating and distinctly magnesian, generally with saccharoidal texture (Jefferson limestone)	800
C.	Gray to brownish shale and sandstone; the latter predominates at the base	210
B.	Bluish-gray limestone, with thin siliceous, argillaceous, and shale films at intervals of 1 inch to 3 inches. These intermediate laminæ weather brownish and show in relief thin, flat, pebble-like concretionary (?) sheets	275
A.	Light-gray to cream-colored hard magnesian limestone	300

This section differs from the two preceding sections in the absence of the Threeforks shale, which seems to be everywhere wanting in the Philipsburg quadrangle.[a]

* * * * * * * * *

[a] For list of fossils see the work cited.—B. W.

Other sections in southwestern Montana might be given which would present the same general sequence with reference to the Jefferson limestone. All the sections show a limestone series in which dark to nearly black limestones predominate, followed by the Madison limestone, which is locally separated from the Jefferson by the Threeforks formation. The Jefferson in all the Montana sections is preceded by limestones and shales in which the latest observed faunas are of Cambrian age.

Sections in Wyoming.—The Montana sections show a close correspondence in these characteristic features to the southwestern Wyoming section, which follows. This section occurs in the westward-dipping beds of Labarge Mountain, northeast of Viola post office and west of the Sayles coal mine.

Section northeast of Viola, Wyo.

	Feet.
J. Light to dark-gray limestone, oolitic in lower 20 feet (Madison limestone)	500±
I. Drab shales and shaly thin-bedded magnesian and siliceous limestone	80
H. Buff to gray limestone with much black magnesian limestone in the upper part, saccharoidal in texture, and weathering with roughly pitted surface; covered in part (Jefferson limestone)	1,000±
G. Gray limestone, partly covered	700±
F. Gray limestone, with Cambrian trilobites abundant	40
E. Green shale and covered	300±
D. Drab shale and covered	30
C. Thin-bedded gray limestone, with Cambrian trilobites abundant	10
B. Drab shale, mostly covered	100
A. Lead-gray limestone, checked by innumerable small joints, which are generally calcite filled	120

In this section the gray and black limestone series is preceded by beds holding a Cambrian fauna and followed by a limestone holding the usual Madison limestone fauna. The shale formation (I) at the top of the magnesian limestone formation appears to occupy the position of the Threeforks shale, but it is barren of fossils. Composition, texture, manner of weathering, and relationship to the section all indicate that the magnesian limestone series of the section is the same formation as the Jefferson limestone of the Montana sections.

The Jefferson limestone of the Labarge Mountain section is nearly barren of fossils. The only fossils obtained in it were Zaphrentis and fragments of another undetermined coral.

* * * * * * * * *

Devonian rocks in Idaho.—The only data we have relating to the Devonian in Idaho are based on a small collection of fossils made by Mr. F. B. Weeks during the summer of 1907. This collection was procured from a dark limestone "in southeastern Idaho, east of Manson station, Oregon Short Line Railroad." The three species represented in the collection are *Atrypa reticularis*, *Productella* cf. *subaculeata*, and *Spirifer disjunctus* cf. var. *animasensis*. The first species is the most abundant in the fauna. The presence of *Sp. disjunctus* seems to indicate an Upper Devonian horizon. The fauna is not sufficient to show whether or not the Jefferson limestone is represented by it. Probably, however, it is from this formation. The appearance of the rock, which is dark, somewhat magnesian limestone, is highly suggestive of the Jefferson limestone. The evidence of the small fauna, though inconclusive, points to the Jefferson limestone rather than to the Threeforks shale as its source.

About 60 miles southeast of this locality, in northeastern Utah, the Jefferson limestone is well developed.

Sections in Utah.—Field studies in Utah were limited to the northern part of the Wasatch Mountains. Numerous excellent sections of the Paleozoic are exposed by the deep canyons east of Cache Valley. The canyons cut at right angles the general trend of the structure, which is of the moderately folded type, few of the heavier dips exceeding 30°. Nearly vertical cliffs 2,000 feet or more in height alternate with slopes of every degree of inclination along the sides of the canyons. * * *

Examination of half a dozen of the canyon sections to the south of Logan Canyon has shown that the Carboniferous and Devonian portions of the section may be distinguished both by physical and faunal characters. In the Devonian series, generally 1,000 to 1,200 feet thick, dark magnesian limestones are the predominant element, although nonmagnesian limestones and in some places argillaceous rocks appear as minor components of the formation. In the Carboniferous the dark magnesian limestones of the lower series are replaced by lighter-colored nonmagnesian limestones. The Carboniferous and Devonian series of these sections show about the same kind and degree of contrast which is found between these series in the Montana section. The Devonian beds of these northern Utah sections appear without question to be the southern continuation of the Jefferson limestone. The following is a representative section occurring nearly east of Paradise post office, in Green Canyon:

Section in Green Canyon, Utah.

	Feet.
D. Gray nonmagnesian limestone, partly covered	900±
C. Dark-gray to black magnesian limestone, generally with saccharoidal texture	1,100±
B. Thin-bedded limestone, buff or brownish near top, with peculiar concretionary development, with thin-bedded bluish-gray limestone in lower part	100
A. White to light-gray magnesian limestone, with chert or siliceous beds locally developed [Silurian, Kindle]	150
	2,250

Kindle mentions the contrast between the Jefferson fauna and that of the Ouray limestone of Colorado, and also comments on the close equivalency of the Jefferson limestone of Montana, Wyoming, etc., and the Nevada limestone of Nevada and their faunas. He says in part:

The fauna of the Jefferson limestone as known at present is a small one, numbering about 32 species. Like many other western faunas, it includes very few species which are common to the standard sections east of the Mississippi. Of the five species which are common to the well-known eastern sections all except *Atrypa reticularis* are characteristic Devonian species, a sufficient number to make evident the Devonian age of the fauna. * * *

In attempting to determine just what part of the Devonian is represented by the fauna of the Jefferson limestone we find that two of the five species which are common to the Jefferson limestone fauna and the eastern Devonian fauna are Atrypas. One of these, *A. reticularis,* has no diagnostic value, while *A. spinosa* has a recorded range from the Corniferous to the Chemung. The other three species, *Schuchertella chemungensis arctostriatus, Productella spinulicosta,* and *Martinia maja,* are known in the eastern sections only in Middle Devonian horizons. The absence from the fauna of any of the large Productellas, which generally characterize the late Devonian faunas, together with the presence of an Upper Devonian fauna following it in the section, both supplement the intrinsic evidence of the fauna that it is earlier than Upper Devonian. The known range of the fossils which are common to eastern sections suggests a Middle Devonian age for at least a part of the Jefferson limestone. The fauna contains no coarsely plicated Spirifers or other fossils generally characteristic of the early Devonian, but other evidence strongly supports the view that the Jefferson limestone represents both Lower and Middle Devonian.

No evidence of a stratigraphic break between the Jefferson and the preceding formation has been observed by the writer in any of the sections examined by him. None of the folios which describe the Jefferson limestone record any unconformity at its base. * * * In Utah the writer has found conditions that seem to indicate there the continuity of sedimentation from the Silurian to the Devonian, which, although probable in Montana, has not been demonstrated. * * *

The fauna of the Threeforks shale, which immediately follows the Jefferson limestone in some of the sections in Montana, is composed for the most part of alien species. Dr. Raymond's list of the Threeforks shale fauna at Logan and Threeforks, Mont., showed but three species which are known in the Jefferson limestone. Evidently very few of the indigenous species of the Jefferson limestone survived the conditions which inaugurated the deposition of the shales that terminated the Devonian in this region.

Raymond's notes on the Threeforks shale refer to the type locality in southwestern Montana. He says in part:[662]

It is the purpose of the present paper to announce the discovery in the Threeforks shales, near Threeforks, Madison County, Mont., of an Upper Devonian fauna containing Clymenia, Entomis, and goniatites.

* * * * * * * * *

The Threeforks shales were divided by Dr. Peale into three portions:

	Feet.
3. Upper shales, with many fossils	65
2. Grayish-brown limestone, without fossils	15–20
1. Lower shales, without fossils	50

Division 3 is subdivided as follows:

	Feet.
D. Yellow sandstone, the lower part calcareous	25
C. Coal-black shale	5
B. Gray limestone	10
A. Green shales with bands of limestone	30

* * * * * * * * *

In the 65 feet of strata constituting the upper shales at Threeforks there are five zones in which the lithology and faunules differ somewhat. 1, 2, and 3 make up A above; 4 is the same as B; and 5 equals D. From C no fossils were obtained. These zones, beginning with the lowest, are as follows:

1. *Red shale zone.*—The shales of this zone are hard, reddish, and fissile, the layers weathering into small, sharp-pointed fragments. The fossils are preserved in pyrite, which is often partially altered to limonite, and they weather out on the surface in numerous bare spots along the strike of the beds. * * *

2. *Green shale zone.*—These are the green shales described by Peale (part of A, above). Fossils abound and further collecting should reveal a much larger fauna. Clymenia and Entomis are abundant, associated with a great number of brachiopods and lamellibranchs. * * *

3. *White blocky shale.*—The exact horizon of this zone is not known, as the fossils were obtained at a locality where the layers seemed to be somewhat disturbed. In the field it appeared to be above the green shale, but it could not be located in any place where the beds were undisturbed. The faunal list is short, but the fossils are abundant. * * *

4. *Gray limestone zone.*—This limestone weathers readily and produces great quantities of fine fossils, mostly brachiopods. Two species of Clymenia occur in this zone, but the goniatites are very rare. This same limestone is well exposed in the Devonian ravine at Logan, but no specimens of Clymenia were found at that locality; it has, however, furnished two fragments of cups of crinoids, one of which has been identified as a species of Mariacrinus, by Mr. Frank Springer. This is of interest, as it is the first crinoid reported from the Devonian of the Rocky Mountains. * * * This seems to be the upper limit of the range of Clymenia.

5. *Yellow sandstone zone.*—This sandstone or sandy limestone forms the capping bed of the Devonian both at Threeforks and at Logan. A few beds are very fossiliferous and the fauna indicates a transition into the Mississippian (Madison limestone).[a]

L 18. ST. HELENS ISLAND, MONTREAL.

A very small exposure of Devonian agglomerate on St. Helens Island, Montreal, has yielded Devonian fossils that appear to present a unique association. Schuchert[713] reviewed the faunas and the conditions of their occurrence and concluded:

The foregoing evidence shows clearly that two distinct faunas are represented on St. Helens Island—one, the Helderbergian, older than the agglomerate, and another, from a block in the agglomerate, of Middle Devonic age.

[a] For lists of fossils from the several zones see the work cited.—B. W.

The Helderbergian fauna is apparently related with that of New York, and belongs to the facies occurring on the western side of the Appalachian folds. The writer has collected this fauna at Dalhousie, New Brunswick, and from the Gaspe region, Quebec, and both are of another facies and belong to another basin.

The presence of Rhipidomella recalling *R. musculosa; Spirifer concinnus;* an early variety of *S. murchisoni;* Spirifer n. sp., connecting phylogenetically *S. concinnus* and *S. arenosus; Camarotœchia pleiopleura; Gypidula pseudogaleata;* and *Rensselaeria acquiradiata* shows that the St. Helens Island Helderbergian is not as old as the New Scotland zone. *Spirifer concinnus* and especially *G. pseudogaleata* and *R. acquiradiata* are characteristic Becraft zonal species. However, the Oriskanian reminders, like *R.* near *musculosa, S. murchison, S.* near *arenosus,* prove that the St. Helens Island Helderbergian is pretty well up toward the top of the New York section, and may represent both the Becraft and Kingston zones.

Spirifer macra and *S. granulosus* establish the fact that, in the region of Montreal, there was once a formation of marine origin later than the Helderbergian and as recent as the Onondaga (Corniferous); further, that the agglomerate of St. Helens Island and other places about Montreal is not older than late Middle Devonic time. Its age is probably more recent, and there may be further paleontologic evidence in the agglomerate.

L 18–19. QUEBEC, SOUTHEASTERN TOWNSHIPS.

Ells[313] states that "areas of Devonian rocks occur at several widely separated points in the area east of the Sutton Mountain anticline and its extension northward." Small outliers are known on the Chaudiere. "While detached areas of Silurian (Lower Helderberg) occur at a number of places between the Chaudiere and the United States boundary, to the southwest, the only outcrops of strata holding typical Devonian fossils are found on the western shore of Memphremagog Lake." These rocks had been previously described by Logan and Billings and had been assigned to the "Corniferous" horizon by Dana and by Ells. They are plumbaginous limestones, underlain by somewhat dolomitic flaggy slates and shales, which Ells describes as resting upon fossiliferous "Silurian" strata [Devonian Helderberg limestone]. They are penetrated by intrusive dikes. With reference to the relations of these Devonian rocks to the Silurian and to the Devonian of the Gaspe Peninsula, Ells[313a] states:

> No well-defined break between the upper Silurian (Lower Helderberg) and the overlying Devonian has been found, the conditions of deposition presumably being similar to those in the Beauce [Chaudiere] district or in the similar beds of the Gaspe Peninsula, described under the head of the Gaspe Limestone series in the "Geology of Canada," as well as in subsequent reports.[a] In all these localities there appears to be a mingling of forms of upper Silurian and lower Devonian horizons, in so much that it has been found very difficult, and in some cases impossible, to define the exact line of separation between the two systems.

L 19. SOUTHERN NEW BRUNSWICK AND EASTERN MAINE.

In southern New Brunswick Devonian rocks occur in two areas—one in Charlotte County south of the Carboniferous basin, the other in St. John County, consisting of the Mispec and Lepreau basins. The rocks of the latter area extend across the international boundary and occupy the Perry Basin in eastern Maine.

The belt which is mapped as Devonian in Charlotte and Queens counties south of the Carboniferous basin was thus described in 1880:[49]

> The largest area of rocks of this age is that occurring in the northern part of Charlotte County and extending eastward into Queens County. These rocks have been described in the

[a] Geology of Canada, 1863, pp. 406–428; Rept. Progress, Geol. Survey Canada, 1880–82, pp. 3–16DD.

report of 1870–71, and are also briefly mentioned in the report of 1876–77. They comprise the former so-called pale argillite group. They are superimposed upon Cambro-Silurian rocks and extend from the St. Croix River, near Spragues Falls, to the Charlotte County line and thence into York. At the line of contact the dips are nearly vertical, but there is in places an apparent conformability between the dark argillite portion of the Cambro-Silurian and the series under discussion. It is probable, however, that faults occur at the line of contact, as the beds of fossiliferous Silurian so well developed about Oak Bay, on the south side of the Cambro-Silurian belt, are entirely wanting along the northern margin. The Devonian age of these rocks has been based by Mr. Matthew upon the occurrence of remains of Lepidodendron, * * * as well as from certain graphitic films, supposed to be the impression of fern leaves, found in the eastern extension of these beds into Queens County. They also possess many points of resemblance, lithologically, to the typical Devonian Mispec, and hence they have provisionally been assigned to this horizon.

Doubt is cast upon the Devonian age of these rocks, as the Mispec group is now known to be meso-Carboniferous.[22a] (See p. 331.)

The Devonian rocks of the St. John-Lepreau-Perry area have been the subject of much discussion as to their true age and have been considered Carboniferous on account of lithologic resemblances. The latest contribution from the Canadian Survey is by Ells,[315] as follows:

One of the most interesting of the geological formations which occur in this portion of New Brunswick is that known as the Perry sandstone group. * * * The rocks consist of conglomerates, sandstones, and shales, generally reddish in color, but occasionally, in the lower portion, some of the heavier sandstones and conglomerates become grayish. Plant stems are quite abundant in some of the shale beds, both in the rocks of Perry and near St. Andrews. These were carefully studied many years ago by Sir William Dawson and several papers relating to their character and age were published by him between 1861 and 1870, in which their horizon was placed as the upper portion of the Devonian system. The same conclusion had been reached at an earlier date by Dr. Jackson and adopted by Prof. Rogers, after an examination of the material from the plant beds of Perry, Maine.

In the report by Bailey and Matthew, 1870–71, the opinion is expressed that the rocks of this group are referable to the base of the Lower Carboniferous, rather than to the Devonian, from a supposed lithological resemblance to certain conglomerates which are found in Kennebeccasis Bay, an arm of the St. John River, where these rocks are assigned to the Carboniferous horizon.

In Charlotte County the Perry group can be well studied in the peninsula extending from the base of the Chamcook Mountain to the point at St. Andrews where the exposures are practically continuous for a distance of about 5 miles. The beds are cut across by several dikes of green diabase which have altered the sediments at their contact. Similar dikes are seen on Minister's Island to the east.

The lowest beds of the group at Chamcook Mountain consist of a coarse, heavy conglomerate with pebbles, often of large size, for the most part derived from the felsitic rock of which the mountain is composed. These conglomerates are a conspicuous feature in many places at the base of this series of rocks, and they also occur occasionally as intermediate beds higher up in the series. They are well exposed in the bluff east of Chamcook Harbor, on the islands and on the shore at the entrance to Digdeguash Harbor and further east on Bliss Island, L'Etang Head, and Pea Point, and again around the shores of Lepreau Harbor, which is the extreme eastern part of the county.

The dip of the strata in the St. Andrews Peninsula is uniformly to the south or southeast, at angles from 10° to 25°. At an average inclination of 15° over a distance of 5 miles, since the southern margin of the basin is not here reached, the thickness for the beds at this place will not be far from 7,000 feet. No well-defined faults or repetitions of the strata are seen in this section. This estimate of thickness far exceeds that hitherto made for any portion of the lower Carboniferous as developed in southern New Brunswick.

* * * * * * * * *

The outlines of this formation were carefully traced along the shores from the St. Croix River to Point Lepreau, and in some places, as at Pea Point, and L'Etang Head, the basal conglomerate was found to have a great thickness, aggregating not far from 4,000 feet. At Lepreau Harbor, where these rocks are well exposed, they apparently rest directly and conformably upon the Devonian shales and sandstones of the Mispec and Little River groups of the St. John Devonian basin. As they elsewhere underlie the basal beds of the lower Carboniferous, including the marine limestones of that series, it would now appear that the rocks of the Perry River group, as a whole, represent the upper portion of the Devonian system of southern New Brunswick, as was early suggested by Sir William Dawson and others from the evidence of the contained plants.

The above statement by Ells that the rocks of the so-called "Perry" of Lepreau Harbor rest conformably upon Devonian rocks of the Mispec group raises a question as to the relation of the "Perry" at Lepreau with the true Perry formation of Maine. If the Mispec rocks are meso-Carboniferous (see p. 331) strata which rest conformably upon them must be middle Carboniferous or later; whereas the true Perry is Devonian, probably Upper Devonian. Furthermore, plant remains which, like those of the Mispec, are now referred to the middle Carboniferous have been found near Lepreau Harbor. In view of the great thickness and highly disturbed condition of the strata it is probable that more than one terrane is represented in that vicinity.

The Devonian age of the Perry formation in the type locality in Maine has recently been placed beyond question by the investigation made by Smith and White,[759] who have assembled in the field and from the literature the essential facts of stratigraphy and paleontology. They thus describe the Perry formation:

The Perry formation as exposed in the towns of Robbinston and Perry is divisible into four members. Two of these members consist of sedimentary strata, while the other two are interbedded lavas and associated volcanic breccia. The section may be described thus:

Upper lava: Green lava with columnar parting and amygdaloidal texture. Includes one bed of conglomerate and sandstone.

Upper sandstone: Coarse red and brown sandstone and conglomerate, with small amounts of shale. Includes one flow of lava near base.

Lower lava: Basaltic lava and breccia. Includes one thin bed of conglomerate near top.

Lower conglomerate: Coarse conglomerate and red sandstone, with thin beds of sandy shale.

The thickness of these members can not be definitely given. The lowest member is evidently the thickest, but probably its thickness varies considerably in different parts of the area. As will be noted later, the Perry sediments were largely shore deposits, so that the distance from the source of the material would control largely the thickness of the beds. In case of the volcanic members the different lava flows give the impression of being rather more persistent in thickness than might be expected.

White made a thorough study of the plant remains originally described by Sir William Dawson, and of others including new collections from the Perry. He describes the species, discusses their distribution, and concludes:[759a]

Of the entire flora described[a] from Perry, *Sphenopteris filicula* and *Bepidocystis siliqua* are types which appear to belong to groups more or less distinctly characteristic of the lower portion of the lower Carboniferous. The fragment described as *Palæostachya?* sp., and the forms earlier published as *Lycopodites comosus* and *Carpolithes lunatus* are too little known or

[a] *Lepidodendron gaspianum*, a characteristic Devonian plant, unknown in the Carboniferous, and reported from Perry by Dawson, is omitted from the list as insufficiently represented for identification in the Perry material which I have seen.

too ambiguous to be at present of stratigraphic value. The correlative significance of *Sporangites jacksoni,* which has not been found elsewhere, is also as yet undetermined. The remaining species which comprise the main body of the Perry flora are Devonian.

As will have been seen in the foregoing review, the evidence of the geologic distribution, so far as known, of the identical species, of the genera themselves, and of the most nearly related plant forms indicates distinctly and overwhelmingly a Devonian age for the Perry formation. The stratigraphic range of most of the species and their allies strongly points to a place in the upper Devonian, the preponderance of the evidence being in favor of the Catskill-Chemung stage. Allowing for the full weight of the two or three species of close lower Carboniferous affinities, the flora can not at latest be assigned to a stage above the upper Catskill as developed in northeastern Pennsylvania and southeastern New York. Compared with the flora of other continents the closest paleontologic affinities of the Perry flora are found in the plant associations of the Donetz and of the Arctic Devonian.

The occurrence of closely related species of Barinophyton and Leptophlæum together with Archasopteris in the Devonian of Australia affords an interesting example of the remarkable intercontinental distribution of the later Devonian plant types.

The conclusions as to the age of the Perry beds recorded long ago by Sir William Dawson are fully corroborated by the study of more extensive material and the discovery of additional plants.

The Devonian of Aroostook County, Maine, is discussed by Williams and Gregory.[937a] Williams gives the following classification of the local subdivisions:

Recent investigation of the rocks of the northern part of Aroostook County has brought to light a few facts regarding the stratigraphic terranes, which may be stated with some degree of precision.

There are a few well-marked groups of rocks which are distinguishable by their lithologic characters, and the relative age of which is determined by their contained fossils. The order which the present knowledge of the faunas seems to indicate is as follows:

Devonian:
- 9. Mapleton sandstone.
- 8. Moose River sandstone.

Silurian:
- 7. Chapman sandstone. [a]
- 6. Square Lake limestone. [a]
- 5. Ashland limestone.
- 4. Ashland shales.
- 3. Sheridan sandstone.
- 2. Graptolite shales.
- 1. Aroostook limestone.

Below the Aroostook limestones are slates, which it is believed are of Cambrian age, but positive evidence of the age is wanting.

The lower seven belong to the Silurian; the upper two to the Devonian. The paleontologic evidence is clear in placing 1 to 5 below the Lower Helderberg horizon of the New York series.

The Aroostook limestone, on both stratigraphic and paleontologic grounds, is believed to be older than any other of the terranes mentioned in this list.

The Ashland limestone, Ashland shales, and Sheridan sandstone are faunally closely associated and belong together as the representatives of the Clinton-Niagara of the New York standard.

The Graptolite shales the writer believes to be of Clinton age, but their stratigraphic position in the Maine series is not satisfactorily established. They may belong in the midst of the

[a] Now known to be of Devonian age.—B. W.

series 3, 4, 5, or even above them; more evidence will be needed to determine their position with certainty.

The Chapman sandstone fauna is younger than the Square Lake fauna; the present opinion is that it corresponds closely with the Lower Oriskany of the New York and interior series. The identification of the fauna with Honeyman's zone D Arisaig and with the "Tilestone" fauna of Wales establishes its place at the top of the Silurian. (See Am. Jour. Sci., 4th ser., vol. 9, p. 203.)

The Moose River fauna is a facies of the Eodevonian and represents the Oriskany.

The Mapleton sandstone is the representative of the higher parts of the Gaspe sandstone, and is the Old Red sandstone facies not expressed in New York until a point higher up, in the Catskill sandstone, is reached.

Besides these terranes, determinable by their fossils, there are slates and crystalline rocks, the precise age of which is undetermined. The slates are presumably Cambrian or pre-Cambrian.

L 20. NOVA SCOTIA.

The supposed Devonian rocks of Nova Scotia were described in 1886 and 1890–91 by Fletcher,[334b, 335c] who distinguished a "lower conglomerate group," a "middle gray sandstone and slate group," and an "upper red slate and sandstone group." In his second report Fletcher gave the following general account:

> Most of the metamorphic areas of the hills of Antigonish, Pictou, and Colchester counties consist of rocks whose geological position is between the group containing marine fossils of Lower Helderberg age, and the Carboniferous or Mountain limestone, also characterized by the occurrence of marine types, whereas all the fossils found in the intervening Devonian consist of shells indicative of shallow-water origin, and of plants both drifted and erect, indicating land conditions. Between this series and those underlying and overlying, there is everywhere the clearest evidence of enormous unconformity, and although from the abundance of their plant remains they have sometimes been confounded with Millstone grit and even higher strata, their relations to the Carboniferous limestone at the East Mountain of Onslow and Penny's Mountain, at Shubenacadie, Stewiacke, Walton, Cheverie, Parrsboro, and wherever the two series are in contact, and the ease with which they can be traced from point to point, show that they are to be compared rather with the Mispeck and Little River groups of New Brunswick, and that the Carboniferous limestone rests unconformably on the slates.

In spite of their disturbed and partly altered condition, these rocks have yielded fossils, which show that a considerable part of the supposed Devonian contains a middle Carboniferous fauna and flora. The stratigraphic evidence of Devonian age has been controverted by the paleontologic evidence of Carboniferous age. Ami [22] has recently summed up the results of investigations covering both lines of evidence as follows:

> For many years it was taken for granted that the highly fossiliferous beds of carbonaceous shales, etc., known as "the fern ledges" of New Brunswick, were of Devonian age, although the character of the flora, even at first sight, is one of decidedly Carboniferous facies. The 80 or more species representing the flora of that period are preeminently Carboniferous, and recently Mr. David White has recorded no less than 17 species of Pottsville forms, which came originally from the "fern ledges." The Lancaster formation of the author was defined as that series of strata which held this very characteristic flora, and it is capped by another Carboniferous formation consisting of red shales and conglomerates, with but few species occurring therein; to which formation the designation Mispeck formation of New Brunswick was applied. These two formations, the Lancaster and the Mispeck, find their equivalents in the Union and Riversdale of Nova Scotia, which Sir William Dawson always held to be of Middle Carboniferous age (Middlestone grit).

The main argument advanced by those that held that these four Middle Carboniferous formations were "Devonian" was based on the supposition that the Lower Carboniferous limestones rested unconformably on these same or equivalent formations.

In two of the crucial localities in Nova Scotia visited by the writer some time ago, where Carboniferous shale rested unconformably on shales, etc., it has been ascertained beyond a doubt that in one instance (at West Bay, near Partridge Island and Parrsboro, in Cumberland County, Nova Scotia) the Carboniferous limestones proved, on examination of the organic remains entombed in them, to be of true and undoubted Upper Carboniferous age and not Lower Carboniferous, while in the other instance (in the MacArras Brook region of Nova Scotia, where the "Lower Carboniferous" strata rested unconformably on the so-called "rocks of Union," or Union formation) the writer finds that the subjacent strata are in no sense equivalent to the rocks of the Union formation at all (as they are developed at the type locality near Union station, on the Intercolonial Railway, just below Riversdale). The Lower Carboniferous strata at MacArras Brook rest unconformably on the upturned edges of the lowest Devonian of that region, as the fossil evidence obtained very clearly showed. The Knoydart formation, of Eo-Devonian age, as seen and developed at MacArras Brook, contains a fauna, which is so nearly allied and identical with that of the lower "Old Red sandstone" strata of Scotland and Great Britain generally that the two can very well be classed as homotaxial and belonging to the same period in the history of the earth's crust—a horizon or formation which had not been previously recorded in America and which, nevertheless, occupies a definite position, not at the summit of the Devonian, as some geologists would have us believe, but indeed at the very bottom of the system or division of the time scale.

The error of correlating the rocks of MacArras Brook with those of the Union has led to confusion, and the paleontological evidence, which has been obtained by the writer in both series of strata has conclusively shown that the one (Knoydart formation) indicates a typical "Old Red sandstone" fauna that is lowermost Devonian in age, while the other formation is distinctly referable to the Middle Carboniferous, being associated with and intimately related to the "rocks of Riversdale," containing a typical Meso-Carboniferous flora and fauna, which opinion Messrs. R. Kidston, Prof. David White, Dr. Wheelton Hind, Prof. Charles Brongniart, and Dr. Henry Woodward and others have shared with the writer. The fact that these "rocks of Union" and the "rocks of Riversdale" had for so many years been referred to the Devonian by Canadian geologists led the writer to seek diligently for Devonian types and forms in those strata, and it must be distinctly stated here that I utterly failed to obtain any horizon markers of Devonian aspect in the true rocks of Union and Riversdale. All types found were of decidedly Carboniferous facies and well up in that system. The fossil plants, the fossil fishes, the Crustacea, the insects, etc., all pointed to a horizon of Meso-Carboniferous age, and there we are constrained to place them.

I desire here to correct an error made by myself in following and accepting without verification the statement made by stratigraphical geologists that the "rocks of Union" and the "rocks of Riversdale" were always found overlain by the marine limestones of the "Lower Carboniferous" and were therefore older. On the contrary, I find that the so-called "rocks of Union" as they are developed at MacArras Brook, are the only strata that can in any sense be referred to the Devonian; in which instance it so happens that these so-called "rocks of Union" are not at all the same as those of the Union formation proper. This error on my part in taking for granted that all the strata were one and the same formation, and which had been referred to the "rocks of the Union" and the "rocks of the Riversdale" as unconformably below the limestones of the Lower Carboniferous, as the stratigraphical geologists had said, led me to make the further statement that the "rocks of Union" and the "rocks of Riversdale" were Eo-Carboniferous in age. In referring these strata to the Carboniferous, I was guided by the fossil remains entombed in them, whereas I was misled by the succession as given by the stratigraphical geologists without any qualifications. It was only when the faunas of the Knoydart formation, from the so-called "rocks of Union" in the MacArras Brook region, were obtained and determined by Dr. A. Smith Woodward and Dr. Henry Woodward and others, that the confusion that existed was evident to me, and the necessity of separating these two sets of strata became apparent. This led to the separation of the Knoydart formations from their supposed equivalents "the red rocks of Union." I have no hesitation in saying now that the Union and Riversdale formations, as they are developed at the type localities at the Union and Riversdale in Colchester county in Nova Scotia, are Carboniferous in age, and are Meso-Carboniferous at that. Further, it is also evident that the New Brunswick equivalents of these two formations, namely, the Mispeck and the Lancaster formations (the latter sometimes designated as the Little River group), can not any longer be classified as Devonian, but as truly Meso-Carboniferous formations, with an abundant flora found the world over, and in all countries other than Canada referred to as the Middle Carboniferous.

In view of the conclusion that the supposed Devonian of the original descriptions is in part Carboniferous, it is difficult to determine what the Devonian rocks of Pictou, Antigonish, and Colchester really are. A basal Devonian formation is, however, distinguished by Ami [18] as the Knoydart formation of Antigonish County. A detailed section of the rocks by Fletcher [18c] shows 684 feet of red sandstone and shale with greenish layers and thin flinty or calcareous or carbonaceous layers, some of which consist of volcanic ash. The included fossils are ostracoderms, constituting a very primitive and early type of fishes and establishing a close correlation with the lower Old Red sandstone of Great Britain.

The Silurian and Devonian iron-bearing formations of Digby and Annapolis counties, southwestern Nova Scotia, are thus described by J. W. Dawson: [266]

In Nova Scotia the rocks older than the Carboniferous system have all undergone more or less alteration and disturbance. This, with the imperfect preservation of their fossils and their inland position, renders the working up of their details of structure very difficult. Large tracts of country thus remain in a state of uncertainty, their rocks being manifestly older than the Carboniferous, but yet otherwise of uncertain age. In the case of the Devonian, the only place in which it has been clearly made out as distinct from the Silurian is the belt of hilly country extending along the south side of the Annapolis Valley. Here, in the section of the Nictaux River, the first old rocks that are seen to emerge from beneath the New Red sandstone of the low country are fine-grained slates, which I shall describe in the sequel as Upper Silurian. Their strike is N. 30° to 60° E., and their dip to the southeast at an angle of 72°. Interstratified with these are hard and coarse beds, some of them having a trappean aspect. In following these rocks to the southeast, or in ascending order, they assume the aspect of the New Canaan beds; but I could find no fossils except in loose pieces of coarse limestone, and these have the aspect of the Upper Arisaig series, or newest Silurian of the eastern part of Nova Scotia. In these and in some specimens recently obtained by Mr. Hartt I observe *Orthoceras elegantulum*, *Bucania trilobita*, *Cornulites flexuosus*, *Spirifer rugæcosta*?, and apparently *Chonetes novascotica*, with a large Orthoceras, and several other shells not as yet seen elsewhere—all Upper Silurian. These fossils appear to indicate that there is in this region a continuance of the upper Arisaig series nearly to the base of the Devonian rocks next to be noticed.

After a space of nearly a mile, which may represent a great thickness of unseen beds, we reach a band of highly fossiliferous peroxide of iron, with dark-colored coarse slates, dipping S. 30° E. at a very high angle. The iron ore is from 3 to 4½ feet in thickness. The fossils of the ironstone and the accompanying beds, as far as they can be identified, are *Spirifer arenosus*, *Strophodonta magnifica*, *Atrypa unguiformis*, *Strophomena depressa*, and species of Avicula, Bellerophon, Favosites, and Zaphrentis, etc. These, Professor Hall compares with the fauna of the Oriskany sandstone; and they seem to give indubitable testimony that the Nictaux iron ore is of Lower Devonian age. * * *

To the southward of the ore the country exhibits a succession of ridges of slate holding similar fossils and probably representing a thick series of Devonian beds, though it is quite possible that some of them may be repeated by faults or folds. Farther to the south these slates are associated with bands of crystalline greenstone and quartz rock and are then interrupted by a great mass of white granite, which extends far into the interior and separates these beds from the similar nonfossiliferous rocks on the inner side of the metamorphic band of the Atlantic coast. The Devonian beds appear to dip into the granite, which is intrusive and alters the slates near the junction into gneissoid rock holding garnets. The granite sends veins into the slates and near the junction contains numerous angular fragments of altered slate.

* * * * * * * * *

At Moose River the iron ore and its associated beds recur on the western side of the granite before mentioned but in a state of greater metamorphism than at Nictaux. The iron is here in the state of magnetic ore but still holds fossil shells of the same species with those of Nictaux.

Still farther westward, at Bear River, near the bridge by which the main road crosses this stream, beds equivalent to those of Nictaux occur with a profusion of fossils. The iron ore is not seen, but there are highly fossiliferous slates and coarse arenaceous limestone and a bed of gray sandstone with numerous indistinct impressions apparently of plants. In addition to several of the fossils found at Nictaux, these beds afford Tentaculites, an Atrypa, apparently identical with an undescribed species very characteristic of the Devonian sandstones of Gaspe, and a coral which Mr. Billings identifies with the *Pleurodictyum problematicum* Goldfuss, a form which occurs in the lower Devonian in England and on the continent of Europe.

Westward of Bear River rocks resembling in mineral character those previously described, and probably of Devonian and Upper Silurian age, extend with similar strike but in an altered condition and in so far as I have been able to ascertain destitute of fossils quite to the western extremity of the peninsula, where they turn more to the southward and are, as I suppose, repeated by a sharp synclinal fold, after which they are succeeded by the Atlantic coast series, of lower Silurian date and consisting of quartzite and clay slate, with chlorite and hornblende slates at Yarmouth and its vicinity, and farther to the southeast of mica slate and gneiss.

I can not certainly indicate the Devonian system in other parts of Nova Scotia. There are, however, in various places, at the margin of the Carboniferous areas, or projecting through these beds, rocks which may be Devonian, though, not having afforded characteristic fossils, their age must remain doubtful, as they might possibly prove to be altered members of the Lower Carboniferous or rocks of Silurian date. They are usually hard gray or purplish sandstones or quartzites, associated with gray or purplish slates or shales.

The above description is quoted by Bailey,[43a] who adds:

In 1892 a collection of fossils from Nictaux, Bear River, and Mistake settlement was made by the writer and Mr. W. H. Prest and tended to confirm the conclusions of Sir William Dawson, so far at least as regards the beds of Nictaux and Bear River. They were examined by Dr. H. M. Ami, who states,[a] as to the two former points at least, that the beds are transitional, being either at the summit of the Silurian or at the base of the Devonian epoch, the weight of evidence being perhaps in favor of the Eo-Devonian. The fossils from Mistake settlement indicate a Silurian tract.

Bailey then gives detailed descriptions of localities with lists of fossils collected at definite localities in the Nictaux-Torbrook, Clementsport, Bear River, and Mistake settlement districts.

[a] In Report (by L. W. Bailey) on southwestern Nova Scotia, vol. 6, pt. Q, 1892–93, p. 14.

M 11. ROCKY MOUNTAINS OF BRITISH COLUMBIA.

In the eastern range of the Rocky Mountains, at the gap of Bow River, Alberta, Ordovician strata are followed with apparent conformity by a quartzite succeeded by dolomites of Devonian age. These strata do not occur in the western range, where the "Halysites beds" (Silurian) are present. McConnell[559c] describes the Devonian ("Intermediate limestone") as follows:

The Intermediate limestone underlies the Banff limestone conformably, and passage beds partaking of the lithological character of both groups occur at the junction of the formations. It is mainly composed of a great series of brownish dolomitic limestones and has a thickness of about 1,500 feet. The typical dolomites of this formation are dark brownish in color, are finely crystalline, and are often irregularly hardened by concretionary action. They have, in many places, a blotched appearance, due to small cavities becoming filled with calc spar, are cherty, and are characterized throughout by an abundance of corals. In some sections a light-grayish variety is not infrequent. It is more coarsely crystalline than the dark variety and is unfossiliferous. In addition to the dolomites, beds and bands of sandstone, quartzite, and calcareous limestone are found all through the series. A light-yellowish siliceous band, varying in thickness from 100 to 400 feet, occurs near its base, on the south fork of Ghost River and along the eastern part of Devil's Lake valley, and is also found at the entrance to the White Man's Pass.

A good section across this series was obtained in the first range, near the Gap of the Bow. Here it dips to the west, at an angle of 40°, and is inclosed between the Castle Mountain and Banff limestones. The former, at this point, is terminated above by some shaly nondolomitic limestone, overlying which is about 40 feet of reddish and bright-yellowish weathering sandstones and quartzites, forming the base of the intermediate formation. Above these come several hundred feet of brownish-weathering, irregularly hardened magnesian limestone, holding cherts and corals, succeeded by light-colored, regularly bedded crystalline dolomites. The latter grade upward into a series of alternating beds of the two last varieties, associated with some beds of quartzite. Then comes a small band, consisting of soft greenish crumbling argillaceous sandstone, and hard yellowish-weathering quartzites, overlying which are 20 feet of grayish limestone. This limestone is succeeded by magnesian limestones and quartzites, above which come 50 feet of heavily bedded brownish-weathering dolomites, forming the top of the series and underlying the bluish massive beds of the Banff limestone. This section affords a fair general illustration of the relative lithological importance of the different members of the series, but could not be even approximately duplicated half a mile away, owing to differences in local detail.

* * * * * * * * *

The fossils of the Intermediate limestone are usually badly preserved and consist mainly of almost structureless corals.

M 19. NORTHERN NEW BRUNSWICK.

A small area of Eo-Devonian is shown on the map at the west end of Chaleur Bay. The rocks are red sandstone and gray shale associated with intrusive traps and with gray and purple feldspathic ash rocks. Coarse sandstones and conglomerates occur and carry Devonian plant remains.[305]

On the Restigouche, at the western extremity of Chaleur Bay, occurs a small area of Devonian strata which have afforded an interesting fish fauna and some plant remains. Whiteaves[922] narrates the early discoveries and summarizes the facts as follows:

The first of these discoveries led to further investigations by officers of the Canadian Survey in 1880, 1881, and 1882, which revealed the existence of a remarkable assemblage of fossil fishes and land plants of Upper Devonian age at Scaumenac Bay, and of an entirely different series of fishes and plants, of Lower Devonian age, on the opposite or New Brunswick side of the river, near Campbellton. Large collections were made at each of these localities, especially of the fossil fishes, which were described by the writer in 1880,[a] 1881,[b] and 1883,[c] and described and illustrated in 1887[d] and 1889.[e] Many of these specimens were exhibited and described at the meeting of this association at Montreal in 1882.

Comments on the species and references to the literature follow in Whiteaves's account.

M 20. GASPE PENINSULA.

Logan [544r] described from this region the Gaspe limestones and Gaspe sandstones and assigned them respectively to the Silurian and Devonian. Ells [306] reviewed their distribution and stratigraphy in the field and concluded that—

> Of these Gaspe limestones it is now considered that only the two lower members, representing a thickness of 160 feet, can with propriety be assigned to this system [Silurian] while the preponderance of fossils of Devonian aspect, even in the basal bed, renders it probable that the whole may ultimately be transferred to the Devonian system.

This statement by Ells is quoted with agreement by Clarke [157b] in a monographic work on the Gaspe section. Clarke, however, goes further and places all of the Gaspe limestones, including Logan's divisions 1 and 2 (St. Alban), in the Devonian as equivalents of the Helderbergian of New York.[157c] The Canadian Survey has not accepted this correlation and the map of North America expresses the classification and distribution determined by Ells.

According to Logan the Gaspe limestones "comprise about 2,000 feet. They are intimately interbedded with calcareous argillaceous shales and exhibit intraformational contortions and conglomerates." The Gaspe sandstones, which aggregate approximately 7,000 feet, are partly conglomeratic and vary in color from drab to red. They contain plant as well as marine animal remains and are interpreted by Clarke as the deposit from a land of strong relief in a lagoon communicating from time to time with the sea.

The fossils from the Gaspe sandstones are described by Billings,[83] who gives a condensed statement of Logan's section.

The age of the Gaspe sandstones has been discussed by Williams, Schuchert, and Clarke. Williams [936] briefly states the problem:

> In the York River beds at the base of the Gaspe sandstones there is found a number (at least a dozen) of fossils which if found alone would be intrepreted as positive evidence of an Oriskanian fauna; associated with these is another lot of fossils, at least as many, which if found alone would be as positive evidence of a Hamiltonian fauna. The sediments were deposited at some particular epoch of the geological time scale. What does this composite fauna signify as to the epoch to which the York River beds belong?
>
> Dr. Clarke in the volume referred to gives the decision in favor of the Hamiltonian epoch, apparently on the ground of the greater number of species identical or closely related to Hamil-

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[a] Am. Jour. Sci., 3d ser., vol. 20, p. 132; reprinted in Canadian Naturalist and Geologist, vol. 10, p. 23.

[b] Am. Jour. Sci., 3d ser., vol. 21, p. 94; reprinted in Ann. and Mag. Nat. Hist., 5th ser., vol. 8, p. 159; and Canadian Naturalist and Geologist, new ser., vol. 10, pp. 27, 93.

[c] Am. Naturalist, vol. 17, p. 158.

[d] Trans. Royal Soc. Canada, vol. 4, sec. 4, p. 101.

[e] Idem, vol. 6, sec. 4, p. 77.

tonian forms. If we accept his view it follows that the associated Oriskanian forms continued to live on after the epoch of the Oriskanian fauna into Hamiltonian time.

By the interpretation here offered it is assumed that the Hamiltonian types of the fauna are possible ancestors of Hamiltonian species living in the Oriskanian epoch, which by some movements of the currents of the ocean were brought together in the Acadian province before the revolution which upset the biologic equilibrium of the Oriskanian fauna had completed its work.

The further conclusion is that it was the same events which caused the cessation of the distinctive Oriskanian fauna, which brought into this area the ancestors of the Hamilton species, and that the geologic time of the events was approximately equivalent to the Schoharie epoch of New York State.

M-N 14. MANITOBA.

The Devonian of Manitoba consists of about 500 feet of strata, chiefly dolomite which represent Lower, Middle, and Upper Devonian terranes. They are described by Tyrrell [817] as follows:

	Feet.
Upper Devonian or Manitoban:	
Light-gray hard, brittle limestone containing *Athyris vittata*, etc., underlain by red argillites, outcropping at Rose Island and in the vicinity in Swan Lake, and at Point Wilkins	100
Light-gray hard limestone, seen at Onion Point, Snake Island, Beardy Island, etc	40
Red and gray shale, seen near the mouth of Bell River, south of Weston Point, etc	70
Middle Devonian or Winnipegosan:	
Whitish or light-yellow hard, tough, generally compact dolomite containing *Stringocephalus burtini* and numerous other fossils. It outcrops chiefly on the island and shores of Dawson Bay, and southward to Point Richard on Lake Manitoba	100
Porous spongy yellow dolomites of Pemmican Island, Devil's Point, Macoun Point, etc	100
Lower Devonian:	
These beds have not been clearly defined, but they appear to be composed of red and other shales	100

Whiteaves [917] has described the fossils from these Devonian rocks and says:

It has already been stated that all the fossils that are enumerated or described in the present paper are probably from the Middle and Upper Devonian. The Middle Devonian appears to be represented in this region by the Stringocephalus zone and the 100 feet or more of fossiliferous dolomite immediately beneath it, and the Upper Devonian by all the beds above the Stringocephalus zone and beneath the Cretaceous.

The discovery of dolomites in which *Stringocephalus burtini* is one of the most characteristic fossils, at many localities on the shores or islands of Lakes Manitoba and Winnipegosis, is of considerable interest to the geologist. In Manitoba the Stringocephalus zone appears to occupy much the same stratigraphical position as the Stringocephalus limestone of Germany and England, and it is noticeable that among the fossils of the Stringocephalus zone of Manitoba there are several which can be identified with well-known European species.[a]

The "Cuboides zone" appears to be represented in this region by those beds on the Red Deer River and elsewhere.

M-N 16-17. JAMES BAY, ONTARIO.

In 1875 Bell [65] reported the occurrence of dark-gray bituminous limestone at the Grand Rapids of the Mattagami (latitude 50°, longitude 82°) and collected fossils, which Whiteaves reported as being of Devonian age, of the horizon of the "Corniferous" limestone. The strata are exposed in a cliff 40 feet high. They are flat lying and rarely outcrop in the district, but extend north beneath James Bay and beyond Albany River. Dowling [291b] states that the Devonian rocks do not reach

[a] For list of fossils see the work cited.—B. W.

the Attawapiskat on the north but are confined to the southern part of James Bay and the adjacent country extending a short distance north of the Albany.

Parks [629] describes the strata exposed on Kwataboahegan River as limestones of a yellowish-brown color, literally filled with organic remains. A grayish limestone, poorer in mollusks but richer in corals and brachiopods, also occurs, but the relations of the two were not determined. Many species are described and figured.

N 9, O 8. SOUTHEASTERN ALASKA.

Devonian limestones occur intercalated with igneous rocks in the islands of southeastern Alaska. The recent work of Wright and Kindle has resulted in collections of fossils which have marked European affinities and represent Lower, Middle, and Upper Devonian but which are not related to the American contemporaneous faunas. No complete section of the series is known. Exposures on Long Island, Kasaan Bay (latitude 55°, longitude 133°), show 470 feet of Middle Devonian limestone, conformably overlying bedded igneous rocks. Lower Devonian limestone occurs at Freshwater Bay, Chichagof Island (latitude 58°, longitude 135°). On the west coast of Prince of Wales Island fossils of the Upper Devonian have been collected.[496a]

N-O 12-13. ALBERTA AND SASKATCHEWAN.

Devonian limestone extends horizontally beneath the superficial deposits of parts of Saskatchewan and Alberta, outcropping here and there in river gorges and occasioning rapids in the streams. On the east it rests upon "Laurentian" and on the west it is overlain by horizontal Cretaceous beds ("Tar sands," referred to the Dakota by McConnell).[561b] The section on lower Peace River, according to Macoun,[568] exhibits thin-bedded limestone strata made up almost wholly of branching corals and carrying beds of white gypsum. Higher up the stream the limestone is evenly stratified, is light grayish or cream-colored, and alternates with softer, more argillaceous bands.[561]

O-Q 9-12. MACKENZIE BASIN.

East of the Rocky Mountains in the Mackenzie basin Devonian rocks have a wide distribution. The strata classed as Devonian may include Silurian below and exhibit a transition phase toward the Carboniferous above. McConnell [560] states:

> Devonian rocks * * * underlie the greater part of the country bordering the Mackenzie, all the way from Great Slave Lake to below old Fort Good Hope, a distance measured in a straight line over 700 miles. They were found all around the western arm of Great Slave Lake and were traced up Hay River to the falls and up the Liard to the "Long Reach." South of the Liard and extending as far south as the Peace River, the Devonian outcrops at the surface in a broad band, averaging fully 150 miles in width, striking in a northwesterly and southeasterly direction, parallel to the western margin of the Archean axis. On the southwest it is generally overlain by the Cretaceous and on the northeast overlaps all the older Paleozoic formations and comes directly in contact with the Archean. In all this region the beds are practically undisturbed and are seldom affected by dips exceeding a few feet to the mile.
>
> * * * * * * * * *
>
> Throughout the Mackenzie district the Devonian is generally divisible lithologically into an upper and lower limestone, separated by a varying thickness of shales and shaly limestones, but in some cases limestones occur throughout. The upper division has an approximate thickness of 300 feet and consists of a compact yellowish-weathering limestone, occasionally almost

wholly composed of corals, interstratified with some dolomitic beds. This limestone is well exposed at the falls on Hay River and also at the Ramparts, on the Mackenzie. In both these places it is underlain by several hundred feet of greenish and bluish shales, alternating with thin limestone beds. At the "Grand View," on the Mackenzie, the shales are hard and fissile and are blackened and in places saturated with petroleum. At the Rock by the River Side and at other places where the beds are tilted and older rocks exposed the middle division is underlain by 2,000 feet or more of grayish limestones and dolomites interbedded occasionally with some quartzites. No fossils were collected from the lower part of this series, and rocks older than the Devonian may possibly be represented in it.

Representative collections of fossils, showing a mixture of Hamilton and Chemung forms, were obtained from the upper part of the shales on Hay River, at a point about 40 miles above its mouth, and from the same horizon at the Ramparts, on the Mackenzie. The lithological characters and the stratigraphical relations of the limestones at these two points, notwithstanding the fact that they are separated by a distance of over 570 miles, are almost identical. The fossil faunas also at the two points show similar close relations, the principal differences being the presence of *Rhynchonella cuboides* and *Spirifera disjuncta* at Hay River and of *Stringocephalus burtini* at the Ramparts. This might seem to indicate that the beds at the Ramparts are slightly older than those at Hay River, but Mr. Whiteaves thinks that both are referable to the Cuboides zone.

Fossils collected from the Devonian of the Mackenzie basin by early expeditions were described by Meek,[585a] who gives an account of the history of exploration and of the fossiliferous localities. Whiteaves [916] has discussed the collections subsequently made by the Canadian Survey parties. He describes the Devonian species from the Mackenzie represented in the museum of the Canadian Survey and lists them according to localities from southeast to northwest. He then comments:

An analysis of these lists shows that 22 of the species are found also in the Hamilton formation of Ontario or the State of New York. [List follows.]

In the Mackenzie River district, however, the subdivisions of the Devonian system that exist in the State of New York and Ontario are probably not recognizable, and there are strong reasons for supposing that the whole of the fossils reported upon in these pages belong to the "Cuboides zone."

It is true that *Rhynchonella cuboides* itself has so far been found only on the Peace and Hay rivers, where it is invariably associated with *Spirifera disjuncta* (or *verneuili*), but other fossils eminently characteristic of the Cuboides zone will be noticed in nearly all the foregoing lists of species from the Athabasca and its tributaries or from the Mackenzie.

The paper concludes with a discussion of the Cuboides fauna and a comparative list of 29 identical species from the Mackenzie basin and the European side of the Atlantic.

P 4–5. ALASKA RANGE AND SOUTHERN ALASKA.

Devonian rocks are included in the Paleozoic complex that forms the western slope of the Alaska Range, in the strike of the formations which occur throughout the Yukon-Tanana region, but they have not been differentiated.[101d] Middle Devonian fossils have been found in a blue siliceous limestone at several localities.

In the Copper River district the Nikolai greenstone, composed of volcanic flows, resembles the Rampart group (Devonian) of the Yukon and is shown by Brooks [101] to occur stratigraphically at a similar horizon. Later studies, however,[599] have tended to prove a later age (late Carboniferous or Triassic) for the Nikolai greenstone.

The Wellesley formation (conglomerate and slate) of upper Tanana and White rivers is either Carboniferous or Devonian. It is correlated with the Chisna formation of the Copper River district and possibly with the Cantwell formation of the Nenana River section and may represent the base of the Devonian, lying unconformably on older rocks. In a recent paper [104a] Brooks places the Chisna, Wellesley, and Cantwell in the Carboniferous.

P 8. YUKON TERRITORY.

The Ogilvie Range, which forms the divide between Stewart and Peel rivers, is said by Keele [474] to consist largely of Devonian strata—limestones, ferruginous slates, and quartzites. These rocks are mapped as altered Paleozoics. Camsell [128d] collected on Braine Creek, a tributary of Stewart River, and at Braine Pass (latitude 64° 30′, longitude 135°), at its head, fossils which Whiteaves identified as Favosites, Productella, and *Atrypa reticularis*.

The Braine Pass and section are described as follows:[128]

> Topographically the country between Beaver River [a tributary of the Stewart] and Wind River [a tributary of the Peel] is one of rather rugged relief. This is the backbone of the great Rocky Mountain system, which here trends northwest and southeast, swinging slightly from its almost north and south trend farther south. This particular section is called the Ogilvie Range. Few prominent peaks occur, and from the tops of any of them a general accordance of level can be noticed. The summit of Braine Pass is estimated at about 3,400 feet, and the elevation of the highest peaks in the neighborhood at 6,800. * * *
>
> A section across the summit from the Beaver River to the Wind shows a series of closely folded and sometimes faulted limestones and slates with some quartzites and conglomerate. Cutting these are some diabase dikes and intrusive rocks. The succession in descending order is somewhat as follows: Massive dovecolored limestone becoming shaly at the base; bands of black slate; massive granular limestone containing fossils; ferruginous slates, weathering red; and black-weathering conglomerate at the base. * * *
>
> The great valley at the head of Braine Creek, which forms the pass across to the Wind River, is apparently a great line of weakness, which has resulted in [from] an overthrust fault, thus bringing up the underlying ferruginous slates to the surface.
>
> Some fossil corals and brachiopods collected from the limestone at the summit and lower down Braine Creek have been identified by Dr. Whiteaves as Devonian forms.

Q 3. SEWARD PENINSULA.

In the southeastern part of Seward Peninsula, north of Golofnin Bay, Devonian fossils have been found on Fish River. Somewhat farther northeast, on the Darby Range, fossils which are regarded as Devonian or possibly Carboniferous have been obtained.[a]

Q 6–7. YUKON-TANANA REGION.

The Rampart group, consisting of volcanic rocks with intercalated slates and limestones, was assigned by Brooks[101e] on fossil evidence to the Devonian, "probably to the Middle Devonian." In general terms the Devonian of the Yukon-Tanana region may be said to be made up of shales, slates, and cherts, with some limestones; locally ancient lava flows and tuffs predominate over the sediments. On the Yukon the igneous rocks are much more abundant than the sediments; on the Porcupine sediments are most abundant. The thickness of the group is much in doubt but

[a] Smith, P. S., personal communication.

can not be less than 3,000 feet and may be twice as great. The relation of the Devonian to the Silurian is unknown, but is probably one of unconformity.[102]

The following notes on the Porcupine Valley are taken from a paper by Kindle:[497]

The lowest division of the Devonian is a limestone formation about 325 feet in thickness. It is a massive light-gray to blue limestone weathering buff and considerably broken by joints. It rests apparently unconformably on the graptolite shales described above and is followed in the section by brown shale. The lower 5 feet of this shale may be seen resting directly on the limestone on the bank of the Salmontrout River just above its mouth. The total thickness of this shale is unknown, but, judging from the covered slope extending upward from the limestone along the Salmontrout River, it probably amounts to several hundred feet. Outcrops of the limestone described occur on both banks of the Porcupine immediately above the Salmontrout River, and it is proposed to call this formation the "Salmontrout limestone," from the Salmontrout River, which is the nearest geographic feature having a name available for a formation name. Fossils are abundant throughout this limestone. Its strike and dip are concordant with that of the subjacent Silurian shale and limestone and afford no evidence of deformation at the close of Silurian sedimentation.

Although no angular unconformity is shown in the relations of the Silurian and Devonian series where observed, unconformable relations between the two are attested both by the lithology and the faunas. In passing from the Silurian to the Devonian the lithologic change is an abrupt transition from black shales to very pure limestones. The faunal change is from a Silurian graptolite fauna to a Middle Devonian fauna, the Lower Devonian fauna being absent. The Devonian limestone forms a continuous outcropping cliff 100 to 200 feet high for 1 mile above the Salmontrout River, along the east bank of the Porcupine. It also outcrops on the opposite side of the river in isolated exposures.

Kindle gives a provisional list of 54 species preliminary to a full description of the fauna and concludes:

There are present in it several species which are either closely allied to or identical with species which first appear in the better-known American sections at a Middle or Upper Devonian horizon. Since characteristic Lower Devonian species appear to be absent from the fauna, its age seems to be either Middle or Upper Devonian. The list contains some species not known below the Upper Devonian in the United States. One of the best known of these is a variety of *Pugnax pugnus*, a species which ranges from the Rocky Mountains to New York State and into the Mackenzie River district. *Stropheodonta arcuata* and *S. calvini* are also known to have a wide distribution in the Upper Devonian. *P. pugnus* and *S. arcuata* first appear in the New York section at the horizon of the Ithaca fauna. Associated with these Upper Devonian forms we find several species characteristic of Middle Devonian horizons. Among these are *Pholidostrophia* cf. *iowensis*, *Cyrtina* cf. *hamiltonensis*, *Schuchertella chemungensis* var. *arctostriatus*, *Reticularia fimbriata*, *Nucleospira* cf. *concinna*, and species resembling the European forms *Gypidula* cf. *biplicatus* and *G.* cf. *galeatus*. Two possible explanations of this association of Middle and Upper Devonian species in the same fauna present themselves. It has been shown by Williams and Kindle that Middle Devonian species sometimes persist till late Devonian time and appear in certain New York sections associated with Upper Devonian species.[a] It appears most probable, however, from what we know of the relations of *Pugnax pugnus* and its associated fauna to the Upper Devonian of New York, that the occurrence of Upper and Middle Devonian species in the same fauna at Old Rampart is not the result of late persistence of the earlier fauna. This species evidently migrated into the New York province from the northwest in Upper Devonian time. The two significant facts of its association with Middle Devonian fossils in an Alaskan fauna and its abrupt appearance in an Upper Devonian fauna in the United States, taken together, point very strongly to the probability that intercommunication between the eastern Alaska province and the interior American

[a] Am. Jour. Sci., 4th ser., vol. 13, 1902, p. 429.

province was cut off during Middle Devonian, but became free about the beginning of Upper Devonian time, when conditions became favorable for the dispersal and migration of such forms as were adapted to it. Some of the species which had during Middle Devonian time been confined to this northern basin spread southward and helped to give a distinctive character to the Upper Devonian fauna as we know it in the United States. This appears to be the probable explanation of an association of species which upon casual examination seems to afford contradictory evidence as to the age of the fauna. If correct, the horizon represented is Middle Devonian.

The Devonian limestone outcrops on both sides of the Salmontrout River near its mouth. Brownish-colored shales overlie the limestone here and extend apparently to the top of the high ridge lying to the south of the stream and represent a thickness of several hundred feet. No fossils were found in these shales, but they are supposed to represent the Upper Devonian, because their relation to the Devonian limestone is similar to that held by shales holding Devonian fossils along the Yukon River. Carboniferous beds replace the Devonian outcrops along the Porcupine about 1 mile below the Salmontrout River. These seem to be of Upper Carboniferous age. Evidence of faulting which appears on the north bank of the river here indicates that the Lower Carboniferous and perhaps a portion of the Upper Devonian may be concealed by a fault. The horizon of the brown shale appears locally to be largely occupied by beds of basalt representing old sea-bottom outflows during the Upper Devonian.

The shale series which terminates the Devonian probably has a considerable thickness, though no estimate can be made from the exposures mentioned, because the thickness exposed to view is probably reduced by a fault lying to the southwest of the Salmontrout River.

The shale horizon appears to be occupied locally by basalt flows of late Devonian age. A considerable thickness of such beds, which are believed to be of Devonian age, forms the lower end of the Upper Ramparts. This rock is a close-grained dark-greenish to black rock, showing bedding planes. These strike about north and south and dip east at about 40° for nearly half a mile above Redgate. Near the top of this igneous series a belt of sedimentary rocks is sandwiched into the basalts, showing the following beds:

Section one-half mile above Redgate.

	Feet.
Gray limestone	4
Red and green shale	14
Brecciated limestone with included masses of shale	8
Light-gray limestone	35
Red shale	30

Two or three miles west of the Coleen River the basalts occur again. Here they overlie a considerable thickness of drab and pale-red shales. Black shales are interbedded with the upper belt of basalt at this point.

Q 8. PEEL RIVER.

Peel River, flowing north from the Rocky Mountains of Yukon Territory to the Mackenzie delta, traverses two canyons in folded black slates, which are alternately thick and thin bedded and in places bituminous, and crystalline limestone, which apparently underlies the slates. These strata are assigned by Camsell[128b] to the Devonian on the ground of their lithologic resemblance to the Devonian of the Mackenzie Valley.

Q–R 5. ENDICOTT RANGE.

Nothing definite is known regarding the age of the pre-Carboniferous rocks of the Endicott Range, but the Fickett "series" and the Stuver "series" may include Devonian rocks, and the Bettles group is referred to the Devonian by Schrader, who found fossils of Devonian or Carboniferous age in gravels of Chandalar River. Brooks,[101c] however, regards the Bettles as possibly Silurian.

R 3. CAPE LISBURNE.

At Cape Lisburne Collier[164,165a] found 2,000 feet of sandstone and slate, conformably underlying Carboniferous (Mississippian) strata, and provisionally assigned them to the Devonian.

S 27. EASTERN COAST OF GREENLAND.

The Devonian of northeast Greenland is described by Nathorst,[609d] who says:

The Silurian strata, as we have seen, are folded and compressed and partly metamorphosed. If this bears any relation to the formation of a mountain range, the folding took place before the deposition of the Devonian strata, for the latter show only a relatively slight amount of disturbance. Otherwise it must be surmised that the folding was the result of a depression of the Silurian strata along a fault at their eastern border, or perhaps between such a fault and another which can be imagined as passing west of the present boundary of the Archean.

On the eastern side of Waltershausen Glacier, north of the mouth of the Myskox Fiord, the wall of the fiord is composed of a light-gray, nearly horizontal sandstone, upon which are situated two hills of red sandstone. At the place where North Fiord turns toward Josefs Fiord there is a slight syncline, the center of which is composed of red sandstone. As the height of the mountain here, according to Desen's calculation is 1,500 meters, the thickness of the formation in question ought to be still somewhat greater. On the south side of Franz Josefs Fiord the Silurian strata south of Cape Weber are overlain by gray sandstone, dipping eastward, and this is in turn followed by red sandstone. The dip then changes to west, so that the gray sandstone crops out again, then again dips east, and disappears. At Cape Graah (the point north of Dusen's Fiord) the dip is again west and a gray-green sandstone is again visible. But I am not sure whether this belongs to the lower gray sandstone or is a member of the red; the latter view seems to me to be the most probable. In the gray-green sandstone, which is very micaceous, I collected at our place of anchorage, the 30th of August, some faint impressions of fossil plants, like those found in the Devonian strata of Spitzbergen, and a fish scale; and in the red sandstone, which overlies the green, I and Forester Nilson found many fine specimens which, according to A. Smith Woodward, belong to *Holoptychius nobilissimus.* Ag. Dusen, who botanized in the mountain to the south, said he found mollusks in the sandstone there. On a little outjutting point just east of here the rocks changed, being more brownish red and tough, with yellowish layers. * * *

The Devonian strata on Ellas Island are separated from the Silurian by a fault. This Devonian part possibly lies only in a local depression. But also north of Cape Weber there is a sharp fault between the two systems; the Devonian is lower in relation to the Silurian. On the south side of Franz Josefs Fiord the Devonian strata appeared to rest conformably upon the Silurian, although the Silurian strata appeared to have been deformed. Nearly everywhere this appeared to be the case near the contact between the two, and in my notebook I used a special term, "the irregular red," for this zone of deformation.

S-U 15-20. ARCTIC ARCHIPELAGO AND NORTHWESTERN GREENLAND.

The occurrence of Devonian strata on the eastern coast of Grinnell Land was mentioned by Dawson.[257g] A full section is described by Schei from the southwestern shores of Ellesmere Land. (See pp. 266–268, Chapter V.)

CHAPTER VII.

PALEOZOIC UNDIVIDED.

Color, light reddish purple.
Symbol, 19.
Distribution: Little-known regions of the northern Cordillera, Montana, and Canada. (See fig. 9.)
Content: Paleozoic in general, where data do not suffice to map the divisions separately. Includes some known marine Triassic in the Canadian Rockies.

METAMORPHIC PALEOZOIC UNDIVIDED.

Color, light reddish purple with light dashes.
Symbol, 20.
Distribution: Venezuela, northeastern Appalachian region, northern Cordillera, California to Alaska. (See fig. 9.)
Content: Metamorphic sedimentary rocks of known or supposed Paleozoic age, together with possibly pre-Paleozoic schists and some igneous intrusive rocks, which have not been separated. Includes some known marine Triassic in the Canadian Cordillera.

Areas mapped as Paleozoic undivided.

B–C 18–19. VENEZUELA.

For the geology of Venezuela, we refer to Sievers's work [741] on the Cordillera de Merida. Under the heading Archean, Sievers describes the granite, gneiss, mica schist and other crystalline schists, and clay slate. After describing the distribution of the granite, gneiss, and crystalline schists and giving in particular many local details which are beyond the scope of this work, he says of the clay slates that they constitute the uppermost division of the Archean, are of general occurrence, and rest as a rule upon crystalline schists, but in part upon the gneiss and also directly upon the granite. From these relations it is apparent that the clay slates are distinguished from the other rocks of Sievers's Archean by an unconformity. The compilers of the map of North America have endeavored to maintain the distinction which appears on Sievers's map and have mapped the clay slates and the underlying crystalline rocks as separate divisions, assigning the former to the metamorphic Paleozoic and

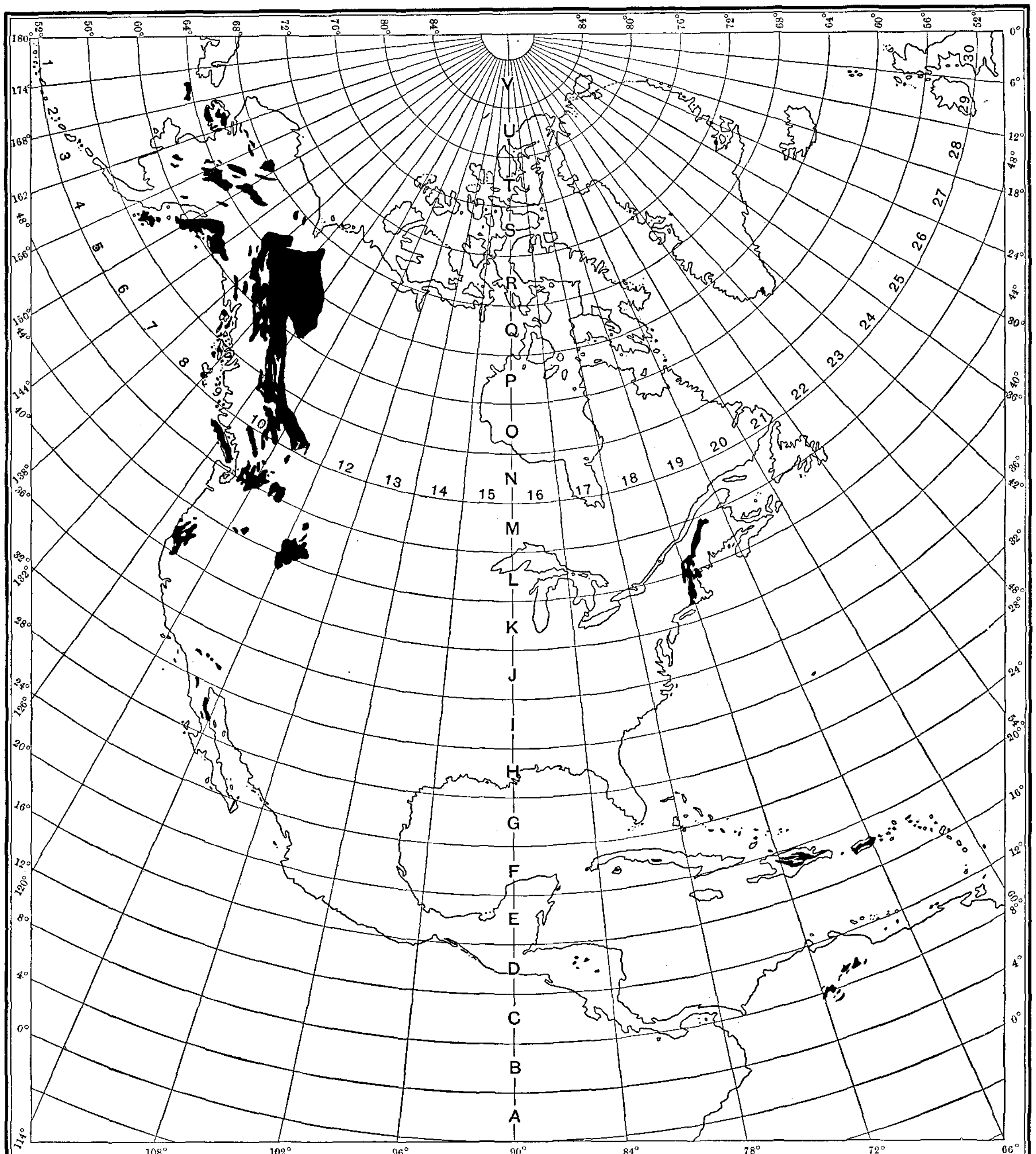

FIGURE 9.—Sketch map showing the distribution of Paleozoic rocks that are undivided on the geologic map of North America and the key to the references in the text.

the latter to the undifferentiated pre-Cambrian. In so doing they have followed only the suggestion of the lithologic descriptions, as there is no evidence on which to assign either division to a particular geologic age. Sievers states:

The clay slate is mostly thinly laminated, grayish, brownish to reddish, or bluish to black in color, and frequently has the character of roofing slate. It occurs chiefly in the middle zones of the Cordillera, from 900 to 3,000 meters, and has an extraordinary development. It is a striking fact in the distribution of the clay slate that in the western portion of the mountains it occurs chiefly south of the gneissic chain; elsewhere, in the eastern mountains, it occurs north of the chain.

Following these general notes are several pages devoted to the local distribution of the clay slate.

C 20. TRINIDAD.

The geology of Trinidad was described in 1860 by Wall and Sawkins,[863] geologists of the Geological Survey of Trinidad. Their work appears to have been so thorough that it is still the basis of our knowledge of the island. They say in part as follows:

It is proposed to term that series of micaceous slates, sandstones, limestones, and shales which are the constituent strata of the northern littoral range of Trinidad the Caribbean group, since it forms the southern boundary of the Caribbean Sea; and, from reasons to be adduced hereafter, probably the littoral chain of Venezuela, partly composed also of mica slates and associated rocks, may present a continuation of the same formation.

The central range comprises an indurated formation of lower Cretaceous age and is apparently a fragment of an immense series which contributes very largely to the Cordillera of northern Venezuela. These deposits are perhaps equivalent to the series of strata observed very extensively in New Grenada and other parts of South America, and described as corresponding to the Neocomian horizon. However this may be, till further investigation more fully exposes the relations of all these deposits, it is well to localize their occurrence; and as this formation was first observed on the shores of the gulf which separates the island from the main, it may be appropriately associated with the name of that sea, and will be described as the older Parian group.

A considerable proportion of Trinidad is occupied by a series of Tertiary strata, probably of Miocene age, but since the precise equivalency is not yet established, this series may, for reasons similar to those above stated, be conveniently designated as the newer Parian group. * * *

The most prevalent beds of the [Caribbean] series consist of mica slates, presenting numerous varieties, sometimes appearing as layers of quartzose matter, separated by thin plates of mica; at others, merely as repetitions of micaceous laminæ with little associated substance, frequently possessing extreme hardness and often degenerating into soft micaceous shales. There are several localities where peculiar black slates of ambiguous nature occur. On closer examination, these seem to be also micaceous schists, the plates of that mineral inclosing pellicles of graphitic matter.

The mica often possesses a peculiar glossy appearance and presents numerous shades of white, yellow, green, brown, red, and black. Of these, green occurs most frequently, after which yellow.

Some of the schists of finer texture are analogous to clay slates but really consist of smaller particles of mica, with finely divided feldspathic matter.

Quartzose slates frequently occur and, what is rarer, ferriferous slates—that is, foliated rocks in which quartz alternates with oxides of iron, characterized sometimes by great regularity, but more generally the ferriferous laminæ occur at unequal intervals.

Of sandstones there are a considerable variety, from fine to coarse grained, some externally soft and others of the hardest consistency.

It is not unusual to meet with varieties, especially the coarse grained, in which the mica is sufficiently abundant as, by the parallelism of its plates, to communicate a laminar and even fissile structure.

The term quartzite must be understood in this report as implying siliceous strata, whose matter exhibits no granular structure but is continuous and yet perfectly distinct from vein or segregated quartz.

Beds of this substance are of common occurrence, generally assuming a vitreous character, but in some instances rather that of hornstone. They are intimately associated with the sandstones and seem occasionally to graduate into the latter.

Shales, which are also numerous, appear sometimes ferruginous or highly carbonaceous, often associated with mica, and generally soft. * * *

Calcareous rocks are represented by two varieties in this series, viz, crystalline limestones contained in the slates and alternating with them, and compact limestones, either quite unconnected with the schistose group or only associated with its upper strata. The former occur sometimes in massive beds, varying from white to blue in color, often with scattered spangles of silvery-white mica, and distinguished by decided crystalline structure. Thinner beds of similar lithological characters, from a few inches to several feet in thickness, exhibit repeated alternations with the slates or shales.

Calciferous slates are beds of calcareous base, but with a considerable proportion of earthy matter and a laminar or schistose structure.

The Caribbean terrane is much folded and sheared. The report cited contains many striking illustrations of the structure. The sequence of the component formations of the group was not satisfactorily made out, and the age, beyond the fact that it is pre-Cretaceous, also remains undetermined.

D 16. NICARAGUA AND HONDURAS.

The pre-Triassic rocks of Honduras are assigned by Mierisch and Sapper to the Paleozoic and are so mapped. Sapper [696] states:

The occurrence of Paleozoic rocks in southern Central America has not been demonstrated with certainty, as it has not been possible to find fossils in the strata. Nevertheless, it appears to be highly probable that there belong to the Paleozoic those rocks which Mierisch assigned to that age, namely, the very steeply dipping limestones, calcareous mica slates, phyllites, clay slates, quartzites, talc, gneisses and amphibolites, talcose and chloritic schists of northeastern Nicaragua; but whether they belong to the Devonian, Silurian, or Cambrian, as Mierisch thought, or may perhaps be of the same age as the Carboniferous terranes of Guatemala, Chiapas, and British Honduras, can not be surmised. According to Mierisch the area covered by these formations in Uli and Uani, as well as in the mining districts of Concepcion and El Dorado, is considerable, although this fact does not appear on his geological map.

Sapper goes on to mention several localities in Nicaragua and Honduras in which he has observed slates, quartzites, conglomerates, and other rocks which are mapped as Paleozoic, though without any specific evidence. He says:

In regard to the age of these rocks I can only suggest an inference. It seems to me most likely on grounds of lithologic similarity that these formations are to be assigned to the Paleozoic, along with the slates of the Rio Coco; but it is not impossible that they may be a part, and in that case the lower part, of the Tegucigalpa formation [Triassic].

E 19. SANTO DOMINGO AND PORTO RICO.

Hill [444] makes the following statement with regard to Santo Domingo:

In general, the geology of the island is similar to that of Cuba and Jamaica, more especially the eastern ends, being composed of four principal formations—the older mountain rocks, of

Cretaceous and Tertiary age, made up of igneous rocks and clays, mantled by gravels and crystalline limestone; the white limestones, of Tertiary age; recent alluvial formations; and the coast limestone of elevated reef rock. No recent volcanic rocks are known. The geology and minerals of Santo Domingo have been the subject of special reports by many writers, including three American geologists, Messrs. Blake, Gabb, and Marvin.

The terrane which is mapped as undivided Paleozoic on the island of Santo Domingo corresponds to the Sierra group of Gabb, who placed it in the Cretaceous. According to his description he collected distinct Cretaceous fossils in the southern part of the island, but elsewhere the strata are metamorphosed to such an extent that no fossils have been found. In view of the facts that much of the terrane is highly metamorphosed and that the discovery of fossils has been limited to the southern margin of the uplands, it seems not unreasonable to suppose that some of the rocks may be not only older than Cretaceous but possibly pre-Mesozoic. Were they colored as Cretaceous they would naturally be associated with the fossiliferous Cretaceous limestone of the West Indies and the adjoining continent. The compilers have therefore distinguished them by placing them in the somewhat indistinct class of undivided Paleozoic rocks, including areas of younger strata. That portion of the strata in which Cretaceous fossils have been found is mapped as Cretaceous. Gabb [352] says:

No formation older than the secondary era has been found on the island, the oldest group being the great mass of slates, conglomerates, and limestones which form its core. These are uptilted and broken by numerous intrusive masses of crystalline rocks which may be, for convenience, grouped under the generic term of syenite, since they almost invariably consist of the three necessary minerals quartz, feldspar, and hornblende.

Flanking the slates, etc., of the Sierra there is a broad development of Tertiary marking all the northern and a part of the southern side of the island, and this in turn is bordered by a more recent deposit of limestones and gravels which I shall call the Coast formation.

The Sierra group forms all of the great mountain mass of the interior, extending the entire length of the Republic.

It also constitutes the greater part of the Peninsula of Samana and appears as a single little outlier, under the Tertiary, near Puerto Plata. It everywhere shows the evidence of active subterranean forces, being not only metamorphosed, with hardly a single local exception, but is everywhere much uptilted and usually strongly folded. Over much of its area the metamorphic action has been so complete as to destroy the traces of stratification or to so nearly obliterate them that they are apt to be confounded with cross fractures. * * *

But enough of the stratification is preserved to show conclusively that these beds lie in a series of east and west folds, the line of folding and upheaval corresponding very closely with the axis of the mountains. The thickness of the deposit is very difficult to determine, since no continuous section exists, where one can be certain of having all the beds and of not being deceived by repetitions. On a very rough estimate, not based on measurements, however, but only on the broadest kind of vague generalization in the canyons of the Ocoa and Nigua rivers and again on what I saw of the formation in the vicinity of the Pico del Gallo, we might set down the total thickness at anywhere between 2,000 and 4,000 feet. It must be understood that this broad margin is not the result of want of care in observation but arises from the almost absolute impossibility of finding a reliable section. In one region a group of conglomerates occurs; in another, within 40 or 50 miles, these same beds are represented by limestone, without a pebble; and on the same strike within another 20 miles neither limestone nor conglomerate is to be found; all is a semitalcose slate too friable to yield a hand specimen and with no distinguishable stratification. Add to this the partial obliteration of character by different degrees of metamorphism, and the sometimes total obliteration of bedding, and the reasons of my cautious statement must be sufficiently obvious.

In the interior of the mountains, especially in the western two-thirds, the disturbance has been greatest, and the reason appears in the existence of great masses of eruptive rock which have pushed up the slates, broken them, and in some cases penetrated them by dikes to a distance of several miles from the parent mass. In some cases pieces of the wall rock are found embedded in the syenite; and pebbles one-half syenite and the other half jaspery are not rare.

In its original state this group of beds seems to have consisted of a series of clay shales, thinly bedded, others more heavily bedded and with layers of sandstone, conglomerate, limestone, and heavy-bedded sandstones. The changes produced in these rocks by metamorphism are almost infinite. On the Ocoa River the shales are so nearly unaltered that I have repeatedly searched in this region in hopes of finding fossils. In the canyon of the river they are gray and friable, with an occasional bed of sandstone; farther south they are red and give rise to numerous salt springs; still farther south they contain more numerous beds of sandstone and are brown and more sandy in texture. These same shales are modified at Recol into a granular greenish-black material resembling an impure serpentine, while on the Nigua they appear as green, gray, or brown jaspers with broad conchoidal fractures, gradually changing again within a few miles to a more serpentinoid form, to reappear as the same jasper on the Jaina and to again change, on the Upper Jaina and in nearly all the mountains eastward, into a whitish rock, more or less talcoid and profusely stained with iron. On the north side of the island the modifications of the shale are just as great. The sandstones also undergo an equal number of variations, appearing of all colors from black or dark-gray sandrock to a white granular quartzite. In short, nearly every color is represented, and naturally all degrees of texture, from the coarse conglomerate of San Jose de las Matas, or Maniel, to the shale above described. In one place only did I find siliceous segregations like the chalk flints, or more probably, like the Corniferous limestones of the New York geologists. In the hill just west of Bani the rock is a limestone, and in it are numerous streaks, lying in the plane of stratification, of a light-brownish limestone, very tough and breaking with an irregular fracture. Near the base of the series, apparently, are strata of conglomerate, made up of pebbles very similar to those of the surrounding beds. These pebbles seem to have been brought from long distances, since they are almost invariably rounded by attrition. They are largest on the upper Ocoa, near Maniel, and on the north flat of the range near San Jose de las Matas, but at these points they are rarely more than a few inches in diameter. I have endeavored in vain to find the probable source of these pebbles. They are certainly not from the adjoining beds, although lithological researches were not wanting. They are not derived from any deposit encountered by us on the island, since the conglomerate strata extend nearly, if not entirely, to the base of the stratified rocks. It is not probable that further examination to the westward, in the yet unknown portions adjoining Haiti, or lying within its borders, will develop their origin, since such a discovery would be foretold by increase in the size and angularity of the pebbles in that direction. They must therefore have been derived from some land then existing, most probably to the north or northwest of the present island, but now submerged or destroyed. The conglomerate is variable in its character and the changes take place over comparatively limited areas. On the north side it is almost always cemented by a coarse-grained red sand, the surfaces of the contained pebbles being stained by the ferruginous nature of the matrix. This is the rule where the metamorphosis is not very perfect. In one place, west of San Jose, the whole mass is rendered nearly homogeneous in texture, the fracture crossing matrix and pebbles alike. In another, on the Mao River, the whole is changed to a dark olive-green, the coloring matter having stained even the interior of the pebbles. On the Ocoa some of the conglomerate is cemented by lime instead of sand, and in this case the pebbles are not so numerous as to be always in contact. This peculiarity gradually changes to the eastward, so that the conglomerate is represented on the Nigua by a group of beds, in part pure limestone, in part an impure limestone, containing occasional pebbles. This last is the stratum from which fossils were obtained.

Statements relating to the discovery of fossils of Cretaceous age are given in Chapter XV (pp. 642–643).

With regard to Porto Rico Hill[442] states:

The mountains are composed largely of black or other dark-colored basic igneous rocks, occurring as tuffs, conglomerates, and sills of hornblende andesite, cut by dikes of diorite. While these rocks are of volcanic origin, there are nowhere any signs of recent or late geologic volcanism, such as craters, unburied lava flows, cinder cones, etc., all original volcanic forms of topography having been destroyed by erosion, to which are due the present features of configuration. Besides, much of this volcanic material has been worked over into sediments in prehistoric ages and now occurs in well-defined strata.

Included in this mass of volcanic rocks are two limestone formations, interbedded with them and relatively inconspicuous in area. One of these, found on the crest of the island near Cayey and Aibonito, is a black bituminous shaly limestone interbedded with the volcanic conglomerate. This calcareous horizon is fully 1,000 feet thick, apparently upholds the crest of the Sierra, and weathers into soils noted as the best tobacco lands on the island. The other is a light-gray crystalline limestone with Cretaceous fossils (Rudistes). * * *

The geologic history of the island may be briefly summarized as follows:

The earliest positive chronology that can be fixed at present is Cretaceous time, when the island, in common with the other Great Antilles, was the site of active volcanism, which resulted in the piling up of vast heaps of igneous rocks now constituting its mass.

At the close of Cretaceous time and during the beginning of the Tertiary this volcanic material was water sorted and converted into marginal sea sediments, as represented in the stratified tuffs, conglomerates, and fossiliferous Cretaceous and Eocene rocks. The history of Porto Rico during Oligocene time is obscure, the vast thicknesses of white limestone of that age which occur in Cuba, Jamaica, and Santo Domingo not having as yet been detected upon the island. It is supposed, however, that the island, together with the other Great Antilles, suffered great subsidence during this epoch.

In late Tertiary time all the aforesaid rocks were uplifted and deformed into their present mountainous aspect, in common with the general Antillean uplift of that epoch. The exact period of this uplift in the later half of the Tertiary has not as yet been fixed, but it was largely accomplished before the close of the Miocene epoch. The tilted Piñones strata of Miocene age, at the northwest corner of Porto Rico, clearly show that the movement was not completed until after the close of the Miocene. In Pleistocene time the island suffered minor oscillations of elevation and subsidence, resulting in the present erosion and configuration of the coast-border topography.

F 17–18. CUBA AND ISLE OF PINES.

The following notes have been prepared for this volume by T. W. Vaughan:

Serpentines, granites, slates, and schists constitute the oldest rocks known on the island of Cuba, except perhaps some limestones of doubtful Paleozoic age in the vicinity of Trinidad, and form the basement upon which the subsequent geologic formations were deposited. Slates and schists occur in small patches in the Province of Santa Clara, some 3 or 4 miles south of the city of that name. They are much folded and metamorphosed, and apparently the serpentine has been intruded into them. Outcrops of serpentine occur in every province of the island. The most westerly occurrence at present known is near Guanajay, in the Province of Pinar del Rio. There are large areas in the vicinity of Havana and Guanabacoa, northwest of Matanzas between Matanzas and Cardenas, and east of Cardenas in the vicinity of Hato Nuevo. Extensive areas also occur in the central portion of the Province of Santa Clara and near the city of Trinidad in its southern portion. Serpentine also constitutes the surface formation of large areas in the northern and central portions of the Provinces of Camaguey and Oriente.

Outcrops of granite were observed at the south coast of the Province of Oriente and south of the city of Santa Clara. A granite porphyry of doubtful age occurs in Oriente Province.

Semicrystalline blue limestones of fine texture outcropping in the vicinity of Trinidad have been considered as doubtfully of Paleozoic age.

In the Isle of Pines, associated with the Gerona marble which is described below, and to some extent interbedded with it, is a great mass of crystalline quartz-mica schist, which rarely reaches the surface except in watercourses, as it is nearly everywhere covered by the Malpais gravel. Wherever it reaches the surface it is deeply weathered to a soft yellowish micaceous sand. In addition to the quartz and mica, some portions of the schist also contain numerous garnets and a thoroughly disseminated black mineral, taken to be manganese. The more siliceous portions of the schist are banded and resemble a gneiss. There are also numerous veins of quartz, from several feet in thickness down to mere stringers. It is evident that these quartz veins and the siliceous bands and grains are the sources of the Malpais gravel and of the extensive deposits of beach sand surrounding the island. Some portions of the schist are highly siliceous, forming essentially a quartzite. In the Cerro Siguanea the rock has been extensively fractured and recemented by iron and quartz, rendering it more resistant and thus causing a series of hills of harder material to stand above the surrounding areas underlain by softer material.

A dark-gray diorite schist has been observed in the Cerro Daguilla and doubtless occurs elsewhere in the island. It is evidently an intrusive basic rock, probably a diorite which has been rendered schistose along with the inclosing formations. It is extremely tough and compact, presenting a high degree of resistance to erosion. Some portions of the rock are rather massive, the schistose structure being most highly developed along the margin of the intrusive mass.

The ridges on either side of Nueva Gerona are composed of crystalline marble which is known as the Gerona marble. It is probable that the same material also forms the Sierra Pequeña, which is parallel to the Sierra Caballos, lying a few miles to the east; and to judge from the topography of the Sierra de Canada, which was seen only at a distance, it is composed of the same formation. This marble is everywhere thoroughly crystalline, retaining no trace, so far as observed, of the organisms it may originally have held. The greater portion is rather coarsely crystalline, although there are some beds of fine white statuary marble. The color varies from pure white to dark gray, and in some places there is strongly marked banding.

Owing to the thoroughly crystalline character of this rock, no evidence was obtained throwing light on its probable age. It can, however, scarcely be younger than Paleozoic. In some beds the impurities of the original limestone have recrystallized to form certain silicate minerals, chiefly fibrous hornblende. This marble was estimated to be not less than 2,000 feet in thickness.

K 10. KLAMATH MOUNTAINS, OREGON.

Diller [282] makes the following statement concerning the Paleozoic rocks of the Klamath Mountains:

The Paleozoic sediments consist of clay slates, dark siliceous, locally banded slates, and greenish slates, interbedded with tuffs and lentils of limestone. Near the contact with granodiorite they are locally metamorphosed into fine-grained mica schist, which usually contains characteristic minerals, such as chiastolite and staurolite. * * *

Measured directly across the strike the area occupied mainly by Paleozoic rocks, both sedimentary and igneous, in the Applegate region has a width of nearly 30 miles, in which there are four more or less clearly defined belts of limestone containing about 50 masses, most of which are located on the accompanying map as quarries or prospects. The largest outcrop is not over one-third of a mile in length and 200 feet in thickness. * * *

The limestones at a number of points are fossiliferous, but the fossils are too poorly preserved to permit definite determination. In two lots * * * corals are abundant, and among them E. M. Kindle recognizes with doubt forms that he compares with *Favosites nitella* and *Cladopora robusta*, as well as a gastropod resembling *Loxonema bella*. * * * A striking feature that occurs locally in some of the limestone ledges of the second belt is the inclosure of vesicular volcanic fragments, which indicates that volcanic eruptions occurred in the region at the time the limestones were forming.

In the third belt of limestone, which outcrops along Kane and Steamboat creeks, the only fossils found were fragments of round crinoid stems; the fourth belt, on Little Applegate River, contains both round and pentagonal crinoid stems well preserved. The general absence of other fossils from these two belts suggests a difference in age from the Devonian, and it is probable that they are either Carboniferous or Triassic.

K-L 11-12. IDAHO AND SOUTHWESTERN MONTANA.

The area mapped as Paleozoic in Idaho and southwestern Montana covers the mountains on both sides of Salmon River. It is little known geologically. Weed, Lindgren, and Willis have reconnoitered portions of it and furnished the notes on which the outlines are sketched.

K-L 18-19. NEW ENGLAND.

In New England rocks which were formerly regarded as Archean have been shown by the work of B. K. Emerson,[319] George Otis Smith,[760] E. S. Bastin,[61] and C. W. Brown to be of Paleozoic age. They are, however, so metamorphosed that separation is difficult, and in the zone here mapped as Paleozoic the distinct systems are not yet certainly correlated with definite periods.

M 9-10, N 8-9. VANCOUVER ISLAND AND QUEEN CHARLOTTE ISLANDS.

For data on Vancouver and Queen Charlotte Islands, Dawson, Webster, Haycock, and Clapp may be consulted. In 1878 Dawson [252] explored and mapped geologically the Queen Charlotte Islands, reporting the discovery of fossils which determined the Triassic age of a certain zone of argillites and limestones repeated in many sections along different parts of the coast. But he also states his belief that "from the intimate association of Carboniferous and Triassic rocks in the southern interior of the province, and more particularly from the occurrence of a great mass of rocks largely volcanic in origin and believed to be Carboniferous in age, in the southern part of Vancouver, it is highly probable that rocks of this age may come to the surface in some places."

In 1885 Dawson [256] examined the northern part of Vancouver Island and stated:

The geological resemblance between the part of Vancouver Island which is here described and the southern half of the Queen Charlotte Islands is extremely close. This resemblance had previously been reported on by me in general terms and was indeed to be expected, as the Queen Charlotte Islands and Vancouver Island form portions of a single axis of elevation which here constitutes the western member of the Cordillera.

Webster,[868a] in his report on the west coast of Vancouver, says:

In describing the geology I shall use the late Dr. G. M. Dawson's nomenclature as far as possible. * * * In his description the igneous dark-colored trappean rocks with associated mica schists and gneisses are said to be interbedded with argillites and crystalline limestones, classed as Triassic on the evidence of the fossils discovered in the argillites and named the Vancouver series. On the west coast of Vancouver Island, however, we find the igneous rocks piercing and including fragments and masses of the crystalline limestones, just as the granites at and near their contact with the traps pierce and include the latter. Nowhere did I see clear evidence of the limestones being interbedded with the traps, though in many places at first view there is every appearance of their being so. I therefore look upon the limestones as being older and unconformable.

Haycock [415a] adds:

Dr. Dawson's descriptions of the metamorpnic rocks of the northern and eastern portions of the island apply with such exactness to this series of the west coast that there can be no reasonable doubt of the latter being a continuation of the former. They may thus be considered as belonging to his Vancouver series and mainly of Triassic but possibly in their lower portions of Carboniferous age.

Clapp has described the topography and geology of the southeastern and southern portions of Vancouver in two articles based on reconnaissance surveys made since 1908. In his earlier report [137] he says:

The formations exposed in the southern part of Vancouver Island range from the Devonian period or older, to the Pleistocene and Recent. * * *

The Tertiary sediments of the south coast are the youngest consolidated rocks. Rocks which when unaltered resemble the Coal Measures have along certain belts been metamorphosed. Metamorphic rocks underlie the greater part of the region.

The older metamorphic rocks can not be definitely assigned to any one period. A careful search for fossils was made in the calcareous rocks, now completely crystallized, but without success until the writer's attention was called to the occurrence of fossil corals on the south shore of Cowichan Lake. * * * Although the material has not yet been worked up, the fauna undoubtedly belongs to the Devonian period. * * *

Provisionally, therefore, one can place the great series of old metamorphics in the southeastern part of Vancouver Island as late Middle Paleozoic.

Dawson and other earlier writers classify the old crystallines which underlie the Coal Measures as the Vancouver series and place them in the Triassic period with possibly some Carboniferous members. As the evidence for assigning part of this great series of rocks—especially those in the northern part of the island—to the Triassic is indisputable, and as Dawson suggests that, should this series eventually prove separable into other formations besides the Triassic, the name Vancouver series be retained for the Triassic members, it seems best to restrict the term Vancouver series to Triassic rocks of the northern part of the island, and to introduce a new term for the older rocks. Hence I suggest the term Victoria series as a general name embracing the older metamorphics of the southern part of the island, belonging to the Paleozoic era.

In his later report, on the southern portion of Vancouver, Clapp [138] says:

The oldest group of rocks in the southern part of Vancouver Island is the Victoria group. This name was proposed by the writer to include the older metamorphic rocks that occur in the neighborhood of Victoria and which were assigned to the Paleozoic and provisionally, in part, to the Devonian, on the evidence of fossils secured at Cowichan Lake. A later, much more complete collection of fossils from the same locality now shows the fauna to be either Triassic or Jurassic. The correlation of the formations is still doubtful, but it is probable that a large part of the rocks assigned to the Victoria group belongs to an older group of rocks than those in which the above fossils occur, and they are still assigned, provisionally, to the Paleozoic.

In view of the uncertainty of age and correlation of the rocks of these islands, and because the marine Triassic in the Canadian Cordillera, of which these islands are considered a part, is mapped with the Paleozoic undivided, these rocks are shown by the Paleozoic pattern on the present map.

For a description of the Triassic as disclosed in both Vancouver and the Queen Charlotte Islands, the reader is referred to M 9–10 and N 8–9, Chapter XII (pp. 536, 539); for a description of the Lower Cretaceous of the Queen Charlotte group to N 8–9, Chapter XIV (pp. 628–630); and for the Tertiary of Graham Island (of the Queen Charlotte group) to N 8–9, Chapter XVII (p. 834).

M 10-11. WASHINGTON AND BRITISH COLUMBIA.

Umpleby [825] gives the following account of the geology of the Republic district, Washington, which may be regarded as representative of the Paleozoic and later rocks mapped as metamorphic Paleozoic in this region.

The geologic history of the Republic district has as its great features sedimentation in the Paleozoic, erosion with minor volcanism in the Mesozoic, igneous activity and erosion in the Tertiary, and continental glaciation in the Quaternary.

The oldest rocks exposed in the district are the metamorphic equivalents of a great series of shales, sandstones, limestones, and lava flows which are of Paleozoic age and are provisionally assigned to the Carboniferous. After the deposition of this series the area passed through a long period of crustal disturbance which, although not developing sharp folds, metamorphosed the beds and raised the area far above sea level. Either during this period of crustal disturbance or shortly thereafter great batholithic masses of granodiorite were intruded into the Paleozoic series.

From the time of the granodiorite intrusions, which are probably of early or middle Mesozoic age, to middle Tertiary times there was a great period of erosion which may be divided into two parts—a first, during which the entire area was reduced probably to base level (Eocene surface); and a second which was introduced by decided elevation and during which broad valleys at least 2,500 feet deep were developed.

The next rocks in order of formation are of Oligocene age and occupy one of these broad, deep valleys. They are dacite flows, including great quantities of stream gravels. Overlying these, unconformably, are andesite breccias, lake beds, and andesite flows, all of which occur within the old erosion valley. Next in order of age are intrusive latite porphyries with which the ore deposits are thought to be genetically related.

From the time of the latitic intrusions to the Pleistocene erosion was the dominant process, although during this time there was a short period of basaltic eruption. In the Pleistocene period the Cordillera ice sheet covered the entire area.

The oldest known formation exposed in the area is a series of metamorphic rocks including slates, schists, quartzites, marbles, and greenstones. It is most extensively developed southwest of Republic, where about 2 square miles are known. East of the San Poil-Curlew valley * * * are extensive areas where the metamorphic series is the predominating formation. Both areas are so poor in exposures that it is impossible to determine detailed relations.

The Paleozoic rocks are very uniformly but not intensely metamorphosed. True schists are not common, and in many instances the limestone has not been changed to marble. Nevertheless, the series has been so disturbed that a given set of characteristics seldom persists for more than a short distance in any direction. Neither bottom nor top of the series was found.

Black carbonaceous argillite is the predominant rock type, although bluish-gray nonfossiliferous limestones have a wide development. Massive gray quartzites were noted in one exposure southwest of Republic. Porphyries of intermediate and basic composition are found both as dikes and sills, apparently intruded into the series before its metamorphism. The age relations of the various phases of the series are not obvious from studies in the Republic area, but to the north, at Phenix, British Columbia, LeRoy [a] reports a section including all the above types of rocks, which he divides into three parts, with an unconformity between the upper two. His section places the argillites in the upper part, separated from the limestones and tuffs (no tuffs of this age were noted at Republic) by a pronounced unconformity, while the lower member is quartzite with intruded dikes and sills of basic porphyrites. The Paleozoic beds are folded and metamorphosed and are in marked contrast with the overlying Tertiary series, in which folding is less marked and the beds are not metamorphosed.

It is not possible, on the strength of facts now known, to assign this formation to a definite place in the Paleozoic series. Near Republic the formation carries certain fossils, not well

[a] Bull. Canada Geol. Survey No. 1072, p. 65.

preserved, but which seem to be crinoid stems. In an exposure of limestone near the top of Buckhorn Mountain, in the northwest part of Republic quadrangle, several fossil crinoid stems were found which are not out of harmony with a provisional assignment to the Carboniferous. These remains, together with the lithologic characteristics of the series, suggest a correlation with the Cache Creek series of Dawson,[a] which is of Carboniferous age. On lithologic grounds, however, it is thought that rocks of more than one age are present.

N 10-11 TO Q 7-9. BRITISH COLUMBIA AND YUKON.

The large area mapped as Paleozoic in British Columbia and Yukon is so assigned on the work of the Canadian Geological Survey and chiefly on that of Dr. George M. Dawson. The Cache Creek group is largely represented and is described in Chapter VIII (p. 390). But there are in the region also other terranes which can not be separated, as the country is largely unknown and the geologic relations are intricate.

O-R 2-8. ALASKA.

It is probable that the rocks in Alaska mapped as metamorphic Paleozoic include strata ranging from pre-Cambrian through the Paleozoic column and may possibly include some highly metamorphosed Mesozoic terranes. Adequate differentiation is in part due to limitations imposed by the scale of the map and in part to the absence of detailed field data. According to Brooks [828 a]—

> Four belts of these younger metamorphic rocks are indicated on the map. The first stretches through southeastern Alaska and probably forms the bedrock throughout the greater part of the unexplored St. Elias Range. It has been identified along the lower Copper River valley and in the Chugach Mountains, and then, bending to the southwest, forms the backbone of the Kenai Peninsula of southeastern Alaska. Silurian,[b] Devonian, Carboniferous, and Lower Cretaceous[c] fossils have been found in these metamorphic rocks of southeastern Alaska.[d] The metamorphic rocks of what appears to be the western end of the same belt have thus far yielded no fossils, and they have been variously assigned to the Paleozoic and the Mesozoic.[e] The intensely folded rocks of the Chugach Mountains may include some pre-Cambrian sediments, but of this no evidence has yet been found.
>
> A second belt of metamorphic rocks forms the major part of the Alaska Range, and Ordovician[f] fossils have been found at a horizon which probably occurs near the base of this series, but it is not impossible that pre-Cambrian sediments are also included.

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[a] Ann. Rept. Geol. Survey Canada, new ser., vol. 7, 1894, pp. 37B-49B.

[b] Brooks, A. H., Preliminary report on the Ketchikan mining district, Alaska: Prof. Paper U. S. Geol. Survey No. 1, 1902, pp. 16-31.

[c] Wright, C. W., Reconnaissance of Admiralty Island: Bull. U. S. Geol. Survey No. 287, 1906, p. 144.

[d] In 1909 Mesozoic fossils of Jurassic or Cretaceous age were found at Berners Bay by Knopf and identified by Knowlton.

[e] Russell, I. C., Expedition to Mount St. Elias: Nat. Geog. Mag., vol. 3, 1890, pp. 173-174. Schrader, F. C., A reconnaissance of a part of Prince William Sound and the Copper River district in 1898: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, pp. 408-410. Schrader, F. C., and Spencer, A. C., The geology and mineral resources of a portion of the Copper River district, a special publication of the U. S. Geol. Survey, 1901, pp. 34-37. Mendenhall, W. C., A reconnaissance from Resurrection Bay to Tanana River: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, pp. 265-340. Emerson, B. K., Harriman Alaska Expedition, vol. 4, New York, 1902, pp. 11-54. Martin, G. C., The petroleum fields of the Pacific coast of Alaska: Bull. U. S. Geol. Survey No. 250, 1905, p. 64. Mendenhall, W. C., The geology of the central Copper River region: Prof. Paper U. S. Geol. Survey No. 41, 1905, p. 133. Paige, S., and Knopf, A., Geologic reconnaissance in Matanuska and Talkeetna basins, Alaska, Bull. U. S. Geol. Survey No. 327, 1907.

[f] Brooks, A. H., The Mount McKinley region, Alaska: Prof. Paper U. S. Geol. Survey No. 70, 1911, pp. 72-73.

A broad belt of metamorphosed sediments is shown on the map between Yukon and Tanana rivers, and in this are known to be Devonian and Carboniferous and probably Silurian[a] horizons.[b] Here, too, pre-Cambrian beds may be included.

Schrader[c] has described a great complex of metamorphic sediments in which Carboniferous fossils have been found near the top of some doubtful Silurian forms in a limestone occurring near the bottom.

Mendenhall,[d] in his exploration of the Allen and Kobuk rivers, not attempting to differentiate the semicrystalline rocks which he encountered in his rapid journey, grouped them together under the term "metamorphic complex." In this group are included schists of various types, limestones, quartzites, and greenstones. The lithology is that of the older terranes of other parts of Alaska, but Mendenhall was unable to ascertain the succession within the complex. The group was traced westward to Kotzebue Sound and was regarded by Mendenhall in a broad way as the equivalent of the metamorphic terranes of Seward Peninsula.

In Seward Peninsula the extremely complex structure, the great amount of metamorphism, and the lack of detailed investigations have rendered any definite statement of the stratigraphy impossible. Schists of different mineralogic composition are intricately associated with recrystallized limestones and basic intrusive rocks, all much sheared. In different limestones at widely separated localities fossils of Cambrian, Ordovician, Silurian, and Devonian or Carboniferous age have been found, although most of the limestones have been too thoroughly recrystallized to afford paleontologic evidence. There is strong probability that pre-Cambrian sediments may also be included, but the lack of definite bedding and the known occurrence of continued folds and thrust faults make the projection of dips, and thus the interpretation of sequence, inconclusive.

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[a] Prindle, L. M., Fairbanks and Rampart quadrangles, Yukon-Tanana region, Alaska: Bull. U. S. Geol. Survey No. 337, 1908, pp. 18–23.

[b] In 1909 Silurian and Ordovician fossils were found in the White Mountains, in the Fairbanks quadrangle, by Prindle and identified by Ulrich.

[c] Schrader, F. C., Reconnaissance in northern Alaska: Prof. Paper U. S. Geol. Survey No. 20, 1904, pp. 55–72.

[d] Mendenhall, W. C., A reconnaissance from Fort Hamlin to Kotzebue Sound: Prof. Paper U. S. Geol. Survey No. 10, 1902, pp. 31–36.

CHAPTER VIII.

CARBONIFEROUS UNDIVIDED.

Color, light blue, horizontal ruling.
Symbol, 14.
Distribution: Western North America, Arctic region, Newfoundland, and Central America. Subdivided into Mississippian, Pennsylvanian, and Permian in eastern North America. (See fig. 10.)
Content: Mississippian and Pennsylvanian limestones of the Cordillera including Devonian where present; Mankomen formation and Nabesna limestone of Alaska; Lisburne formation, Alaska; Carboniferous of the Parry Archipelago, Arctic region; Carboniferous of Newfoundland; doubtful Carboniferous or Devonian of Honduras.

Areas mapped as Carboniferous undivided.

E 16. BRITISH HONDURAS.

Sapper [698] in 1899 compiled the available information concerning the geology of British Honduras, or Belize. The map of that region as furnished by the Mexican Survey in 1906 follows his reconnaissance map of 1899. The Carboniferous and the

[a] M 10–11, N 10–11, O 9–10, and P 8–9 in general mapped with Paleozoic undivided.

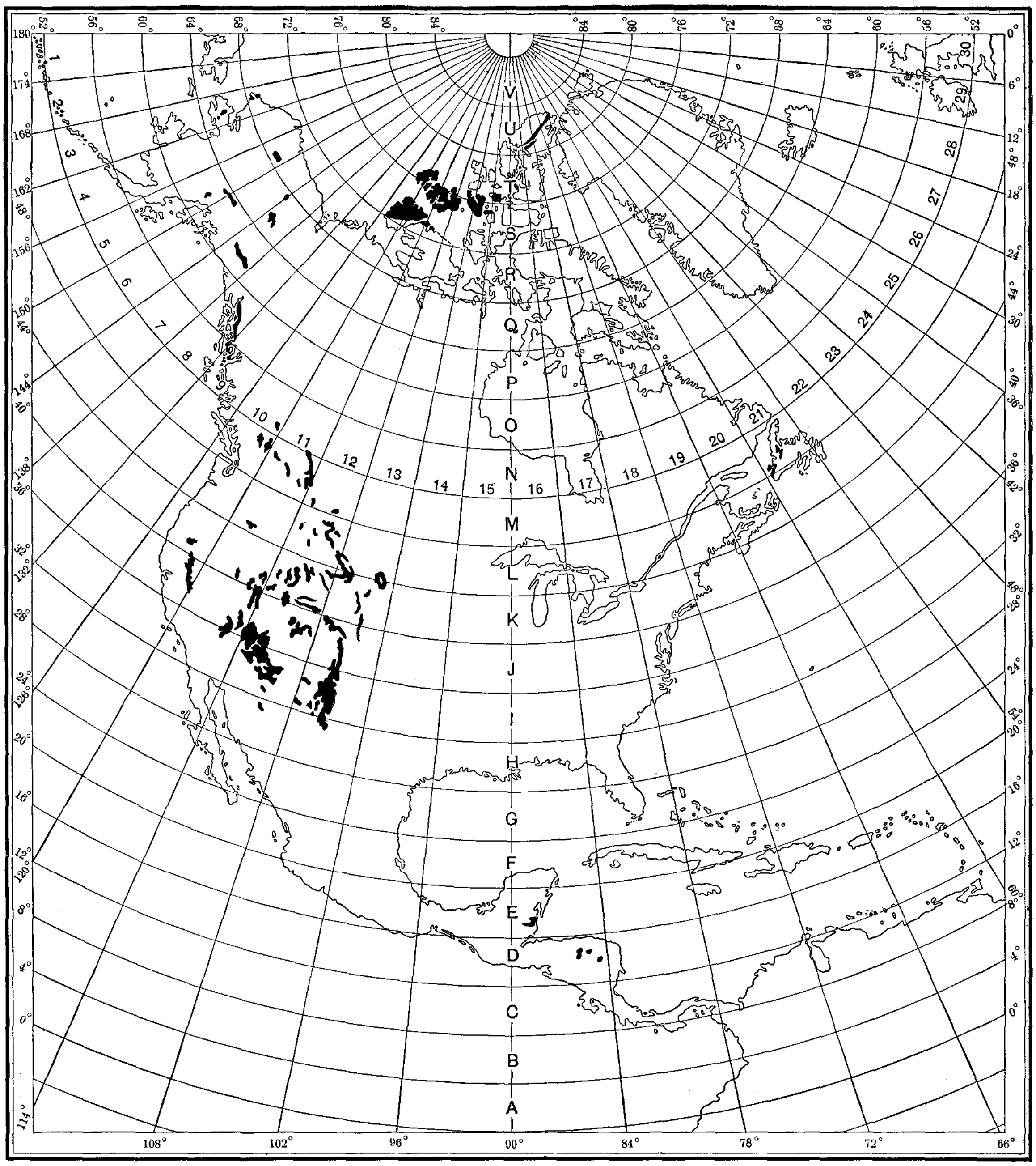

FIGURE 10.—Sketch map showing the distribution of Carboniferous rocks that are undivided on the geologic map of North America and the key to references in the text.

eruptive rocks constitute the Coxcomb Mountains, which have been crossed by Cockburn, Fowler, Wilson, and Sapper. Sapper's notes contain repeated references to phyllite clay slate and crinoidal limestones. Regarding the latter he says:

Although the crinoidal limestones do not afford definite data for the determination of age, since the crinoids are not specifically determinable, it is nevertheless most likely that the limestone is Carboniferous, since it is only in this terrane that crinoidal limestones have thus far been found in Guatemala.

Crinoids are mentioned also as occurring in a graywacke.

Since the position of these slates and associated limestones within the Carboniferous is not definitely determined, the terrane is mapped as undivided Carboniferous, but it is highly probable that the strata are of the same age as those of adjacent areas in Guatemala, which, as stated in Chapter X (p. 425), are regarded by Girty as not older than lower Pennsylvanian or uppermost Mississippian.

H-I 12. SOUTHERN ARIZONA.

Several isolated sections of Carboniferous strata in southern Arizona are described by Ransome and Lindgren, and in the failure of exact equivalency they are given local formation names: "Globe limestone" of the Globe district (upper part only is Carboniferous), Escabrosa and Naco limestones of the Bisbee district, and Modoc and Tule Spring limestones of the Clifton district.

The "Globe limestone" consists almost exclusively of limestone in beds ranging from 1 to 6 feet in thickness and attains a maximum of 700 feet. It rests without angular unconformity upon the Apache group (Cambrian?), and is cut off at the top by a plane of erosion. Ransome [657b] states:

It appears from the Pinto Creek sections that the Globe formation includes in its lower part at least 300 feet of Devonian strata and in its upper part at least 500 feet of Upper Carboniferous beds. No unconformity, however, has been found between the beds belonging to these different periods. While future work in the broader region about the Globe quadrangle may result in the discovery of such an interruption of sedimentation and in the consequent splitting up of the Globe limestone, it is believed that no such division is at present practicable within the area covered by this report.[a]

The case of the Globe limestone recalls that of the Ouray limestone in Colorado, to which Cross has recently called attention. The Ouray limestone, an apparent stratigraphical unit containing characteristic Devonian fossils, was at first referred wholly to that period. Later work, however, has resulted in the discovery of Lower Carboniferous fossils in the upper part of this limestone unit. There is nothing as yet known that precludes the presence of Lower Carboniferous beds in the Globe limestone between the known fossiliferous Upper Carboniferous and the known fossiliferous Devonian. The absence of any recognizable unconformity within the mass of limestone strata is suggestive of uninterrupted deposition from the Devonian to the Upper Carboniferous, and consequently of the presence of some Lower Carboniferous or Mississippian. The paleontological note furnished by Dr. Girty also intimates that the Lower Carboniferous may be represented.

The Escabrosa and Naco formations are Carboniferous limestones of the Bisbee district, Arizona, the former having a thickness of 700 feet and representing the Mississippian series, the latter being 3,000 feet or more thick and equivalent to the Pennsylvanian (Aubrey group and Redwall limestone of northern Arizona in

[a] As a result of recent work in the Ray quadrangle, which adjoins the Globe quadrangle, Ransome has separated the Carboniferous from the Devonian. See Min. and Sci. Press, vol. 102, 1911, p. 747.—B. W.

part, according to G. H. Girty). The Escabrosa succeeds the Martin limestone (Devonian) apparently conformably; it is in turn conformably succeeded by the Naco; and the section ends at the top in a surface of pre-Cretaceous erosion.[658c]

The Modoc limestone (Clifton district) is a remnant of the Mississippian series, about 170 feet thick, which rests conformably upon the Morenci formation (Devonian?), and is limited above by a surface of erosion. The Tule Spring limestone is a representative of both the Mississippian and the Pennsylvanian series.[541b]

H-I 13. TRANS-PECOS TEXAS.

With reference to the Carboniferous in trans-Pecos Texas Richardson [668c] states:

> The Hueco limestone outcrops in an area of several hundred square miles in trans-Pecos Texas. It underlies the Diablo Plateau, a large area between the El Paso and Van Horn quadrangles, and outcrops in the Sierra Diablo, Finlay, Hueco, and Franklin mountains. The Hueco is a rather homogeneous gray limestone, generally massive, though in places it is thin-bedded. It is comparatively free from chert and differs from the limestones of Silurian and Ordovician age in that it contains little or no magnesia. Although the limestone is prevailingly gray, there are local variations in color from light gray to almost black.
>
> In the Franklin and Hueco mountains the Hueco limestone immediately overlies the Fusselman limestone, apparently conformably, in spite of the fact of the great hiatus indicated by their ages. But in the Van Horn region a well-developed basal conglomerate averaging approximately 100 feet in thickness and composed of pebbles of all the pre-Carboniferous formations is present at the base of the limestone, which rests with marked irregularity on the underlying formation. The Hueco limestone generally is overlain by Pleistocene débris, but in a few areas, notably in the Finlay mountains and also 8 miles northwest of Van Horn, it is directly overlain by Cretaceous strata. The total thickness of the Hueco limestone has not yet been determined, but it is more than 3,000 feet.
>
> The Hueco limestone carries an abundant fauna of Pennsylvanian age. * * * According to Dr. Girty, this fauna with some modifications is similar to that found over much of the Cordilleran region, and the Hueco limestone is tentatively correlated with the Aubrey formation and the Weber quartzite.[a]
>
> In the Van Horn quadrangle and north of it the bolson plain known as Salt Flat, which is occupied by an unknown depth of unconsolidated Quaternary deposits, lies between the Sierra Diablo on the west and the Guadalupe-Delaware Mountains on the east and completely conceals the relations of the rocks in the two mountains. As has been stated, the Sierra Diablo is made up of the Hueco limestone, the stratigraphic top of which has not been observed, and the Guadalupe-Delaware Mountains are composed of Paleozoic strata, younger than the Pennsylvanian, which contain a fauna not elsewhere known in North America, that Girty has named Guadalupian. This fauna, which has Permian affiliations, is described by Dr. Girty in a paper now in press,[b] and it is intended here only to outline the stratigraphy of these rocks, which complete the long Paleozoic sequence of trans-Pecos Texas.
>
> The Delaware Mountain formation includes a varying mass of sandstone and limestone having a maximum thickness of at least 2,300 feet, but the base of the formation is not exposed in Texas and has not been determined. In the northern part of the Guadalupe-Delaware Mountain uplift, the formation is prevailingly sandy and contains only thin beds and lenses of limestone. Southward the sandstone decreases and the limestone increases in amount until, in the southern part of the main Delaware Mountains, the formation consists of gray limestone

[a] Proc. Washington Acad. Sci., vol. 7, 1905, p. 14.

[b] Since published as Prof. Paper U. S. Geol. Survey No. 58, 1908.—B. W.

with only subordinate beds and lenses of sandstone. The sandstone is a massive to thin bedded buff to brownish quartzose rock and the limestone likewise is both thick and thin bedded, of a prevailing gray color, and contains little chert. * * *

In the Guadalupe Mountains, 60 miles north of Van Horn, about 2,200 feet of the Delaware Mountain formation is conformably overlain, in a magnificently exposed section, by 1,800 feet of limestone named the Capitan limestone. The name is taken from El Capitan Peak, which, having an elevation of 8,690 feet, is the highest point in Texas. The Capitan is a light-colored, usually white limestone which, although possessing minor variations, is homogeneous in general appearance. Bedding planes in many places are not apparent and the rock is characteristically massive. Chemically it is of variable composition, some analyses showing the presence of considerable magnesium while others indicate its almost complete absence. Besides its main occurrence in the Guadalupe Mountains the Capitan limestone was determined in 1907 to be present in the southern end of the Delaware Mountains, where it has been faulted down and adjoins the limestone of the Delaware Mountain formation. R. S. Tarr reports,[a] in the paper cited above, the presence of 1,000 feet or more of sandstone lying above the Capitan formation, but these rocks have not been studied, so that neither the base nor the top of the strata bearing the Guadalupian fauna has yet been determined. It is expected that these relations can be determined in the northward continuation of the formations in the Sacramento Mountains of New Mexico.

The age of the Guadalupian fauna has been much discussed. Girty tentatively regarded the Guadalupe group as younger than the lower portion of the Kansas Permian, from which alone invertebrate fossils were known. This view was based on the close faunal relationship of the Kansas Permian with the Kansas Pennsylvanian, on the general resemblance to the Pennsylvanian shown by the fauna of the Hueco limestone, which underlies the Guadalupe group, and on the great unlikeness of the Guadalupian fauna both to the fauna of the Hueco limestone and to that of the Pennsylvanian and Permian of Kansas. Subsequent investigations, however, have seemed to indicate, as noted below, that the striking peculiarity of the Guadalupian fauna is only regional. Furthermore, J. W. Beede has reached the conclusion, on stratigraphic and paleontologic evidence not altogether satisfactory, that the lower part of the Capitan limestone, which is the upper formation of the Guadalupe group, is equivalent to the lower part of the Kansas Permian; that the upper part of the Capitan is equivalent to the middle part of the Kansas Permian; and that the upper part of the Kansas Permian (equivalent to the Greer and Quartermaster formations of Oklahoma and Texas) overlies the Capitan limestone. The lower formation of the Guadalupe group (the Delaware Mountain) he correlates with the Pennsylvanian of Kansas, while the still older Hueco limestone is inferentially of early Pennsylvanian (Pottsville?) age.

In 1909 Richardson [670b] traced the Guadalupe group from the type locality in Texas northward in New Mexico for 50 miles and found that the stratigraphy is varied and that both the Delaware Mountain formation and the Capitan limestone lose their individuality when traced far along the strike. The northward continuation of the group lies between the Pennsylvanian Hueco formation, as developed in the Sacramento Mountains, and the Permian red beds of Pecos Valley. The fossils in the northward continuation of the Guadalupe group, according to Dr. Girty,[367] show but little relationship to the typical Guadalupian fauna but

[a] Tarr, R. S., Reconnaissance of the Guadalupe Mountains: Bull. Texas Geol. Survey No. 3, 1892.

rather are similar to those of the upper part of the Hueco formation. It seems probable that this difference in the fauna is due to changed environment, which is indicated by the varied lithology. Whether the Guadalupian fauna should be regarded as late Pennsylvanian or Permian is still an open question, but the weight of evidence is in favor of the Permian and that view has been adopted by the United States Geological Survey.

In an earlier report Richardson [666] described the formations overlying the Guadalupe group, as follows:

The Castile gypsum is a massive white granular variety. It is comparatively pure, and a characteristic sample analyzed qualitatively by Mr. W. T. Schaller shows it to be of no unusual composition. Considering its great extent the Castile gypsum is remarkably homogeneous, yet it varies somewhat. On the surface it is generally disintegrated and earthy. In places it is grayish or dark in color owing to the presence of organic matter, and at other places it is stained red by iron oxide. Locally selenite is abundant. Some sections show occasional thin beds of banded gray limestone in the gypsum. Deposits of native sulphur are also associated with the Castile gypsum. The thickness is not known, but it is considerable. A well at the old sulphur works about 6 miles north of Rustler Spring shows a thickness there of a little over 300 feet, though the base of the gypsum is not known to have been reached.

* * * * * * * * *

The Castile gypsum outcrops in a belt between the Delaware Mountains and Rustler Hills, the width of which averages about 15 miles, though at the New Mexico-Texas boundary it is about 30 miles. This gypsum belt begins about 15 miles north of the railroad and extends into New Mexico. Within Texas the gypsum outcrops over 600 square miles. The name of the formation is derived from Castile Spring, which is in the midst of the gypsum about 12 miles south of the State boundary.

The Castile gypsum along its western outcrop lies on little knolls and valleys of the underlying Delaware Mountain formation, indicating an erosional unconformity. Another evidence of unconformity at the base of the gypsum consists in the absence of the Capitan limestone. It appears that either the gypsum was deposited at or near the top of the Delaware Mountain formation as a lens which did not extend westward to intervene between the Delaware Mountain formation and the Capitan limestone in the Guadalupe Mountains, or that erosion removed the former southwestward extension of the limestone (the thickness of which is unknown) before the deposition of the gypsum. The former supposition necessitates the correlation of the Rustler formation, which overlies the gypsum, with the upper part of the Delaware Mountain formation or with the Capitan limestone. But there is little to support this interpretation, and it is tentatively assumed that the Castile gypsum and the Rustler formation were formed after the deposition and erosion of a part of the Capitan limestone.

The Rustler formation consists of a fine-textured white magnesian limestone and less abundant sandstone. The formation occurs in the Rustler Hills, in the dissected southwestern extension of the Rustler Hills between Cottonwood and Hurd's Pass draws, and in a few isolated areas west of the hills.

The formation as here exposed averages about 200 feet in thickness and varies in composition. In the southern outcrops there is no sandstone and the hills are capped by about 150 feet of massive gray limestone, which directly overlies the gypsum. Northward sandstone is present below the limestone. * * *

Recent work [670] has shown that the Castile gypsum and Rustler formation are parts of the group of red beds of Pecos Valley, which are of Permian age.

I 12. ARIZONA AND NORTHWESTERN NEW MEXICO.

Reagan [663a] states in regard to the Carboniferous of the Fort Apache region, in Arizona:

Lower Redwall group.—The first series above the Devonian is from 400 to 1,000 feet of alternating gray limestone and shale. It terminates at the top in a massive to shaly coarse sandrock, often of the millstone grit type. The lime rocks are very fossiliferous from the middle of the series to the top and seem to belong to the lower Carboniferous group; but as yet the writer has not identified fossils enough from the group to verify such a conclusion.

Upper Redwall group.—The writer has included in this group all of the strata superimposed on the millstone grit rock of the group just described, to and including the dark-gray limestone series about 1,000 feet above its base. The series here is very variable, indicating a rapid transformation from west to east. Ripple marks and old shore lines are noticeable and indications of large swamp land areas are exposed on Cibicu Creek and in the vicinity of Fort Apache. As evidence that the country reached the swamp stage the writer found several specimens of Lepidodendron and one whole tree of the species *Calamites cannæformis.* The group belongs to the coal-measure series, as is attested by its fossils: *Spirifer cameratus, Productus semireticulatus, P. costatus,* Lepidodendron, *Calamites cannæformis,* etc.

Aubrey group.—The interstream spaces of all the streams in their upper course, as well as the south front of the Mogollon Range and the Cibicu divide, where not covered with later deposits, are capped with 280 feet of calcareous sandstone followed by 500 feet of soft red and gray shales, interrupted by sectile limestone. The Aubrey limestone occurs in one locality—at the headwaters of the Cibicu and Canyon creeks. The rocks of this group are usually nonfossiliferous, but fossils enough were obtained (*Athyris subtilita, Productus punctatus, Spirifer cameratus,* Productus, and Bellerophon) to identify it as upper Carboniferous.

The Zuni Plateau lies just north of the thirty-fifth parallel in New Mexico. It is composed largely of Carboniferous strata, which Dutton [301b] discusses and compares as follows:

The Carboniferous strata of the plateau country have been divided into two portions, an upper and lower. To the lower portion the local name of the "Redwall group" has been given and the upper portion has been named the "Aubrey group." The Redwall takes its name from the great vertical escarpments which its most massive member presents in the canyons of the Colorado. In the Grand and Marble canyons especially a band of limestone from 800 to 900 feet thick constitutes the face of the principal vertical cliff and becomes the most impressive stratigraphic feature of those great chasms. It has always been spoken of as the Red Wall. Its lower Carboniferous age has been well ascertained. Above and below it are numerous bands of limestone and calcareous sandstones belonging to the same group and always classed with it. While it is always found at the exposures of its proper horizon in the other parts of the plateau country, it is plainly wanting in the district we are about to study, and its absence is certainly a striking fact. It appears to be absent also from the Nacimiento Range, northeast of the Zuni Plateau, where the upper Carboniferous rests on the Archean just as it does here. In southern and southwestern Colorado, however, it is usually found in its proper place. The conclusion seems obvious that it was never deposited here, and that this locality was a land area in early Carboniferous time.

The upper Carboniferous or Aubrey group is usually subdivided into two portions, an upper and a lower Aubrey. This subdivision is quite proper as well as convenient, for the two portions are strongly contrasted with each other in their lithologic features and in the topography to which their erosion has given origin. The lower Aubrey consists of bright-red sandstones throughout, deposited usually in rather thick and less frequently in moderately thin layers. They are much alike in all outward respects, color, texture, and grouping and in the erosional forms sculptured out of them. They are very fine grained, without traces of conglomerate or coarse shingle or gravels, and, having a calcareous cement, they weather easily and break down into very fine red sand. Fossils are scarce but may be found here and there in sufficient quantity and distinctness to identify their age. These fossils, so far as I have seen, are the same as those which abound in the beds above them.

The upper Aubrey is composed largely of sandstones, but they have a very different aspect from those below. In color they are yellowish brown and the cement, instead of being calcareous, is siliceous—in fact, a regular chert. * * * These sandstones are conspicuously cross-bedded, and the silicification of the rock has in no way obscured it. * * * There are several bands of these adamantine sandstones, and intercalated with them are three or four thick beds of pure limestone, containing an abundance of fossils of many and characteristic species.

While the Mesozoic strata of this district show some differences in comparison with those north of the Grand Canyon, the upper Aubrey shows none, except in its thickness. Its cliffs in the upper wall of the Grand Canyon and those overlooking the granite of the Zuni Plateau are so similar that it is hardly possible to doubt that their materials came from the same source and were deposited under the same conditions. In the former locality they are thicker in about the ratio of 5 to 3, and this ratio holds good not only for the Aubrey series as a whole but for all its subdivisions and principal members. In the Grand Canyon the thickness of the Aubrey is about 2,000 feet; here it is about 1,200.

I 13. NEW MEXICO.

Lindgren [542d] describes the Carboniferous of New Mexico as follows:

The Mississippian, or lower Carboniferous, has been recognized at several places south of latitude 34°. W. T. Lee found limestone of this age in the Ladrones Range and Gordon believes, on the basis of evidence collected by C. L. Herrick, that the lower part of the section in the Magdalena Mountains belongs to this series. Characteristic Mississippian faunas were found by Gordon at Kingston and Hillsboro, and the horizon has for some time been known to be represented at Lake Valley, where a thickness of over 200 feet of limestone has been measured. Rocks of the same age are also present in the Silver City district. Gordon states that at Hillsboro these limestones rest upon the eroded surface of the Devonian calcareous shales, but farther west there is no evidence of unconformity.

The Pennsylvanian, or upper Carboniferous, is deposited with a considerable thickness over the whole Territory and reaches its maximum in the country between Santa Fe and Las Vegas. As far south as the latitude of Socorro the Pennsylvanian consists in large part of sandstones and shales in repeated alternation with some limestone beds. But south of this line the pure limestones prevail and at the same time the total thickness appears to diminish. Everything indicates near-shore conditions in the northern part of the Territory, where some land areas probably existed even at that time.

In northern and central New Mexico there appear to be two divisions of the Pennsylvanian, the upper in certain parts possibly including the Permian. According to W. T. Lee and C. H. Gordon [a] the Pennsylvanian of central New Mexico is divisible into two groups, the lower called the Magdalena group and the upper called the Manzano group. The Manzano consists in fact of the "Red Beds" of Carboniferous age.

The average thickness of the Magdalena group in the vicinity of Socorro is 1,500 feet. This group is subdivided into (1) a lower formation called the Sandia, consisting chiefly of shales, limestones, and sandstones, the first two predominating, with a thickness ranging from 500 to 700 feet; and (2) an upper formation called the Madera limestone, 300 to 500 feet thick, consisting of blue limestone with some shale. Both formations are well exposed in Socorro and Bernalillo counties.

The Manzano group, best exposed on the east side of the Rio Grande near Socorro, consists of 2,000 feet of red and variegated sandstones, shales, limestones, and gypsiferous beds. Its

[a] Gordon, C. H., Note on the Pennsylvanian formations in the Rio Grande valley: Jour. Geology, vol. 15, 1907, pp. 805–816. Lee, W. T., and Girty, G. H., The Manzano group of the Rio Grande valley, New Mexico: Bull. U. S. Geol. Survey No. 389, 1909.

upper part is a bed of blue limestone 300 to 500 feet thick, with Pennsylvanian fossils, which Lee has named the San Andreas limestone. Beneath this is the Yeso formation, consisting of 500 to 1,000 feet of yellow, pink, and white sandstones and shales, with gypsum and some limestone. The basal formation of the Manzano group, to which the name Abo sandstone has been given, is composed of dark-red sandstones interstratified with sandy shales. There are distinct unconformities produced by erosion at the top and the bottom of the Manzano group.

South of Socorro County Lee has traced the red beds of the Manzano group down to Rincon. In the Franklin Mountains, according to G. B. Richardson, the Carboniferous "Red Beds" and in fact all "Red Beds" are absent and the Pennsylvanian is represented by the Hueco limestone, 3,000 feet thick. Still farther east on the boundary line between Texas and New Mexico the Hueco is covered by 2,500 feet of Guadalupian[a] sandstone and limestone. Near Silver City and in the southwest corner of the Territory the Pennsylvanian consists almost exclusively of limestones of moderate thickness. The "Red Beds" are absent and Cretaceous rocks carrying Benton fossils rest with distinct unconformity on the eroded Carboniferous formations.

In the Zuni Mountains, according to Dutton, there are 1,650 feet of Pennsylvanian and Permian "Red Beds" resting directly on the pre-Cambrian rocks. In the Mora uplifts there are, according to J. J. Stevenson, 3,276 feet of upper Carboniferous, consisting of sandstones, shales, and limestones in rapid alternation. In the upper Pecos Valley, above Pecos, there is, according to Lindgren, about 4,000 feet of the same series which apparently can not be further divided. At neither place does this series comprise any "Red Beds." Several coal seams, at least one of which is workable, are present. Between Pecos and Glorieta, the relations being especially well exposed in La Cueva Creek, this lower series is covered by a thick mass of "Red Beds" and coarse grits, containing some interbedded limestone, evidently of Paleozoic age. These coarse grits are beyond doubt derived from the pre-Cambrian mass of Thompson and Penacho peaks, just to the northwest, and their extensive development demonstrates the existence of a land area along the Santa Fe Range and probably also an epoch of erosion within Pennsylvanian time. Above these grits and "Red Beds" are similar strata of uncertain age which underlie the Glorieta Mesa and which are capped by a yellow sandstone, outcropping at the edge of the escarpment; the sandstone has been regarded as of Dakota age. The total thickness of the "Red Beds" in the upper Pecos Valley, as measured by Newberry, is 1,350 feet.

I 16. ALABAMA.

Plant remains, probably of Carboniferous age, are recorded by Smith[747] from the metamorphosed rocks near Moseley (now Erin), in Clay County, Ala., which have been regarded as a part of the Ocoee group of Safford. (See Chapter III, p. 90.)

J 10. SIERRA NEVADA, CALIFORNIA.

On pages 373–376 is given an account of the Carboniferous of northern California. South of the fortieth parallel in the Sierra Nevada occur schists, slates, quartzites, and limestones, which constitute a metamorphic series not usually divisible and which under the name Calaveras formation are assigned to the Carboniferous. In the "Description of the gold belt" included in folios of the Geologic Atlas of the United States relating to the Sierra Nevada[813] published prior to 1900 occurs the following statement:

> The great mass of the Paleozoic sediments of the gold belt consists of quartzite, mica schist, sandstone, and clay slate, with occasional limestone lenses. On the maps of the gold belt these sediments are grouped under two formations:

[a] Richardson, G. B., Paleozoic formations in trans-Pecos Texas: Am. Jour. Sci., 4th ser., vol. 25, June, 1908.

The Robinson formation, comprising sediments and trachytic tuffs. This contains fossils showing the age to be upper Carboniferous. The formation is known on the gold belt series of maps only in the Downieville quadrangle, a short distance south of the fortieth parallel.

The Calaveras formation, comprising by far the largest portion of the Paleozoic sediments of the gold belt. Rounded crinoid stems, corals (Lithostrotion and Clisiophyllum), Foraminifera (Fusulina), and bivalves have been found in the limestone lenses and indicate that a considerable portion at least of this formation belongs to the middle or lower Carboniferous. In extensive areas of the Calaveras formation no fossils have, however, been found, and older rocks may be present in these. It is not likely that post-Carboniferous rocks are present in these nonfossiliferous areas.

In the Colfax quadrangle, which lies in the northern-central part of the Sierra Nevada (latitude 39°–39° 30′, longitude 120° 30′–121°), the sedimentary rocks of the "Bedrock series" are divided by Lindgren [538] into three "groups," of which the oldest is "the Carboniferous group equivalent to the Calaveras formation of other folios. * * * This group can be subdivided into five formations, lithologically very distinct, though the fossils do not afford data for paleontologic discrimination. These are enumerated from east to west as follows: Blue Canyon formation, Relief quartzite, Cape Horn slates, Delhi formation, and Clipper Gap formation."

According to Lindgren the principal Carboniferous area in the quadrangle is that of his Blue Canyon formation, occupying the southeast corner, adjacent to "Jura-Trias" (Sailor Canyon) rocks, and intruded by granite. The rocks are black fissile clay slates and fine-grained quartzitic sandstones, with one occurrence of fine conglomerate and a few limestone lenses. At two localities these limestones contain fossils (Lithostrotion, Aviculipecten, a lamellibranch, and Murchisonia at one place; Syringopora, Diphyphyllum or Lithostrotion, and crinoid stems at the other). These suffice only to indicate a Paleozoic age.

Lindgren described his Relief formation as a very hard, fine-grained quartzite, alternating with streaks of siliceous clay slates, plainly exhibiting the stratification but unfossiliferous; his Cape Horn formation as consisting of typical clay slates, fissile, almost black, weathering to gray, and containing small limestone lenses which have yielded round crinoid stems of Paleozoic age; and his Delhi formation as composed of a peculiar dark-brown or black hard rock, resembling hornfels (a character probably due to metamorphism of siliceous sediments of a certain kind), with a few lenticular masses of limestone and round crinoid stems.

Lindgren's Clipper Gap formation consists of black clay slates and argillaceous sandstones. Lenticular bodies of limestone are abundant and chert is common. Obscure fossils (Phillipsastrea and Pleurotomaria) were obtained at one locality, and others (*Clisiophyllum gabbi* Meek, *Lithostrotion whitneyi,* and brachiopod fragments) of lower Carboniferous age were found in a disconnected mass that is probably a fragment of the formation torn loose by a diabase eruption.

J 11. EASTERN NEVADA.

From Hague's very full account [391c] of the Carboniferous section at Eureka, Nev., the following extracts are taken:

At Eureka the Carboniferous rocks have been estimated to measure 9,300 feet in thickness, which, however, does not represent the full development of the Carboniferous period, the upper Coal Measures, the top of the Paleozoic system, having suffered a very considerable amount of erosion. This upper limestone is by no means so thick as that found elsewhere.

The Carboniferous rocks have been subdivided into four epochs—first, Diamond Peak quartzite; second, Lower Coal-measure limestone; third, Weber conglomerate; fourth, Upper Coal-measure limestone.

* * * * * * * * *

At the base of the [Diamond Peak] horizon fine conglomerates firmly cemented together lie next the argillaceous shale of the White Pine epoch,[a] but quickly give place to a more massive, usually vitreous quartzite with a characteristic grayish-brown color and breaking irregularly with a flinty fracture. Intercalated black cherty bands, carrying a more or less ferruginous matter, occur near the middle portion of the horizon. Near the summit the beds pass into thinly laminated green, brown, and chocolate-colored schists and clay shales. The Carboniferous age of the epoch is determined by a narrow belt of blue limestone, which occurs interstratified in the quartzite about 200 feet above its base, in which the widespread species *Productus semireticulatus* occurs associated with an undetermined species of Athyris. As the fauna at the top of the black shales foreshadows the coming in of the Carboniferous, the presence of this characteristic Productus, with only a Carboniferous fauna higher up in the series, determines without question the geological position of the quartzite between the black shale and Coal-measure limestone.

* * * * * * * * *

In the Diamond Range the Lower Coal-measure limestone overlies conformably the Diamond Peak quartzite, the transition beds passing rapidly from siliceous to calcareous sediments. In their lithological character and physical habit they do not differ essentially from the same beds elsewhere, except, perhaps, at their base, where they carry intercalated beds of chert, argillite, and gritty, pebbly limestone, with evidences of shallow-water deposition. They pass rapidly, however, into purer gray and blue limestone, for the most part heavily bedded and distinctly stratified at varying intervals. In broad masses they resemble the Upper Nevada limestone but are rather lighter in color in distinction from the dark blue and black of the latter horizon. No true dolomite beds of any considerable thickness have been recognized, 9.21 per cent being the largest amount of magnesium carbonate obtained in any of the rocks subjected to chemical analysis. Across their broadest development they measure about 3,800 feeet in thickness, which is much less than has usually been assigned to this horizon in other mountain uplifts, more especially those lying eastward.

As the term Lower Coal-measure has been employed by most geologists to designate this epoch throughout the Great Basin, it has been thought best to retain the name provisionally, although not exactly applicable, as the epoch includes such a commingling of species from both the Upper and Lower Coal measures that a separation of the beds seems quite impossible.

* * * * * * * * *

Three salient features in the life of the Lower Coal measures at Eureka call for special mention, and each is worthy of still further investigation—first, the occurrence near the base of the limestone of a fresh-water fauna; second, the varied development of the lamellibranchiates, a class which has heretofore been but sparingly represented in the collection of Carboniferous fossils from the Cordillera; third, the mingling near the base of the horizon of Devonian, Lower Carboniferous, and Coal measure species in gray limestone directly overlying beds characterized by a purely Coal measure fauna.

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Conformably overlying the Lower Coal measures comes the Weber conglomerate [probably of Pottsville age], one of the most persistent and well-defined horizons over wide areas of the Cordillera, stretching westward all the way from the Front Range in Colorado to the Eureka Mountains. It varies in the nature of the sediment with every changing condition, but it is nearly everywhere easily recognized as a siliceous formation between two great masses of Carboniferous limestone. In places it is made up of an admixture of calcareous and sandy beds; in others of fine grits and shales; and again of nearly pure siliceous sediment, varying from fine to coarse grained, dependent largely upon the distance from any land area and depth of

[a] Mississippian, according to G. H. Girty (comment on manuscript).

water in which it was deposited. Here at Eureka the material is exceptionally coarse, with abundant evidence of shallow-water deposition and the existence of a land surface not very far removed at the time the beds were laid down.

* * * * * * * * *

Beds of the Upper Coal measures are found conformably overlying the Weber conglomerate. * * * The thickness attained by the rocks of this epoch is nowhere exposed in the district, the overlying beds having either suffered removal by the denudation or else been concealed beneath flows of igneous rocks. * * * The beds are estimated at 500 feet. In the northern and central portions of the State of Nevada the Upper Coal measure limestones attain a development of nearly 2,000 feet. * * *

In the field the Upper Coal measures may be distinguished readily from the Lower Coal measures by their lighter color and the greater prevalence of fine-grained beds. These colors are light bluish gray and drab, the latter possessing a conchoidal fracture and compact texture. These compact limestones frequently present forms of erosion quite different from the coarse-grained and granular limestones of the Lower Coal measures. Throughout the horizon the limestones are interstratified with belts of grit and siliceous pebbles, held together by a calcareous cement, in which are intercalated thin beds of purer limestone. One or two prominent beds are apparently made up of quartz pebbles and fragments of an older limestone, carrying such fossils as *Fusilina cylindrica* and *Productus semireticulatus*, as if indicating that they had been derived from the underlying Carboniferous rocks. The fossils, however, which are all Coal measure species, might be derived quite as well from the Upper as from the Lower beds. A chemical examination failed to detect any beds of dolomite in the limestones, the highest amount of magnesium carbonate obtained being 1.33 per cent. This is not without interest, as it is the only limestone horizon in the Paleozoic series at Eureka free from dolomitic strata.

J 12. SOUTHERN UTAH AND NORTHERN ARIZONA.

The eastern margin of the Great Basin in southwestern Utah is mapped according to information supplied by F. B. Weeks.[a] The data for the eastern portion of the State, comprising the Green River and Grand River sections and the San Rafael Swell, are derived from McGee's map [567] and appear to represent observations by Powell and Dutton that are not otherwise recorded.

The later Paleozoic section of northern Arizona comprises the Carboniferous formations known as the Redwall limestone (Mississippian and lower Pennsylvanian), the Aubrey group (upper Pennsylvanian), and the Moencopie formation (Permian?). The Redwall and Aubrey were first described by Gilbert,[360] who gives the following generalizations regarding the stratigraphy, beginning at the top with the "Aubrey" limestone (renamed Kaibab limestone by Darton [246a] in 1910, Aubrey being retained for the group), which in some areas is overlain by Triassic strata and in other areas by the Moencopie formation [246b] (Permian?):

The Aubrey limestone has a thickness of 820 feet on Kanab Creek, and this is about its maximum. * * * Lithologically the limestone is characterized by a great abundance of chert, which, toward the top, sometimes constitutes half the mass. Near the middle it is, in some places, interrupted by a belt of shale, with gypsum. * * *

The Aubrey sandstone series has a thickness, in the Aubrey Cliffs and along the Grand Canyon, of about 1,000 feet. In every exposure a portion of this body is massive and cross-bedded and another portion soft and gypsiferous, but the order of these parts is not constant. In the Aubrey Cliff the compact rock is at the top and, together with the Aubrey limestone, holds a sheer bluff, at the foot of which the softer portion spreads a broad slope. Along the

a Personal communication.

Grand Canyon, at Kanab Creek, and near the Uinkaret Mountains the upper sandstone is soft and produces a slope in the profile, while the lower is hard and unites its steep escarpment with that of the Redwall limestone. The sandstones contain no fossils, but an intercalated limestone below the middle of the series at Canyon Creek bears the familiar Coal Measure shells.

The Redwall limestone has, upon fresh fracture, a gray color and shows its red rust only on weather-stained cliffs. In its general character it is heavy bedded to massive. At the top sandstone alternates with the limestone for from 200 to 500 feet. Through its lower half the firm limestone is interrupted by occasional shaly bands, which serve to break its escarpment into a series of narrow terraces, but above them stands a sheer perpendicular face, of from 800 to 1,000 feet. The average total thickness is 2,500 feet.

Accompanying these stratigraphic notes are lists of fossils, according to which the highest beds were referred to the "Permo-Carboniferous" and the upper half of the Redwall to the "Coal Measures" (Pennsylvanian), with a doubtful determination of "Lower Carboniferous" below the middle. Gilbert regarded it as possible that the Redwall extended down to include Devonian.

A recent publication on the stratigraphic succession and age of the rocks of northern Arizona is that by Darton,[246] already cited.

J 13. COLORADO.

The Carboniferous terranes of Colorado have been described, compared, and correlated by Girty [362] in a monographic work, to which reference should be made for a general treatment of the whole subject.

The following extracts present the general relations:

The lower Carboniferous strata of Colorado are geologically comparatively unimportant by reason of their thinness, but they are widely distributed and form one of the richest metalliferous horizons in the entire rock series. This horizon is everywhere a limestone or a dolomite, sometimes more or less interstratified with shale, but owing to minor differences of lithologic character and circumstances of distribution several local names have been received by it. In central Colorado this limestone is called the Leadville limestone. In the San Juan region it is called the Ouray limestone, and along the Front Range it has received the name of the Millsap limestone. The lower portion almost everywhere contains a distinctive and unmistakable Devonian fauna. At least this fauna has been found at so many and such widely separated points that it may safely be regarded as generally present over the central part of the State wherever the formation is brought to view. In the few fragments of it which are still visible along the Front Range, however, the Devonian fauna seems to be wanting.

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Along the eastern margin of the Front Range the Mississippian limestone appears in several places. It is in this tract called the Millsap limestone. The Millsap limestone was first described in the Pikes Peak folio, from which I abstract the following: It consists only of local remnants resting upon the Fremont limestone in Garden Park and along the western line toward Canyon. It is represented by about 30 feet of thinly bedded variegated dolomitic limestone, with a few thin sandstone layers. Chert nodules in the upper limestone layers carry casts of *Spirifer rockymontanus* and *Seminula subtilita*. It is divided from both the formation which preceded and that which followed it by an erosional unconformity.

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In the San Juan region Mississippian time is represented by the Ouray limestone, the major portion of the formation, however, containing a Devonian fauna.

The Ouray limestone is defined by Cross and Spencer somewhat as follows: It consists of massive beds of limestone separated by thin intercalations of marl or shale. Certain thin bands are frequently quite coarsely crystalline, but the large mass of the formation is a dense or semicrystalline limestone. The thickness is about 150 feet. The greater part of this formation appears to be of Devonian age, and it was only comparatively recently that a Mississippian fauna was obtained from its upper portion. The latter is intimately related to the Mississippian faunas at Leadville and Aspen, and also to the Waverly fauna of the Wasatch limestone of Utah, the Madison limestone of Wyoming and Montana, the typical Waverly of Ohio, and the Chouteau limestone of Missouri. The fauna of the Millsap limestone, as we know it from Perry Park and also from Garden Park and Canyon, and that of the Leadville limestone at Leadville present a rather peculiar facies, but even this fauna seems to be related to those of the early Mississippian, and it is somewhat singular that the Leadville fauna is more nearly allied to that of Perry and Garden parks, while lithologically and stratigraphically the Leadville as a formation is especially to be compared with the Leadville of Aspen and of the Crested Butte region. I think we can safely regard these faunas as varying facies of a single widespread and contemporaneous fauna, the differences being due in part to varying environmental conditions and in part to quite a different cause. Our collections from these beds are extremely meager, and to this circumstance can be referred some of the differences at present existing.

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It is now fairly certain that the Carboniferous portion of the Leadville, Ouray, and Millsap limestones are of early Mississippian age.

This formation, or, as it has received several names, this horizon, is widely distributed in Colorado. It is known in the Grand River region (the Devonian portion has been recognized on the White River and at Glenwood Springs and the Carboniferous probably on Eagle River), in the Elk Mountain region, in the South Park region, in the northern part of the Sangre de Cristo Range, in the San Juan region, and along the Front Range. It is probably lacking over much of the Front Range and Sangre de Cristo areas, in the Uinta Mountains, and in the valleys of the Dolores and the Grand, and it is concealed over extensive areas by deposits of later geologic age; but it is perhaps the most widespread of all the Paleozoic formations except those belonging to the Pennsylvanian. The remarkable persistency of this horizon as a limestone formation, not only in Colorado but throughout the West, and the widespread distribution of essentially the same fauna would argue extended and uniform marine conditions during Mississippian time.

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The Lower Carboniferous period was followed by an epoch of elevation and erosion. At all events none but the early portion of Missisippian time is apparently represented in the Colorado sediments. The chronological point at which this elevation took place is, except in a general way, unknown. It may have occurred soon after the formation of the Leadville limestone, the absence of the upper Mississippian horizons being due not so much to erosion as to nondeposition; but it seems to me rather more probable that this episode was nearly contemporaneous with the elevation in eastern North America at the close of Mississippian time. That the elevation is of wide extent is indicated by the absence over such large areas in our Western States of upper Mississippian faunas. To the erosion which resulted from this elevation the variation in thickness of the Leadville limestone in different sections can often be ascribed. When subsidence again permitted the formation of sediments, the earliest deposits were frequently of a less purely marine character, and shortly a great thickness of sands and conglomerates intermingled with nonpersistent limestone bands began to form over great areas in the State.

The Paleozoic section of central Colorado, by which term I would include the Grand River, Elk Mountain, and South Park areas, is singularly uniform, and this is scarcely less true of the strata of Carboniferous age than of the earlier Paleozoics. Though these are fairly constant in lithologic characters, the nomenclature employed for them has varied somewhat. Thus in the Anthracite-Crested Butte folio the Carboniferous formations are called the Leadville limestone, Weber limestone, and Maroon conglomerate; in the Aspen monograph the Leadville limestone, Weber formation, Maroon formation, and the Triassic; in the Tenmile folio the Leadville limestone, Weber shale, Weber grits, Maroon formation, and Wyoming formation; and in the Leadville monograph the Blue limestone, Weber shale, Weber grits, and Upper Coal Measures.

From special reports the following details are cited:

The Carboniferous of northwestern Colorado south of the fortieth parallel is described in the Anthracite-Crested Butte folio by Eldridge,[304] who distinguished the following, in ascending order: Leadville limestone, Weber formation, and Maroon conglomerate.

In the Leadville district, central Colorado, Emmons [321] distinguished the following subdivisions of the Carboniferous:

Carboniferous, 3,700 to 4,200 feet:

Upper Coal Measures: Blue and drab limestones and dolomites, with red sandstones and shales. Mud shales at top. 1,000 to 1,500 feet.

Weber grits: Coarse white sandstones, passing into conglomerates, and siliceous and highly micaceous shales, with occasional beds of black argillite and blue dolomitic limestone.

Weber shales: Calcareous and carbonaceous shales, with quartzite.

Thickness of Weber grits and shales, 2,500 feet.

Blue [Leadville] limestone: Compact, heavy-bedded dark-blue dolomitic limestone. Siliceous concretions at top, in form of black chert. 200 feet.

The Leadville ("Blue") limestone is regarded by Girty as equivalent to the upper part of the Ouray limestone of southwestern Colorado. The "Weber shales" are treated by Emmons [321a] as a subdivision (150 to 300 feet thick) of the "Weber grits." The siliceous beds of the "Upper Coal Measures" he states [321b] are "not distinguishable from those of the Weber grits at the base, but pass upward into reddish sandstones, which in their turn are sometimes difficult to distinguish from the overlying red sandstones of the Trias."

This sequence at Leadville is at the north end of the belt of Carboniferous rocks which extends thence southward west of the Colorado Front Range into New Mexico, to the vicinity of Santa Fe. Beyond that point after a brief interruption the strata continue in the upper Rio Grande valley.

In Colorado east of the Front Range the Carboniferous presents a less complete section than that found west of the range at Leadville and thence southward. In the Pikes Peak quadrangle occur the Millsap limestone and the Fountain formation. The Fountain is not very definitely correlated with other Carboniferous formations. The Millsap is a thin-bedded dolomitic limestone, which rests unconformably upon the Fremont limestone (late Ordovician) and which, having been deeply eroded before the close of the Carboniferous, is but 30 feet thick in this locality. It is regarded as approximately equivalent to the Leadville limestone of north-central Colorado. The Fountain is made up of red sandstone and conglomerate and forms a part of the so-called "Red Beds," which were deposited unconformably upon Ordovician and pre-Cambrian and composed in part of detritus from the gneisses and granites. The local thickness is 1,000 feet.

The age of the Fountain formation has been in doubt on account of the scarcity of fossils. It is now regarded by Girty as wholly Pennsylvanian and by Henderson as Mississippian below and Pennsylvanian above. Henderson [434] states:

At the northern boundary of Colorado we found a chert concretion zone containing *Spirifer centronatus* Winchell, *Cranæna subelliptica* var. *hardingensis* Girty, and *Spiriferina solidirostris* White, a fauna which is considered Mississippian and is found on the east side of the Front Range at Canyon City and elsewhere. The first-named species and others of like age were long ago reported from that region, but the record had little value because the position in the formation was not given. We traced the chert zone for 8 or 9 miles southward, finding it everywhere within a few feet of the contact of the conglomerate with the granite and uniformly containing fossils, but found none farther south. The coàrse sandstone and conglomerate series in which this fossiliferous zone occurs appears to be stratigraphically continuous with the Fountain formation in the Boulder district as defined by Dr. Fenneman,[a] who correlates it with the Fountain of the Colorado Springs region. We have traced the formation in the field the entire distance from the Wyoming line to Boulder and find no reason to doubt that the horizon containing the chert fossils is the equivalent of the base of the Fountain as represented at Boulder, or possibly even much higher than the base as it occurs immediately north of Boulder, where the formation is much thicker than near the Wyoming line.

In limestones at a much higher horizon we found a Pennsylvanian fauna (tentatively considered older than Knight's so-called "Permian" of Wyoming), consisting of *Productus cora* D'Orb., *P. nebrascensis* Owen, *Spirifer rockymontana* Marcou, *Squamularia perplexa* McCh., Derbya n. sp. ?, *Phillipsia* aff. *major* Shumard, *Myalina swallowi* McC., abundant crinoid stems and others. These limestones were said by Darton [b] to pass into the Fountain conglomerates in traveling southward. Of this we are by no means certain without further investigation, but they seem certainly to belong at the very top of the Fountain or base of the overlying Lyons formation of Fenneman's bulletin. These limestones nearly disappear at the Cache la Poudre, and a little work just north of that stream is necessary to determine their exact position. We have traced the contact of the Fountain and Lyons all the way from the northern line of the State to Boulder except 2 or 3 miles between the Cache la Poudre and Owl Canyon, and believe the Tensleep sandstone of Darton's paper to be the stratigraphic equivalent of Fenneman's Lyons.

It seems very clear that all of the Fountain sandstones and conglomerates of northern Colorado are Carboniferous, the base being probably Mississippian (certainly so in the northern portion of the field) and the upper portion possibly as late as Pennsylvanian. It also seems likely that the Lyons is Pennsylvanian.

The fossils were, through the kindness of Dr. T. W. Stanton, of the United States Geological Survey, submitted to Dr. G. H. Girty, whose determinations are followed in this paper.

Girty[c] states that he believes the fossiliferous cherts which occur in the Fountain formation to be derived from Mississippian limestone, and he does not think they determine the age of the Fountain. David White[c] states that the fossil plants found in the Fountain formation are of Pottsville age.

The San Juan Mountain district of southwestern Colorado has become through the studies of Cross, Spencer, Howe, and others, a standard of reference for the geologic section of that central region of the Rocky Mountains where the Carboniferous is characterized by several very distinct formations and unconformities. The base of the section, the Ouray limestone, has already been described (pp. 367–368). The lower part contains a Devonian fauna, but an upper fossiliferous horizon is of Mississippian age. Cross [194] states:

The erosion in the interval following Mississippian sedimentation removed those strata completely over large areas. As neither the upper Devonian nor the basal Carboniferous horizon is everywhere fossiliferous, it is impossible to decide in many places whether the upper portion of the Ouray limestone ledge is Carboniferous or not.

From the great quantity of Carboniferous chert nodules in the succeeding formation it must be assumed that above the known horizons of the Ouray there once existed in this region a considerable thickness of chert-bearing limestone of Mississippian age. It seems not unlikely

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[a] Fenneman, N. M., Geology of the Boulder district, Colorado: Bull. U. S. Geol. Survey No. 265, 1905.

[b] Darton, N. H., Geology and underground water resources of the central Great Plains: Prof. Paper U. S. Geol. Survey No. 32, 1905.

[c] Notes on the manuscript of this paper.

that somewhere on the slopes of the San Juan Mountains notable remnants of these beds may be found.

From a comprehensive study by G. H. Girty of all Carboniferous invertebrate fossils thus far collected in Colorado, and available to him, the following brief summary concerning the Mississippian of the San Juan region may be made. Thirty-two determinable species have thus far been obtained from the chert pebbles of the Molas formation, which were derived from the eroded beds, and from two localities in the upper zone of the Ouray limestone. This fauna is closely similar to that of the Wasatch limestone of Utah and the Madison limestone of the Yellowstone National Park. It is also similar to the small faunas obtained in Colorado from the Leadville limestone in the Mosquito Range, at Aspen, Crested Butte, and near Salida, and that from the Millsap limestone of the Front Range near Canyon and in Garden and Perry parks. Dr. Girty concludes that the Leadville limestone, which was originally assigned to the Mississippian because of fossils found in its upper part, and the Ouray limestone, which has been considered Devonian on account of the fauna in its lower and middle portions, are equivalent. He thinks that careful search would in many cases show both faunas where only one is now known.

The Pennsylvanian of the San Juan district comprises, from the base up, the Molas, Hermosa, and Rico formations. These are succeeded by the Cutler (Permian?) formation. The sequence is summarized as follows from the Needle Mountains folio,[194a] where full descriptions may be found:

Generalized section for the Needle Mountains quadrangle.

System.	Series.	Formation.	Thickness (feet).	Character and distribution.
Carboniferous.	Permian(?).	Cutler formation.	300±	Complex of bright-red sandstone, lighter-red or pinkish grits, and conglomerate, alternating with sandy shale and earthy or sandy limestone of varying shades of red. Limestone conglomerate fossiliferous.
	Pennsylvanian.	Rico formation.	100±	Dark reddish-brown sandstone and pink grits, with intercalated greenish or reddish shale and sandy fossiliferous limestone.
		Hermosa formation.	2,000	Series of limestone, grits, sandstones, and shales of variable distribution and development. Limestone in thick, massive beds predominates in the middle and upper parts of the section, the lower portion being mainly sandstone and shale, with a few limestone layers. Numerous invertebrate fossils occur in shales and limestones.
		Molas formation.	75±	Red calcareous shale and sandstone, containing pebbles of Mississippian chert and limestone, and limestone lenses with Pennsylvanian fossils.
		Unconformity		
	Mississippian.	Ouray limestone.	100–250	Buff limestone, compact above, thin bedded below with shale and quartzitic partings. Mississippian fossils in upper third, Devonian in lower portion.

In southwestern Colorado and southeastern Utah the Carboniferous formations distinguished in the San Juan district have recently been traced and correlated in part with other occurrences in Utah, Arizona, and New Mexico. Fossils collected by Newberry and Powell near the junction of Grand and Green rivers recently compared by Girty with other collections made by Cross and Spencer at Moab, on Grand River, though within a few miles of one another, appear to show different relations with western and eastern faunas. Cross [189d] quotes Girty as follows:

Considering the Powell and Newberry collections together it is notable that they contain a considerable number of species which may be called distinctive western types, as compared with the Pennsylvanian fauna of Colorado and of the Mississippi Valley. * * * In some cases nothing at all closely related to the types indicated is known from the region to the east. In other instances there are more or less similar species known which are not yet regarded as identical with western forms, although they may prove to be so.

The collections from Moab consist entirely of typical Pennsylvanian species, lacking the forms specified as characteristic of the far western areas. The distinctly Pennsylvanian forms found at the junction of the Green and Grand occur, however, at Moab. The Sinbad Valley fauna is very closely related to that from Moab.

In view of the fact that none of these collections can be considered as exhaustive for the localities, numerical comparisons are more or less untrustworthy; yet the table brings out certain contrasts or resemblances which seem worthy of note. Out of 42 species represented in the Powell and Newberry collections but 9 have been found at Moab, or in the Sinbad Valley, while out of 43 species obtained in these latter localities 29 are known from the Pennsylvanian rocks of southwestern or central Colorado.

On the basis of the fossil evidence alone there can be no hesitation in considering the Moab and Sinbad Valley sections as belonging to the Hermosa formation rather than to the Aubrey, as represented in the lower Grand River valley.

J–L 13. WYOMING, NORTHERN COLORADO, AND SOUTH DAKOTA.

The stratigraphy of the Carboniferous sequence in the Bighorn Mountains and other ranges of Wyoming, and in the Black Hills has been summed up by Darton: [237g]

The Lower Carboniferous rocks are exposed principally in the Black Hills and Bighorn uplifts, and a few small areas occur along the foot of the Front Range, in Colorado. It is probable that these rocks extend widely under the Great Plains, but no borings have gone deep enough to reach them, except in eastern Kansas and southeastern Nebraska.

In the Black Hills the Mississippian is represented by two limestone formations, the Englewood and the Pahasapa, both containing an abundance of characteristic fossils, those of the Englewood being equivalent to the lowest Mississippian (Chouteau or Kinderhook) and the Pahasapa equivalent to the Madison limestone of the northwest. Some Leperditia in the concretions in red shale at the base of the Minnelusa are of a type characteristic of the Mississippian, especially at about the horizon of the St. Louis limestone. It is possible that considerable of the lower part of the [overlying] Minnelusa is also of Mississippian age, for it appears to be equivalent to the Hartville limestone. The Littlehorn limestone of the Bighorn uplift consists mainly of a representative of the Madison and Pahasapa limestones, and doubtless the Englewood is also included, but the upper limit of rocks of Mississippian age in both uplifts has not yet been ascertained.

Further details concerning the Black Hills are given in another paper by Darton [232b] as follows:

[The Englewood limestone] appears to extend continuously around the Black Hills, everywhere immediately underlying the Pahasapa limestone. It averages 20 to 30 feet in thickness and presents frequent outcrops in the lower slopes of the limestone escarpment and in numerous canyons. It merges rapidly into the overlying [Pahasapa] limestone, occasionally with a few feet of impure buff limestone intervening. It is usually sharply separated from the [underlying] Deadwood formation, but only by a sudden change in the nature of the materials. The Englewood limestone is usually fossiliferous, containing numerous corals and occasional shells. The following forms have been reported: Fenestella, Orthothetes [Schuchertella], Leptæna, Spirifer, *Chonetes logani, Reticularia peculiaris, Syringothyris carteri,* and crinoids. It is correlated with the Chouteau or Kinderhook of the Mississippi Valley.

The Pahasapa limestone (Mississippian), directly overlies the Englewood limestone (also Mississippian), into which it merges. It is a massive gray limestone without noteworthy subdivisions, varies in thickness from 225 to 500 feet, and according to Darton contains *Spirifer rockymontanus, Seminula dawsoni* (*Athyris subtilita*), Productus and Zaphrentis.

Darton[237b] describes the Minnelusa sandstone as follows:

> The Minnelusa formation consists mainly of thick beds of gray, buff, and reddish sandstones, usually fine grained, most of which, in their unweathered condition, contain a considerable proportion of carbonate of lime. Thin sheets of limestone occur in some districts and, less frequently, sandy shales of red or gray color. Some layers are cherty. * * * [The formation] is thickest on the western side [of the Black Hills], where it is fully 750 feet, and it thins gradually to the south and east, being about 400 feet thick in the southeastern portion of the uplift.

On the evidence of "indistinct casts" of *Productus semireticulatus* and *Seminula dawsonii* (*Athyris subtilita*), "recognized with a fair degree of certainty," the upper part of the Minnelusa sandstone is assigned to the Pennsylvanian. The lower part, if correctly correlated with the lower part of the Hartville formation,[237f] is Mississippian.

The Minnelusa sandstone is succeeded by the Opeche formation (Permian). (See pp. 495–496.)

The relations of the Carboniferous of the Black Hills to that of the Laramie and Hartville ranges of Wyoming are thus discussed by Darton:[237h]

> Along the Laramie Range the apparent absence of Lower Carboniferous is an interesting feature, indicating either nondeposition or removal by the very profound later [middle] Carboniferous erosion. A short distance eastward, in the Hartville uplift, there are comprised in the Mississippian the Guernsey formation, 150 feet or more in thickness, and the lower members of the Hartville formation, the two formations being separated by strongly marked erosional unconformity. The basal sediments of the Hartville formation are red sands, and there is strong suggestion that these are of the same age as the red shale at the base of the Minnelusa formation of the Black Hills and base of the Amsden formation in the Bighorns. The representative of the Lower Carboniferous in Colorado appears in the small areas at Perry Park, about Manitou, about Canyon City, and southwest of Pueblo, and is known as the Millsap limestone. This limestone lies unconformably on the Cambrian, Ordovician, and pre-Cambrian and is unconformably overlain by the Fountain [Pottsville age] or lower Wyoming formation, which overlaps directly on the granites in most portions of the area. Its fauna is regarded as moderately early Mississippian.

K 10. KLAMATH MOUNTAINS, CALIFORNIA.

The Klamath Mountain section includes, according to Diller,[276e, 279] several Carboniferous terranes—Bragdon formation, basal Mississippian of the region; Baird formation (Mississippian); McCloud limestone and Nosoni formation (includes the "McCloud shales"), Pennsylvanian; and limestones of the Hall City locality, which are Permian.

Of the section on McCloud River, in the northeastern belt of the Klamath Mountains, the original description by J. Perrin Smith[762] is given below:

Columnar section of the metamorphic series of Shasta County.

Cretaceous.				Shasta-Chico formation.	
Jura.		Bend formation.		Mormon sandstone of Big Bend. Shales and shaly limestones of Big Canyon.	Thickness ?
Trias.	Upper Trias.	Cedar formation.	Hosselkus limestone.	Spiriferina beds, 50 feet siliceous limestone. Atractites beds, 100 feet siliceous limestone. Trachyceras beds, 50 feet soft limestone.	400 feet.
			Swearinger slates.	Halobia slates, 100 feet calcareous slates. Monotis shales, 100 feet argillites and tuffs.	
	Middle Trias.	Pitt formation.	Pitt shales.	Siliceous and calcareous shales and conglomerates, at Silverthorn's ferry and on Squaw Creek, with *Trachyceras whitneyi*, etc., about 1,500 feet below the Hosselkus limestone. Several hundred feet of shales and conglomerates without fossils.	2,000 feet.
Carboniferous.	Upper Carboniferous.		McCloud shales.	Siliceous and calcareous shales and conglomerates, with Upper Carboniferous fauna at the base. Occurs on the McCloud River, about 20 miles north of the United States fisheries.	1,000 feet.
		McCloud formation.	McCloud limestone.	Massive limestones and marbles of the McCloud River; rich in corals and brachiopods.	2,000 feet.
	Lower Carboniferous.		Baird shales.	Siliceous black shales of the United States fisheries at Baird; very fossiliferous in places.	500 feet.
Devonian.		Sacramento formation.	Kennett limestones and shales.	Limestones and shales near Kennett, on Sacramento River, with Devonian corals.	Thickness ?

The McCloud formation is especially well developed in the region of the McCloud River in Shasta County, and from this it receives its name. The formation consists entirely of Carboniferous strata, the Baird siliceous shales, overlain by the heavily bedded McCloud limestone, with some beds of igneous rock. The thickness is estimated at about 2,500 feet, but this may be far from the true thickness.

* * * * * * * * *

The Baird shales consist of about 500 feet of black metamorphic siliceous shales, in places calcareous and occasionally sandy. At the top, too, are beds of diabase and other eruptives, which, however, do not seem to make up any considerable thickness of the rocks. The Baird shales extend from near the junction of the Pitt and the McCloud rivers northward for about 20 miles along the McCloud, but they were studied by the writer only in the neighborhood of the United States fisheries at Baird.

The strata have a general dip to the east, but this is very inconstant; their strike is approximately north and south. What underlies them could not be made out. They certainly are younger than the Kennett limestones, but what the interval between the two formations and whether they are conformable or not could not be ascertained. They are probably overlain conformably by the McCloud limestone, but the contact could not be observed, and the diabase which separates the two divisions may mark an unconformity.

* * * * * * * * *

The list of fossils from the Baird contains a total of 84 species, of which 19 were not specifically identified. Out of the 65 forms specifically determined 26 occur in the Waverly of the Mississippi Valley, although 8 of these also occur in the Upper Carboniferous of that region. Fifteen are known to occur in the Devonian of the Eastern States, but of these 6 also occur in the Waverly; thus there are only 9 forms that in the Mississippi Valley, or east of it, would be considered as decidedly Devonian. Thirty-six are known from the Waverly and Lower Carboniferous of Utah, Nevada, and New Mexico; of these 29 correspond to forms described by Walcott from the Lower Carboniferous of the Eureka district, Nevada. Three species, *Aviculopecten caboniferus*, *Aviculopecten interlineatus*, and *Macrodon tenuistriatus*, have been considered characteristic of Upper Carboniferous.

With this assemblage of species one would not hesitate to place these strata low down in the Carboniferous, but whether they are equivalent to the Waverly is a question not so easily settled. Although about one-half of the species are found in the Waverly and nearly one-fourth in the Devonian of the Mississippi Valley, 29 of these and a large number of others as yet unknown in California, were found in the Eureka district, Nevada, in strata of Lower Carboniferous age but lying 3,000 feet above the Upper Devonian White Pine shale.

We do not know the age of the rocks immediately underlying the Baird shales, but the siliceous shales of the Sacramento River lie some distance below them and are probably in part of Carboniferous age. It thus becomes probable that in California, as in Nevada, the Waverly fauna, with a few Devonian forms, lived on after the corresponding faunas had become extinct in the eastern region. A migration of these survivors into the Lower Carboniferous sea of the Mississippi Valley may explain the supposed colony mentioned by C. R. Keyes from the Burlington of Missouri, and observed in Arkansas by the Geological Survey of Arkansas. In both places, in the midst of the undoubted Lower Carboniferous faunas, there appears a group of fossils that if found alone would be classed as of Waverly age. They are not colonies in the sense in which Barrande used that word but are simply migrations from one faunal region into another, due to shifting of physical barriers; these migrations have taken place during all time and have complicated correlations, until we lose faith not only in the idea of synchronism as proved by fossils, but also in homotaxis, unless we can find the direction of the migration.

In the paleontological sense the Baird shales are homotaxial with the Waverly, while stratigraphically they probably are not but would agree more nearly in position with the higher divisions of the Lower Carboniferous of the Mississippi Valley.

The occurrence of *Productus giganteus* Martin in these strata is very interesting. This is a common Lower Carboniferous fossil in Europe, but in America is not found east of this place, unless *P. latissimus* Sowerby, which F. B. Meek has cited from Montana, on the western slope of the Rocky Mountains, is an equivalent of it. This fact has been used by the writer as evidence that the European Carboniferous species found in America migrated through the ocean that connected on the west the American with the European Carboniferous waters.

Immediately above the Baird shales, and probably conformably with them, lies the McCloud limestone. This series is about 2,000 feet in thickness, uniform in bedding, and very siliceous in places. Some few beds are altered to a crystalline marble, but in the main the series is made up of a fine-grained hard gray limestone, which at the base contains few fossils besides corals, *Clisiophyllum gabbi* Meek, and *Lithostrotion californiense* Meek. But toward the top the beds become more fossiliferous and contain a varied assemblage of species, which, however, do not rival in number those of the Baird shales.

* * * * * * * * *

Taken by itself the fauna [of the "McCloud formation"] would not be characteristic of Upper Carboniferous, and indeed it is arbitrary to draw the line at the base of the limestone. Even *Fusulina cylindrica*, which in the region east of the Rocky Mountains seems to be characteristic of Upper Carboniferous, in Nevada is found also in Lower Carboniferous. But the most decisive proof of the Upper Carboniferous age of these strata is their position so far above the Baird shales, which have been shown in this paper to be equivalent to the Lower Carboniferous of the Eureka district, Nevada, which is known to occur 3,000 feet above the base of the formation.

The McCloud limestone is probably equivalent to the limestone of the Caribou formation of Plumas County. But J. S. Diller thinks that they belong to a lower horizon than that assigned them by the writer. The Robinson beds of the Taylorville section are probably higher up in the section, but nevertheless the McCloud limestone is, in part at least, equivalent to the Coal Measures.

Collections obtained by Diller were subsequently studied by Girty, who finds "little of material importance" to add to the lists made by J. Perrin Smith. "It may be remarked, however," says Girty,[276f] "that recent collections made in the Carboniferous of Alaska are so suggestive of the fauna of the McCloud shale by way of containing the same or similar species as to indicate the extension of this fauna and, possibly, of the earlier Carboniferous faunas of the California province to that region."

A later article by Diller [278] gives detailed descriptions of the Bragdon formation and cites paleontologic evidence of its early Carboniferous age, controverting Hershey's conclusion that it was Jurassic.

The latest description, comprising a summary of all the facts relating to the Carboniferous of the Klamath Mountains, is given by Diller [279] in the Redding folio.

K 11. NEVADA.

(See J 11 (Eureka district), pp. 364–366, and K 12 (Wasatch section), below.)

K 12. WASATCH AND UINTA RANGES.

The stratigraphic relations of the Carboniferous of the Weber Canyon section, Utah, are thus described by King: [505]

Directly and conformably overlying the Ogden quartzite comes the great Wahsatch limestone, which shows continuous outcrops for several miles and is thoroughly exposed from summit to base, making a total single series of limestone of 6,500 to 7,000 feet. The most valuable part of the whole Weber section begins with the bottom of this limestone, which rests on a few thin sheets of olive-colored argillites separating it from the Ogden quartzite below. There seems to be no intercalation whatever of limy material at this point. The quartzite comes up sharply to the argillites, which are here not over 10 or 15 feet thick and give way immediately to impure earthy limestones of a very dark color. Thus far, on this section, the lower 1,200 feet of the Wahsatch have not yielded any fossils, but at the height of from 1,200 to 1,400 feet from the bottom of the limestone, in the neighborhood of Weber station, the hills directly north of the depot are rich in Coal Measure forms.

* * * * * * * * *

At Weber station the beds, which are about 1,300 feet stratigraphically above the base of the limestone, * * * are usually of quite pure limestone, and the strata vary in width from extremely thin sheets to heavy tables. So, too, they vary in their lithological condition, some being highly crystalline, others merely granular, and some even very roughly granular.

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Passing up the canyon, the series of limestones continues consecutively, without interruption, for 5 or 6 miles, exposing 5.000 to 6,000 feet in thickness above the depot.

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About 300 feet from the summit of the series are some extremely dark beds, which emit a fetid odor upon being struck with a hammer and are intercalated with very impure arenaceous limestones. * * *

The limestones at 1,000 feet from the top inclose a series of thinly bedded but heavily blocked quartzites, which contain two or three sheets of small pebbles. These, however, are very thin and localized. The quartzite is more properly indurated sandstone and occupies a belt 150 feet thick. In general, the upper 1,000 or 1,500 feet of this limestone series are made up of thinly bedded rocks, less pure than the strata below and more or less intercalated with siliceous zones. Some of the beds are also considerably argillaceous.

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The closing members of the Wahsatch group are arenaceous limestone with a brilliant brick color.

The passage from the Wahsatch limestone into the Weber quartzite is made in perfect conformity and, as the beds clearly evidence, with undisturbed consecutive deposition. Above the reddened and arenaceous summit of the Wahsatch limestone are a few intercalations of siliceous limestone. * * * In this lower zone are sheets of conglomerate, the pebbles of which are usually small and composed of white quartz. The general appearance of the quartzite zone is here that of a coarse, rather gritty sandstone, unevenly compressed into quartzite. The bottom of the series is prevailingly red for about 250 feet and averages coarser than the material above. Over the red is a very finely laminated white and grayish quartzite, quite uniform in texture and with only the most sparing inclosures of pebbles. * * * A mile and a half east from the base of the series there is scarcely any conglomerate at all, and the rock is true quartzite of whitish or greenish hue, developing on many of its weathered surfaces a peculiar dark brown stain which looks like the oxidation of manganese. * * * Conformably overlying the quartzite is a very heavy bed of much altered gray limestone from 600 to 700 feet thick. The bedding planes are often entirely obliterated and the material extremely crystalline, showing traces of great interior disturbance. The lower beds show a true conformity with the underlying quartzite. * * * The average colors of these limestones are cream-grays, inclining often to white in the more crystalline portions. * * * Overlying this main body of 700 feet of limestone is a series of yellow shaly limestones 175 feet thick. * * * Overlying these calcareous shales, as heretofore quite conformable, is a series of sand and mud rocks, all more or less calcareous, varying in color from chocolate to olive, with red argillaceous sandstones, the whole about 225 feet thick. It has the appearance of a comparatively shallow water deposit, made of argillaceous material, limestone, and sand, the thickness of the individual beds being unusually limited. There are very many beds not over an inch thick. On the upper surface of the strata, at several horizons, ripple marks are preserved with unusual distinctness and on a scale of fineness not often seen, the distance between the wave and the trough being frequently not over an inch or an inch and a half. Alternating dark chocolate and olive-colored shales form the lower 200 feet of this group, while the upper 25 or 30 feet are pretty solid sandstone. Over these, still conformable, are 100 feet of yellow and olive calcareous shales, which are so earthy as usually to decompose, yielding a bad outcrop. Above this is a bed of bluish-gray limestone, rather compact, about 150 feet in thickness. Next comes 20 feet of reddish-brown clayey sand, hardly compacted into rock, containing thin stony seams intercalated at intervals in the soft, easily eroded matter. This is immediately followed by 75 feet of a yellowish-gray, brittle, easily decomposed limestone. Next above are 100 feet of light-colored, very thinly bedded limestones, that give way to 100 feet more of dark, siliceous, tough limestone, which breaks under the hammer with great difficulty, yielding an exceedingly rough, ragged fracture.

This section comprises both Mississippian and Pennsylvanian rocks. Weeks,[873a] describing the Uinta sections, says:

Wherever fossils have been found in the lower and upper members of the Wasatch limestone, they show the former to be of Mississippian age and the latter of Pennsylvanian age. This is also true of the Uinta Range. The precise line of division has not yet been determined. In the Uinta Range about 600 feet of the 1,070 feet of beds that have been correlated with the Wasatch limestone are certainly of Mississippian age. Powell correlated the beds of the Wasatch limestone with his Grand Canyon section. They correspond in general to the Redwall group

The basal beds of this series are buff, blue, and gray limestones weathering darker in color, and some of them have a decided greenish tinge. They are usually in massive, brecciated beds having a thickness of 150 to 200 feet. Besides the brecciation or fracturing, many small faults occur in them. The succeeding beds, 6 inches to 1 foot thick, are buff-colored crystalline limestones having a total thickness of 300 feet, followed by 25 feet of thinner-bedded dark-blue and purple limestones containing a large amount of dark-colored chert. The fossils found in the above-described beds indicate that they are of Mississippian age.

* * * * * * * * *

The Pennsylvanian series comprises the upper part of the Wasatch limestone and the Weber formation. No name is given to the limestones of this series occurring beneath the Weber formation, leaving it for future detailed work to determine the beds which are to be assigned to this formation. In the Wasatch Mountains a similar succession of strata is exposed. In Powell's Grand Canyon section, Lower Aubrey group, and the Yampa sandstone of the Upper Aubrey group correspond to the Pennsylvanian series. The limestones below the Weber formation are to be correlated with the Lower Aubrey limestone and the Weber formation with the Aubrey sandstone of Walcott's section. So far as the faunas are known, they corroborate these correlations.

The strata forming this subdivision are 300 to 500 feet of light-blue and gray limestones containing a considerable amount of light-colored chert, interstratified with fine-grained light-gray sandstones which toward the top contain bands of sandstone weathering brown and resembling in a marked degree the weathered material of the "Uinta" sandstone. These are succeeded by the quartzites of the Weber formation.

The lower part of the Weber formation is a white and gray to greenish quartzite in thin and thick beds, some of which weather brown. In the upper part of the formation are alternating blue and white siliceous limestones and quartzites. The transition to the next series is through blue and reddish limestones and shales. The greatest thickness occurs on the south side of the Weber River, on the north slope of the range. To the east, on this side of the range, the formation is largely covered by Tertiary sediments or glacial débris. On the opposite (south) side of the range the formation is well exposed in all the principal canyons from the Provo River to Green River. This formation, like the "Uinta," is quartzitic in the western and central parts of the range and grades into a rather soft sandstone in the eastern part. No fossils were found in the Weber formation.

The Permo-Carboniferous series of the Uinta Range seems to correspond in position, thickness, and general lithologic characters to the Upper Coal Measure and Permo-Carboniferous formations of the Fortieth Parallel Survey. On similar grounds they may be correlated with the Aubrey limestone [Pennsylvanian] of Walcott's Grand Canyon section. The correlation with Powell's section is less definite. The limestones overlying the Yampa sandstone of the Upper Aubrey group and an undetermined thickness of the shales and soft sandstones of the Shinarump group appear to correspond to the beds under discussion.

The upper beds of the Weber formation are calcareous sandstones and siliceous limestones which weather yellow and grade into thin red shales and red and blue limestones of the upper part of the Permo-Carboniferous series. This series is well exposed on the Duchesne River, Rock Creek, Whiterocks Creek, on the south side of the range, and in the Horseshoe Canyon of Green River, on the north side of the range.

One of the best sections occurs on the east side of the Duchesne River below the mouth of West Fork. There the lower 600 feet of the Permo-Carboniferous are formed of red and purple shales and blue limestones. Above is 1,000 feet of light-gray and white sandstones, with some interbedded limestones in the lower part. In the upper part these sandstones occur in alternating layers of soft and compact beds full of peculiar black points or specks. These are succeeded by 800 to 900 feet of red shales, with a prominent band of light-colored shale at the top.

Girty states that the "Permo-Carboniferous" of the foregoing section is equivalent to Walcott's Permian, not to the Aubrey group of the Grand Canyon section.

Blackwelder[a] states that the Weber Canyon section as described by King is subject to corrections brought out by more recent study. Near the base of the section there are faults which complicate the succession. The quartzite, supposed to be the Ogden quartzite of King (Devonian), is in reality the Middle Cambrian (Brigham quartzite) and the olive-colored argillites are Middle Cambrian shale. The nonfossiliferous lower portion of the Carboniferous limestone may well include beds of Devonian age such as have been found on the borders of Cache Valley farther north. The fossils in the "Wasatch limestone" are typical members of the widespread Madison fauna, which is of early Mississippian age. Upon the weathered and slightly irregular surface of the limestone rests the Morgan formation of Weeks,[84a] consisting of brick-red shale and sandstone with a few beds of gray limestone and light-colored sandstones which become bright red on exposure. This passes up conformably into the lower, more or less calcareous portion of the Weber quartzite. The quartzite itself has not been remeasured accurately, but the thickness reported by King is believed to be somewhat excessive. The alternating series of dark limestone and shale with local sandstone beds, which rests upon the Weber quartzite, corresponds to Boutwell's Park City formation. It contains the workable phosphate deposits of the region. There is considerable although not conclusive evidence of an important unconformity between the Weber and Park City formations. A section measured in undisturbed strata near the headwaters of Ogden River is given below for comparison with the Weber Canyon section:

Partial columnar section of Carboniferous beds in the northeastern part of Weber County, Utah.

	Feet.
Pennsylvanian:	
Park City formation (upper portion concealed or removed by erosion):	
Dark shale with beds of limestone and rock phosphate	438
Gray limestone with chert nodules and beds of shale	301
Creamy-white sandstone with beds of cherty limestone	220
Unconformity?	
Mississippian (perhaps including early Pennsylvanian at the top):	
"Wasatch limestone:"	
Gray crystalline limestone and purplish shale containing nodules of bright-green limestone (abundant fossils—Productus, Spirifer, etc.—tentatively referred by G. H. Girty to the Kaskaskia formation of the Mississippi Valley)	140+
Dark-gray limestone and dolomite with beds of calcareous sandstone. Fossils rare or poorly preserved	795
Black phosphatic shale and cherty limestone	126
Limestone, black to gray, with chert nodules only near the top. Abundant fossils, especially in the lower layers, the species being typical of the Madison fauna	1,015
Gray shale and limestone with poorly preserved marine fossils like those just above.	180
Shale, dolomitic limestone, and sandstone; ripple marks and sun cracks and bright ferruginous bands suggest nonmarine origin. No fossils	220
Obscure unconformity.	
Hard siliceous limestone and dolomite, largely concealed. No fossils found in these rocks, but the lower layers may be equivalent to the Devonian limestone of the Bear River Mountains	1,100+
	4,535+

[a] Personal communication.

The section of Pennsylvanian and Permian beds exposed in Big Cottonwood Canyon, southeast of Salt Lake City, is described in detail by Boutwell,[93] who gives the following section:

Columnar section of portion of Carboniferous in Big Cottonwood Canyon, Wasatch Range, Utah.

Series.	Formation.	Thickness (feet).	Character.
Permian.	Ankareh shale.	1,500+	Red shales, locally sandy, with interbedded coarse gray sandstones. Carries in lower portion *Aviculipecten weberensis, A. curticardinalis, A. parvulus, Myalina permiana.* No economic importance.
	Thaynes limestone.	1,190	Calcareous with sandstones and shales; "Midred" shale separates more calcareous upper from more arenaceous lower portion. Carries large fauna, with many new fossil species, chiefly pelecypods, including Pentacrinus sp., *Myalina permiana, M. aviculoides, Aviculipecten curticardinalis, A. weberensis, A. parvulus, A. occidaneus,* Lingulas, Spirifers, Dentalia. Forms country rock for replacement ore bodies and lodes.
	Woodside shale.	1,180	Red shale, thinly bedded, fine grained. Bears ripple marks, mud cracks, and raindrop imprints. No direct economic importance.
Pennsylvanian.	Park City limestone.	590	Calcareous with interbedded quartzite, sandstones and some shale. Carries Lingulidiscina sp., *Productus cora,* Productus sp., *Plagioglypta canua, Euphemus subpapillosus,* Bellerophon sp. Forms country rock for principal bonanza replacement ore bodies.
	Weber quartzite.	1,350+	Gray quartzite, massively bedded, homogeneous, dense. Carries, in Weber Canyon, Lingula sp., *Productus subhorridus,* Schizodus sp., *Plagioglypta canna, Euphemus subpapillosus.* Forms wall or walls of lead-silver lodes.

L 11. BLUE MOUNTAINS, OREGON.

Lindgren[540] refers certain clay slates, siliceous argillites, and limestones of the Blue Mountains in Oregon doubtfully to the Carboniferous:

Rocks referred to the Paleozoic system occupy a large area in the lower Burnt River region, about Pleasant Valley, in the southern Elkhorn Range, and on the headwaters of Burnt River and Granite Creek. Smaller isolated areas of clay slate, inclosed in diorites, diabases, and serpentines, also occur near Susanville, in the Quartzburg district, and near Canyon. There is no clue to the age of these, but they are believed to belong to the * * * Paleozoic series. The prevailing rocks through the whole of this large sedimentary area are dark and very fine grained, ranging from cherts to siliceous argillites and ordinary clay slates. A large proportion of the sediments show no distinct stratification in ordinary outcrops, but in thin sections the carbonaceous streaks which indicate the planes of deposition are readily recognized. In many places, however, the rocks are normal clay slates of fairly fissile character.

* * * * * * * * *

The only place where fossils were found is near the Bonanza mine, at Winterville, where round crinoid stems occur in a small mass of crystalline limestone. The other limestone lenses in the series, though carefully examined, yielded no fossils. Round crinoid stems are most common in Paleozoic rocks; taken in consideration with the fact that the series as a whole has a distinctly older appearance than the Triassic of Eagle Creek, from which it is also petrographically very different, we may with some confidence refer it to the Paleozoic and possibly to the Carboniferous. The series is similar to the Delhi division of the Calaveras formation in the Sierra Nevada,[a] which is believed to belong to the Carboniferous.

Well-defined Carboniferous fossils have been found by Prof. Condon in the Crooked River drainage, in the extreme western part of the Blue Mountains.

L 12. WESTERN MONTANA.

The general succession of Carboniferous rocks in the Philipsburg quadrangle, Montana, as stated by F. C. Calkins, in an unpublished manuscript, is as follows:

	Feet.
Pennsylvanian, Quadrant formation:	
Quartzitic member	400
Shaly member	600–50
Slight unconformity (?)	
Mississippian, Madison limestone:	
Thick-bedded limestone	1,000–300
Shaly black limestone	300

Madison limestone.—The Madison limestone in all the Montana sections has basal shaly beds overlain by more massive beds. Although in the Little Belt mines Weed has recognized three lithologic subdivisions, only two are recognizable in the Philipsburg quadrangle. The lower consists mainly of flaggy limestones, black on fresh fracture but weathering to a delicate blue-gray or drab tint. In most places two thin beds of coal-black calcareous shale are intercalated with these limestones, one lying near the base and the other a little below the middle of the lower member. The upper member contains abundant chert. Its lower part is mostly dark blue-gray and in beds of moderate thickness. The upper part is of more massive limestones, mostly white to pale gray and nonmagnesian, their smoothly weathered surfaces and translucence being in contrast to the dull and gritty character of the Jefferson limestone.

Dr. Girty characterizes the abundant fossils collected from the Madison limestone in the Philipsburg quadrangle as referable to the lower Mississippian fauna, which is so widely distributed over the West. He has identified the following forms:

Syringopora surcularia.
Syringopora sp.
Aulopora geometrica.
Menophyllum ulrichanum.
Amplexus sp.
Echinocrinus sp.
Fenestella 2 sp.
Schuchertella inflata.
Rhipidomella pulchella.
Rhipidomella michelini?
Chonetes illinoisensis.
Productus lævicosta.
Camarotœchia metallica.
Spirifer centronatus.
Composita immatura.
Composita sp.
Eumetria marcyi.

Apparent unconformity between Pennsylvanian and Mississippian.—The difference of age between the faunas from the Madison and Quadrant indicates the lapse of a considerable time interval between them. Physical evidence of unconformity is given by the sharp lithologic distinction between the uppermost beds of Madison limestone and the lowest part of the Quadrant formation. A further indication of an erosion interval between them is the dwindling of the upper Madison west of Foster Creek in the Flint Creek Range, to about half its normal thickness. Angular unconformity has not been proved.

Quadrant formation.—The two members of the Quadrant are lithologically in strong contrast. The lower, generally not well exposed except where indurated by contact metamorphism, consists of maroon shales containing gray concretions and thin-bedded gray, white, and pink magnesian limestones. The thickest limestone layer observed is about 8 feet thick. The best-exposed section is on the east fork of Rock Creek in the Anaconda Range. Here 125 feet of shale and limestone immediately beneath the quartzite are continuously exposed, and the imperfect exposure below indicates a total thickness of about 500 feet. This is near the maximum, however, and at the place above mentioned where the Madison was observed in

[a] Colfax folio (No. 66), Geol. Atlas U. S., U. S. Geol. Survey, 1900.

much less than normal thickness, the Quadrant is only about 50 feet thick. The usual thickness is nearer the maximum than the minimum.

Fossils have been collected from the lower member of the Quadrant formation at two localities in the Philipsburg quadrangle. Two miles south of Georgetown Lake the red shales below the quartzite have yielded the following forms, identified by Dr. Girty:

Archæocidaris sp.
Fenestella sp.
Rhombopora sp.
Derbya crassa.
Productus cora.
Spirifer rockymontanus.
Euomphalus catilloides.

Dr. Girty considers this faunule referable to the Pennsylvanian.

The upper member of the Quadrant, in the Rock Creek section, is a single massive stratum of pure hard quartzite about 300 feet thick. Almost everywhere else in the quadrangle it comprises (1) a basal stratum of pure vitreous quartzite; (2) a medial stratum, generally not well exposed, of calcareous shale, shaly and cherty limestone, and a peculiar cherty quartzite with irregular limestone concretions; (3) an upper quartzite, less pure than the lower. The aggregate thickness of these is about 400 feet on the little hill just west of the Philipsburg high school.

Fossils collected at this place from the medial calcareous bed (2), were reported by Mr. Weed in 1900.[a] Girty referred these to the following forms:

Camarotœchia sappho.
C. near C. congregata.
Glyptodesma rectum?
Aviculopecten sp.
Cyathophyllum sp.

These fossils, in Girty's opinion, had a Devonian aspect.

In 1906 D. F. MacDonald gathered at the same place a small collection, even less satisfactory than Weed's. This was submitted to E. M. Kindle, who, although unaware of Girty's report, likewise hesitatingly referred the horizon to the Devonian.

In the light of later evidence Girty has further discussed this fauna as follows:[b]

"The fauna of lot 1 is with little question the same which Mr. Weed obtained from nearly the same locality and which I reported on in 1900.

"Although when I first encountered this fauna I referred it to the Devonian, I now believe that it is probably Pennsylvanian. The two most significant types are the Camarotœchias and the *Glyptodesma rectum?* Large Rhynchonellas are rare in the typical Pennsylvanian, and none are known having the structure of Camarotœchia, as is the case with these. An exception must be made of Rhynchopora, but that genus has also a punctate shell. It was largely on this account, since Camarotœchia appeared to be restricted to the Devonian and Mississippian, that I was previously led to determine the horizon as Devonian. The force of this evidence holds good to-day, more or less. On the other hand, the *Glyptodesma rectum?*, represented only by one external mold, is probably a Myalina related to *M. deltoidea* Gabb. In view of the facts that there has recently come to hand a large species of Camarotœchia (distinct, however, from the Philipsburg forms) from Utah high in the Pennsylvanian and that the stratigraphic position of lot 1 is above that of lot 12, it now seems probable that the age of the former is, as already stated, really Pennsylvanian. In this event the fauna is unusual and interesting."

H. S. Gale[c] in 1910 examined beds belonging to the Quadrant formation in the area south of the Philipsburg quadrangle. He considers the lower and purer quartzite of the quartzite member of the Quadrant equivalent to the Weber quartzite of southern Idaho and Utah, and the portion of the formation above this quartzite as equivalent to the Park City formation of the same regions. This correlation is based on lithologic similarity and the presence of phosphate, which was found at the top of the cherty limestone between the two siliceous strata.

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[a] Weed, W. H., Geology of the Little Belt Mountains, Montana: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1899, p. 188.

[b] Personal communication. See also Kindle, E. M., Fauna and stratigraphy of the Jefferson limestone in the northern Rocky Mountain region: Am. Paleontology, Bull. Cornell Univ. No. 20, 1908, p. 19, footnote.

[c] Oral communication to F. C. Calkins.

L 19–20. NEW BRUNSWICK.

The Carboniferous of New Brunswick comprises Mississippian, Pennsylvanian, and Permian strata. They have been studied in detail and have been the subject of several reports and discussions. Bailey[45a] has recently summed up the general facts in an article from which the following extract is taken.

In the reports and maps of the Geological Survey it has been usual to regard this system in New Brunswick as embracing three principal members, somewhat strongly contrasted in lithological characters and conditions of origin, viz, the Lower Carboniferous, the Carboniferous proper or Coal Measures, and the newer or Permo-Carboniferous, the first consisting of reddish sediments, with evidences of a generally marine origin; the second mostly gray or purplish, rarely red beds of marsh or fresh-water origin; and the third again showing a predominance of red tints, though without the marine limestones, gypsums, and salines which distinguish the Lower Carboniferous formation. In the "Acadian geology" of Sir William Dawson (1868) the Carboniferous proper was further subdivided into the "Millstone grit series" and the "Middle coal formation;" while with the marine limestones of the Lower Carboniferous division were associated, under the name of Lower Coal Measures (in addition to some beds resembling the Middle Coal Measures) the bituminous deposits known as the Albert shales.

It has already been stated as regards the peculiar shales last mentioned that there is at present a growing tendency to regard them as of Devonian rather than Carboniferous age, being the equivalents of the fish-bearing and fern-bearing rocks of the Baie des Chaleurs, though very unlike them in their physical aspects. It has also been stated that there are serious objections to this view; but as the question is mainly one of the interpretation of fossils and has little or no bearing upon the main subject of this report, that of the true coal-bearing rocks, it need not be further considered here. The doubtful beds in question being thus eliminated, the rocks which lie above them are very easily and clearly divisible into two great groups, viz, the Lower Carboniferous formation and the Carboniferous proper, or Coal Measures, while another, viz, the Upper or Permo-Carboniferous is less certainly distinguishable. The characters of these several subdivisions may be briefly summarized as follows:

Lower Carboniferous.—The lowest beds of this formation, as here limited, are usually coarse conglomerates, their composition and hence their general appearance varying with the nature of the rocks upon which they rest. They are, however, in almost every instance of a reddish color, varying from a clear rich red to a dark brownish red. They are usually also much harder than similar beds higher in the series, and in places are much stained with oxide of manganese. The cement is always to some extent and often very markedly calcareous. At some points, as at Quaco Head, St. John County, similar conglomerates are underlain by beds of limestone, but the principal limestone strata are situated at the summit rather than at the base of the formation. The conglomerates are usually followed by or interstratified with sandstones, also usually of a reddish color and markedly calcareous. Higher still the beds become finer, embracing shaly and marly deposits, upon which in many instances rest beds of gray flaggy, sometimes bituminous limestone and heavy beds of gypsum. Between these higher beds and the basal rocks of the coal formation (Millstone grit) it is common to find extensive sheets of igneous rocks, sometimes in the form of compact diabase, sometimes as a vesicular or amygdaloidal ash rock, and sometimes as claystone or rhyolite; but such plutonic masses are not confined to the summit of the formation, being sometimes, as at Quaco, near its base. Where igneous rocks are associated, as at Quaco and Hampstead, Queens County, with limestones, the latter have been more or less completely converted into marble.

The thickness of the Lower Carboniferous system varies greatly, but, according to measurements made by Dr. R. W. Ells in Albert and Westmorland, it reaches in those counties about 5,000 feet. Its thickness in the central basin is probably much less. [For "Coal Measures," see Chapter X, p. 473; for "Permo-Carboniferous" see Chapter XI, p. 498.]

L 20. NOVA SCOTIA AND ADJACENT PARTS OF NEW BRUNSWICK.

Writing of the eastern counties of New Brunswick, Ells and Bailey[317] in 1876 distinguished—

1. Metamorphic rocks of pre-Carboniferous age, with intrusive syenite.
2. Lower Carboniferous formation, including the Albert shales.
3. Millstone grit formation, or lower member of the Carboniferous system.

The Lower Carboniferous rocks * * * lie along the northern flank and at the eastern end of a chain of highlands * * * [and] consist largely of slates, usually either chloritic or talcose in character and of various colors; but with which are associated at some points thick beds of grit and conglomerate, also chloritic or talcose, and, less commonly, beds of pink or flesh-red felsite or petrosilex. Their age has not yet been definitely determined, but from observations made upon the more westerly portions of the same belt in St. John and King's counties, they would appear to belong to what, in previous reports, has been described as the Coastal group, which is believed to be of pre-Silurian and possibly Huronian age.

Along the northern border of the metamorphic belt, and immediately adjacent to the Lower Carboniferous tract * * * chloritic slates are associated with large quantities of reddish and gray syenite, which, in addition to occupying considerable areas, may be seen penetrating the slates in numerous veins and irregular masses of greater or less extent. They are * * * the source from which the materials of the Lower Carboniferous conglomerates have been to a great extent derived.

The Lower Carboniferous rocks * * * form the eastward extension of a considerable area. * * * The red sediments of which it is composed are at several points covered unconformably by isolated areas of gray rocks, having usually a much less inclination and belonging to the Millstone grit series, or the basal portion of the coal measures. * * * Being unconformable alike to the older slates upon which they rest, and to the newer gray rocks which succeed them upon the north, these sediments present in their distribution great irregularity, filling on the one hand depressions and indentations in the underlying formation, while on the other they are themselves often wholly or partially concealed by the deposits of the Millstone grit. * * *

The rocks being greatly disturbed, Ells and Bailey give the following section— as probably representing the true succession, while the thicknesses given are in each case the least assignable to the different groups, allowance being made for their apparent increase by faulting. The order is an ascending one.

	Feet.
1. Basal conglomerate, sometimes wanting; when present usually of a dull greenish color, less coarse than the conglomerates which succeed, and made up mostly of slaty fragments. Thickness unknown.	
2. Calcareo-bituminous shales, from gray to dark brown in color, and including the so-called "Albert shales." At the base these beds are unconformably overlain by brownish-red sandy shale	850
3. Gray bituminous and micaceous oil-bearing sandstones and coarse conglomerates, in massive beds of very various composition, usually of a reddish tint; less rubbly and more calcareous than those of division 1	700
4. Red and gray calcareous, sandy, and argillaceous beds, in frequent alternations, with thin beds of conglomerate and toward the top heavy beds of fine, rubbly brownish-red shales	450
5. Red and gray conglomerate, gray flaggy limestone, and gypsum	1,950

In his report for 1884 (published in 1886) Ells[309] repeats the above section without modification and describes many local sections in New Brunswick and Nova Scotia.

Fletcher[333] reported on the geology of the northern counties of Nova Scotia (Richmond, Inverness, Guysborough, and Antigonish) in 1879–80, giving many minutely measured sections, which together with those of other systems are in the report for 1886 generalized and accompanied by details of local sections and distribution.[334] The latest general account of the Carboniferous of Pictou and Colchester counties, which appears to hold in its broader features for the region as a whole, is contained in Fletcher's report for 1887–1891,[335] from which the following notes are taken:

Permian:
- Upper red sandstone and shale group, with thin bands of limestone.
- Middle gray sandstone and shale group, with small coal seams.
- New Glasgow conglomerate.

Carboniferous:
- Coal measures.
- Millstone grit.
- Carboniferous limestone.
- Carboniferous conglomerate.

Devonian:
- Upper red slate and sandstone group. Red rocks of Union, on the Truro & Pictou Railway.[a]
- Middle gray slate and sandstone group. Riversdale [a] and McKay Head rocks.[b]

The lowest Carboniferous is described as a coarse basal conglomerate, which contains pebbles of the underlying rocks from 1 inch to several inches in diameter and which is interstratified with gray and red sandstone. The identification of this formation in distinction to the middle Carboniferous "Millstone grit" is not always certain. The deposit is not everywhere present, the Carboniferous limestone overlapping upon older rocks in many places.

The Carboniferous limestone is a formation "characterized by the occurrence of gypsum, limestone, sandstones, marls, and other soft and friable rocks, apparently everywhere unconformable upon all underlying formations." [335d]

With reference to these two formations of the "Lower Carboniferous" and the "Millstone grit" Ami [18b] says in describing the section of the Knoydart (Devonian) of McArras Brook, Antigonish County:

> To the north and west of this Devonian area are seen newer measures referable to three distinct horizons of the Carboniferous system as developed in this portion of Nova Scotia. These include—
>
> (*a*) The so-called "Carboniferous conglomerate" formation described in the above report.[c] This series is presumably equivalent to the Bonaventure formation of Gaspe, and is doubtfully referred to it here.
>
> (*b*) The "Carboniferous limestone" series with its marls, sandstones, and marine limestones and gypsum, designated (in part at least) by the writer as the Hopewell formation.
>
> (*c*) The so-called "Millstone grit" series, for the most part very flat-lying and undisturbed, showing that the physical disturbances and agencies to which the Silurian and Devonian strata have been subjected which have dislocated and tilted their strata had disappeared previous to the time when these Carboniferous grits were laid down. The so-called "Millstone grit" series, which is very doubtfully the equivalent of the true "Millstone grit" of England, was designated by the writer as the Westville formation, in order to separate it from the other formations in the district.

In 1899 Ami [21] presented a discussion of facts and opinions relating to the classification of the Carboniferous of eastern Canada and included as "Eo-Carbon-

[a] Middle Carboniferous (Pottsville).—B. W.

[b] True "Coal Measures" (Allegheny?), Stellarton formation of Pictou, etc.—B. W.

[c] Ann. Rept. Geol. Survey Canada for 1886, pp. 71P, 85P, and 124P; idem for 1890–91, p. 173P.

iferous" the two formations known as the Union and Riversdale, which had been classed as Devonian on stratigraphic grounds. He sums up his conclusion in a table as follows:

Formations of the Carboniferous of a portion of Nova Scotia.

Formations.		Northern areas.	Southern areas.	Order.
Neo-Carboniferous	Cape John	Cape John sandstones		XII.
	Pictou	Pictou freestones		XI.
	Smelt Brook	Smelt Brook shales		X.
	Small's Brook	Spirorbis limestones		IX.
	New Glasgow	New Glasgow conglomerates		VIII.
			Coal Measures	VII.
		Unconformity.		
Meso-Carboniferous	Stellarton	Millstone grit	Millstone grit	VI.
	Westville		Unconformity (?)	V.
	Hopewell		Hopewell and Windsor	IV.
	Windsor			III.
		Unconformity		II.
Eo-Carboniferous	Union		Union	I.
	Riversdale		Riversdale	

In placing the Union and Riversdale at the base of the Carboniferous Ami accepted Fletcher's determination of their stratigraphic position below the lower Carboniferous limestone. Subsequent field study led him to recognize the fact that the limestone is overthrust upon these formations and normally belongs below them. He then accepted the evidence of the fossils, which places them in the "Meso-Carboniferous."[22] (See pp. 330–331.)

L-M 11-12. WESTERN MONTANA AND NORTHERN WYOMING.

Near the intersection of the forty-ninth parallel with the one hundred and fifteenth meridian, just west of the Flathead Valley, Montana, Carboniferous limestone of St. Louis age was identified by Weller.[940b] It rests conformably upon a pure quartzite, 25 feet thick, which lies unconformably, though without marked angular discordance, upon pre-Cambrian argillite of the Belt series. The extension of this formation in the McDonald Range of southern Alberta has been noted by Leach [526] under the general term "Devono-Carboniferous."

On the headwaters of Teton River, a branch of the Missouri, in latitude 48°, Carboniferous limestone forms the eastern portion of the Rocky Mountains between the Great Plains (Cretaceous) and the central ranges (Belt series, Algonkian).

In the Belt Mountains and other ranges of southwestern Montana and northern Wyoming the Carboniferous is represented, according to Weed and others, by Madison limestone and Quadrant quartzite. The type locality from which they were described by Peale is in the Gallatin Valley near Three Forks, Mont. Peale [631a] summarized the section. Girty [393d] has since discussed the fauna and correlation of the Madison limestone under the heading "Lower Carboniferous," as follows:

> The Madison limestone has been divided by the geologists of the Survey, upon lithologic characters, into nine beds, ranging from 24 to 32, both inclusive, of their section scheme. The following table, representing in condensed form the stratigraphic succession ascertained in the

Yellowstone National Park, was kindly supplied by Mr. Arnold Hague, geologist in charge of the Yellowstone National Park survey:

	Quadrant quartzite.	
	Madison limestone.	Feet.
32.	Four strata of light-gray, more or less cherty limestone	655
31.	Gray banded limestone, with abundant fossils	400
30.	Massive light-gray limestone	65
29.	Light-gray and brown, very finely crystalline or granular limestone	85
28.	Limestone, crystalline, light gray, and generally massive	200
27.	Limestone, dark gray and buff, very argillaceous, thick and thin bedded	50
26.	15 feet of quite pure and 60 feet of thin-bedded argillaceous limestone, both containing fossils	75
25.	Coarsely crystalline dark-gray limestone	80
24.	Limestone, finely crystalline and massive below, cherty in its upper portion	60
	Three Forks limestone.	
		1,670

All the evidence available seems to indicate that the Madison limestone is faunally a unit and can not be subdivided on the basis of its contained fossils.

Having given a table showing the range of species in the Madison limestone and having discussed certain diagnostic species, Girty [393e] concludes:

(1) The fauna of the Madison limestone can be referred wholly and without question to Carboniferous time; (2) it has a marked Kinderhook facies; (3) it is essentially the same fauna as that described by White, by Hall and Whitfield, and by Meek, and by them referred to the Kinderhook or Waverly; (4) the fauna is not separable into independent units but must be regarded as a whole.

These views regarding the position of the Madison were reaffirmed by Girty [363a] in 1905:

The fauna of the Madison limestone, which has so wide a distribution in the West, is * * * closely related to the typical Mississippian faunas. In my earlier work I correlated the Madison limestone with the Kinderhook, Burlington, and Keokuk groups of the Mississippi Valley and have seen no reason since to change my views. Nevertheless, it seems to be almost unquestionable that in some areas these western faunas, in their later developments, take on the aspect characteristic of the St. Louis epoch. Nowhere in the West, however, have any Kaskaskia faunas been discovered. One of three hypotheses seems necessary to explain this fact, which is no less striking, even should local areas of Kaskaskia rocks subsequently be discovered. Either no strata equivalent to the Kaskaskia have ever been deposited in this region; or, though deposited, they have since been removed; or else contemporaneously formed sediments supported a fauna which was so unlike the Kaskaskia that its equivalence has failed of recognition. Of these three hypotheses it is probable that the second is the correct one. Unmistakable evidence of unconformity between the Madison limestone (and its correlates) and the overlying beds has been found in so many points in the West that a period of erosion previous to the Pennsylvanian sediments can be hypothetized for all this western country, a generalization which is all the more safe from the widespread evidence of a similar occurrence in the central and eastern United States, and indeed in other parts of the world.

Girty [a] states that we now have reason to believe that the Quadrant, from which no fossils were known when the foregoing was written and which was generally supposed to be equivalent to the Weber quartzite (Pennsylvanian), may be in part of upper Mississippian or Kaskaskian age in some areas.

[a] Comment on manuscript.

M 11. FRONT RANGE, ROCKY MOUNTAINS OF ALBERTA.

The Banff series, consisting of upper shale, upper limestone, lower shale, and lower limestone, in the order named, constitutes the Carboniferous and possibly Upper Devonian of the eastern range of the Rockies in Alberta. McConnell [559b] describes the strata as follows:

The Cretaceous is underlain by the Banff limestone, of Lower Carboniferous or Upper Devonian age, and, notwithstanding the complete absence of all the intervening formations, no unconformity was anywhere detected between them, except where faulting is known to have occurred. The apparent conformity is perfect, even in the clearest sections, and the difficulty in drawing an exact line between the two series is further increased by the close lithological resemblance which the upper part of the Banff limestone bears to the lower beds of the Cretaceous.

The Banff limestone series has a total thickness of about 5,100 feet and is divisible into a lower and upper limestone and into lower and upper shales.

The upper shales vary in thickness from 500 to 1,500 feet but are usually in the neighborhood of 700 feet, and where this is much exceeded, as at the mouth of Johnson Creek, there is reason to suspect that some of the Cretaceous beds are included with them. They exhibit great diversity in structure and pass, according to the amount of arenaceous matter present, from finely fissile shales through flaggy and ordinary sandstone into hard quartzite. The quartzites, where present, occupy the lower part of the division and are overlain by the shales, and the two sets of beds in this position can occasionally be traced from one end of the range to the other. In other cases, however, this regularity is wanting and shales constantly pass into quartzites and vice versa. These shales are often calcareous or dolomitic and in places are represented by an impure limestone, and they always contain sufficient iron to give them a reddish color when weathered. They are found on the western slopes of most of the ranges in the eastern part of the chain and also in the bottoms of most of the longitudinal valleys of the same district, as from their relative softness they are one of the valley-making formations of this part of the range, an office which they fill in common with the Cretaceous shales. The Upper Banff shales are underlain by about 3,000 feet of limestone, which may be called the Upper Banff limestone in order to distinguish it from the lower limestones of the same series. This usually occurs as a grayish, purely calcareous and well-crystallized rock but is also found under a number of other forms. It is often dolomitic, and hard, bluish, compact beds are not uncommon, nor are shales and sandstones altogether absent. Its most characteristic features, however, are the abundance of crinoidal remains which it everywhere shows (some of the beds being wholly composed of the broken stems of crinoids) and the cherty concretions which are distributed through it, either irregularly or arranged in lines along the bedding. These concretions are especially abundant in Pilot Mountain and along the western side of the Sawback Range and in both these places are often united into thin irregular beds. They also become more numerous toward the top of the limestone and are occasionally continued on into the shales.

Below these limestones come from 500 to 700 feet of shales and shaly limestone, constituting the Lower Banff shales. The shales are dark colored but usually weather red and are somewhat arenaceous and pass into flaggy sandstone. They are also nearly always calcareous, and in places the series is represented altogether by impure shaly limestones. At a point about 2 miles up a small creek, which joins the Bow River gap, this group is underlain by from 15 to 20 feet of coal-black fissile shales, which rest directly on the massive limestone beds of the underlying formation and are interesting on account of their fossiliferous character. A number of specimens of a Clymenia, besides other fossils, were collected here. At one point these black shales bend around a large and well-rounded limestone bowlder, belonging apparently to the Castle Mountain group, and looking exactly like an erratic of the glacial drift.

The lowest division of the Banff limestone consists of from 600 to 800 feet of heavily bedded bluish and fairly compact limestone. In composition it is mostly calcareous, but it also contains a certain amount of dolomitic matter distributed in an irregular manner through the beds and evidently collected together by concretionary action. The dolomite is not visible on a fresh fracture, but, owing to its superior durability, it projects from weathered surfaces, over which it often forms a rough reticulation. This limestone differs from the Upper Banff limestone in being darker, more compact, and in the smaller number of crinoidal fragments and cherty concretions which it contains, although neither of these are altogether absent. * * *

The fossils of the Banff limestone show both Devonian and Carboniferous forms, and include a Rhynchonella like *rockymontana*, another like *R. metallica*, *Atrypa reticularis*, and a Spirifer like *S. whitneyi;* also a species of Athyris, Productus, Lichas, Eridophyllum, and Diphyphyllum. A large number of other species have been obtained, but these have not yet been studied.

The upper shales of this series have yielded some Aviculipectens and Lingulas.

M 21. NEWFOUNDLAND.

The Carboniferous of Newfoundland occurs in the general basin which contains the lower Carboniferous (Mississippian) and upper Carboniferous (Pennsylvanian) of Nova Scotia and New Brunswick. The former is probably represented by divisions *a*, *b*, and *c* of the classification quoted below, and the Pennsylvanian by divisions *d* and *e*. They can not be separated on the geologic map with the information at hand.

Murray [608b] in his report for 1873 gave the following account:

By a glance at the geological map of Canada it will immediately be observed that a vast area of the provinces of New Brunswick and Nova Scotia is spread over by members of this series; and further that the geographical position, where similar measures have been recognized in Newfoundland, is suggestive of the latter being the prolongation of a great elliptical-shaped trough extending from the former, the center of which is concealed beneath the waters of the Gulf of St. Lawrence. It may also be perceived that while in New Brunswick the formation extends in a uniform unbroken sheet over the surface, it becomes broken and patched in Nova Scotia and Cape Breton. The symmetry of the ellipse, moreover, will be seen to be broken near its center at the Magdalen Islands, where a part of the lower members of the system come to the surface, indicating the axis of an anticlinal fold bearing in the direction of St. George's Bay. Proceeding from the westward, this fold would thus appear to be the first of a series of disturbances, which increase in frequency farther east and which are intensely developed in Newfoundland. The contemporaneity of the Carboniferous rocks of the latter with those of the mainland is manifested by the same want of conformity with the older and supporting formations and the almost exact resemblance which obtains in mineral, lithological, and fossil characters throughout the stratigraphical sequence, from the base upward; but the accumulation in the island would appear to be in considerably less volume than on the mainland, and so far as our researches will permit the expression of opinion, it seems that it is in the upper members that the Newfoundland series is principally wanting. The southeastern boundary of the formation may be traced from a little way north of Cape Ray along the northwest flank of the Long Range of Laurentian mountains, up to the extreme head of St. George's Bay, where, although concealed from view, it was supposed to cross over, and making a further stretch beneath the marshes to the northward, finally sweeps round in a westerly course and crosses Harry's Brook below Spruce Brook, where it rests upon strata of Lower Silurian age. Its course westward is then interrupted by the protrusion of the labradorites of the Indian Head Range; but westward from that range the whole of the flat country is supported by Carboniferous rocks, which rest upon the upturned edges of Lower Silurian strata, displayed in the mountains which bound the plain, and on the coast of Port-a-Port Bay. Irregular patches of the formation are then found farther west in Port-a-Port Bay, and a strip is displayed along the outer coast of the Long Point Peninsula of the same, while to the northward it is recognized in the valley of the Coal River.

For convenience in describing the distribution of the series, I have divided it into five members, distinguished by letters, from *a* to *e*, inclusive, the general vertical section of which is given below, in descending order. Corresponding letters will be found on the map.

	Feet.
(*e*) Green and red sandstones, with brown and black carbonaceous shale, and brown and drab-colored clays. Fossil trees and flora abundant. Coal seams with underclays holding Stigmaria. [Pennsylvanian, "Coal Measures."—David White]	1,000
(*d*) Brown and reddish sandstones and conglomerates; brown, blackish, and greenish micaceous and arenaceous shale. False bedding in sandstones and ripple-marked surfaces frequent. Fossil plants, among which Sigillaria and Calamites are frequently met with. Thin seams and nests of coal. [Pottsville?—David White]	2,000
(*c*) Variegated red, green, and drab-colored marls; red, green, and brown sandstones, which are frequently calcareous; beds of bluish and gray limestones, some beds apparently magnesian, and many contain a profusion of organic remains, marine shells, etc., carbonized plants in the arenaceous strata. Salt springs frequent. [Mauch Chunk?—David White].	2,000
(*b*) Great masses of gypsum, with green and brown argillaceous shale; red marly shale; bands of black or dark-gray limestone, and occasionally jet-black shale. [Pocono?—David White]	150
(*a*) Very coarse conglomerate composed of great bowlders and pebbles of Laurentian and Silurian rocks, cemented in a matrix of greenish-colored sand; great lenticular intercalations of sandstone with coarse arenaceous shale; large fragments of magnetic iron ore; passes at the top into a brownish-gray flaggy sandstone with brown and greenish shales which underlie the gypsum	1,300
	6,450

M-P 8-11. ROCKY MOUNTAINS OF BRITISH COLUMBIA.

The Cache Creek group of British Columbia is an ill-defined sequence which comprises Carboniferous limestone and various other sedimentary and volcanic rocks. It has been identified more or less surely from the forty-ninth parallel to Alaska in the belt of metamorphic Paleozoic rocks. A comprehensive description is given by Dawson [261, 262] in his account of the Kamloops area, in British Columbia, from which the following is condensed:

The Cache Creek formation, as shown on the present map and as now understood, must therefore be regarded as including a very thick series of Paleozoic rocks, of which the greater part is definitely referable to the Carboniferous period by means of its fossils but of which it is scarcely probable that the upper and lower limits agree precisely with those of the typical Carboniferous. It may very possibly be found at the base, particularly, to transgress these limits and to include beds older than those of the system.

In attempting a brief general description of this formation, it must in the first place be observed that the extremely broken and disturbed character of the rocks almost everywhere renders it next to impossible to learn much about their attitude or sequence in any one locality. It is very generally impossible to determine whether the dip of the beds is normal or has been overturned. It is thus only by following the general association of the rocks from place to place and by piecing together facts observed at many different places that it becomes practicable to outline the salient features of the whole.

The western part of the Kamloops sheet, between the Thompson and Bonaparte rivers on one side and the Fraser on the other, is the typical area for the Cache Creek formation, and the most definite feature which can be traced throughout is the belt of massive * * * and whitish limestones, sometimes marbles. * * *

Practically the entire mass of the Marble Mountain Range is composed of these limestones, as well as the whole eastern part of the Pavilion Mountains. They include comparatively insignificant intercalations of argillite, cherty quartzite, and materials of volcanic origin. Farther south, in the region to the east of Hat Creek, such materials become more abundant and form thick beds among the limestones, particularly the cherty quartzites and the greenstones. In this region it is probable that the lower part of the great limestone series is most prominently displayed and that the higher beds are more characteristic in the north, particularly in the Marble and Pavilion mountains. The earlier stages of the great period of limestone deposition appear to have been marked by frequent interruptions, during which argillaceous and volcanic products were laid down; while in its later stages the deposition of the limestone must have been almost unbroken. The interlocking of the different classes of materials is such, however, as to show the close connection which obtains between the Marble Canyon limestones and the lower parts of the Cache Creek formation. * * *

The extremely unsatisfactory condition of the rocks of the Cache Creek series for all purposes of measurement [is such that] in endeavoring to give some idea of the total volume of the formation, no even approximately correct data can be quoted. The subjoined summarized section is therefore merely an attempt to indicate the general order of succession, and to some extent the importance of the formation, in the western part of the area of the [Kamloops] map. The order is descending.

	Feet.
1. Massive limestones (Marble Canyon limestone), with some minor intercalations of volcanic rocks, argillites, and cherty quartzites. At least 1,000 feet seen in some single exposures. Total thickness probably at least	3,000
2. Volcanic materials and limestones, with some argillites, cherty quartzites, etc. Minimum thickness about	2,000
3. Cherty quartzites, argillites, volcanic materials, and serpentines, with some limestone. The thickness of these beds, or of a part of them, was roughly estimated in two places as between 4,000 and 5,000 feet. Minimum total thickness say	4,500
	9,500

* * * * * * * * *

Thus, the entire volume of the rocks of the Cache Creek formation as this is now defined, may be assumed to be about 10,000 feet as a minimum, while I am inclined to believe that it really exceeds 15,000 feet.

* * * * * * * * *

A few characteristic fossils have been obtained in a number of places beyond the limits of the present map. At Stuart Lake (latitude 54° 30′), Dease River (latitude 59° 15′), Frances River (latitude 60° 30′), and on Tagish Lake (latitude 60°), fusuline limestones have been observed.

To the westward of the Coast Ranges (in which it is probable that numerous infolds of Paleozoic rocks will yet be found) a formation known from its fossils to be of Carboniferous age is again well represented. This has, so far, not been very minutely examined or reported in detail, but it is known to comprise thick beds of limestones, argillites, and volcanic materials, the latter being even more characteristic and in greater development than in the region here specially dealt with.

In the Rocky Mountains proper, or eastern member of the Cordilleran system, the section which must now be regarded as the typical one for these latitudes is that worked out by Mr. R. G. McConnell. In this section the Carboniferous period is represented by the Banff lime series, which, including two shaly zones, has a thickness of 5,100 feet. This has yielded a number of fossils and these show that the series as a whole represents the lower part of the Carboniferous, passing below into the Devono-Carboniferous. The later part of the Carboniferous period seems either to be unrepresented, or, if represented at all, to find but a partial equivalent in the upper shales. It is thus very probable that before the close of the Carboniferous the present position of the Rocky Mountains formed part of a land area.

* * * * * * * * *

It has already been noted that the lower portions of the Cache Creek formation may be older than the Carboniferous period. The very general blending of the Carboniferous and Devonian systems in the West shows that no well-marked line need be anticipated at the base of the Carboniferous. The separation of any beds of Devonian age can only be made in the event of the future discovery of characteristic fossils. The same may be said respecting the possible existence of Silurian or Cambro-Silurian beds.

Reference is made to the occurrence of limestone of the Cache Creek group on Atlin Lake, British Columbia, where it is present on both sides of Taku Arm,[389a] in latitude 59° 30′; and 10° farther south dolomites, argillites, serpentine, and greenstone, probably belonging to the Cache Creek group, have been noted.[99] In studying the Boundary Creek district, in British Columbia, adjoining the State of Washington, Brock[100] again distinguished the Cache Creek group among the metamorphic rocks of the region. He says:

On Observation Mountain near Grand Forks and on the rounded hill a little south of west of this and some of the hillsides on Newby's ranch are crystalline mica and hornblende schist with a few bands of crystalline limestone. These highly altered rocks resemble lithologically those of the Shuswap series (Archean) but may only be the argillites and limestones found elsewhere, in a more metamorphosed form.

The argillites, in places altered to schists and hornfels, limestone, usually crystalline, often highly so, quartzite, the latter occurring only sparingly, together with serpentine, which occurs in many portions of the districts associated with these, form a group which closely resembles the Cache Creek series described by Dr. Dawson and assigned by him to the Carboniferous. In the Boundary Creek sedimentary rocks no fossils have been found, but they are probably of about the same age as similar rocks occurring to the north and west and may, on this ground, be provisionally classed as Carboniferous.

N–O 8–9. SOUTHEASTERN ALASKA.

At Freshwater Bay, in the northeastern part of Chichagof Island, in latitude 58°, occur limestones about 1,500 feet thick, which carry a lower Carboniferous fauna that is related to the Mississippian of the interior of the continent but is of a different facies. Kindle[496b] correlates the formation with the lower Carboniferous of the upper Yukon and of the Cape Lisburne section.

An upper Carboniferous fauna characterizes a limestone 600 feet thick which occurs about Pybus Bay, Admiralty Island, in latitude 58°. Kindle gives the following section:

The oldest Carboniferous fauna which has been found in southeastern Alaska was obtained at Freshwater Bay, in the northeastern part of Chichagof Island. This fauna was submitted to Dr. George H. Girty, who states, in a report furnished the writer, that, "while not unlike the American Lower Carboniferous or Mississippian, it resembles and probably should be correlated with the Russian Lower Carboniferous or *Productus giganteus* zone or Mountain limestone." Freshwater Bay is the only locality visited where the Lower Carboniferous fauna has been found in southeastern Alaska. This locality is important also because the stratigraphic relation of the Lower Carboniferous to the older rocks may be observed.

On the northeastern side of the bay, and opposite the Silurian and Devonian limestones already described, the Carboniferous limestones form a low, narrow peninsula. * * * The thickness of the several divisions of the limestones which are exposed along the north shore of this peninsula is indicated approximately in the following section, which begins about one-half mile above (northwest of) North Passage Point:

	Feet.
(*e*) Breccia of large gray limestone fragments	100
(*d*) Hard gray limestone, much fractured by numerous irregular joints and breaking into small irregular fragments on weathering. Large productoids common. Dip 30° to 90° toward southwest; strike N. 40° W	90
(*c*) Gray limestone with frequent bands of black chert. Fossils scarce. Strike N. 10° to 20° W.; dip 80° to 90° NE	275
(*b*) Dark-gray limestone with black chert bands. Fossils abundant near upper and lower limits. Average strike N. 30° E.; dip 70° to 80° NW	250
(*a*) Limestone similar to *b*. Corals common	275
	990

Exposures on the north side of the bay and just west of the peninsula, which are lower but not continuous with this section, would add, if included in it, several hundred feet to its thickness. The total thickness of the Lower Carboniferous section is probably not less than 1,500 feet.

* * * * * * * * *

The Lower Carboniferous in southeast Alaska, while representing a different facies from that of the Mississippi Valley, is still much more closely allied to the interior continental faunas than is the Upper Carboniferous fauna of this region. The Lower Carboniferous fauna is widely distributed in Alaska. It has been recognized as far north as Cape Lisburne, on the Arctic coast, and it occurs at numerous points on the Yukon and Porcupine rivers in eastern Alaska.

Concerning the interval between the Upper and Lower Carboniferous faunas in this region we have but few data. No fauna representing it has been found.

The younger of the two Carboniferous faunas of southeastern Alaska is well represented in the limestones about Pybus Bay, on the southeast side of Admiralty Island, where they outcrop extensively along both arms of the bay. The limestones characterized by this Upper Carboniferous fauna have a thickness of about 600 feet at Pybus Bay. These Upper Carboniferous limestones are generally heavy-bedded or massive. * * * The Lower Carboniferous limestones where observed have thinner bedding and are darker colored than those of the higher horizon.

The following section, taken along the west shore of the east arm of the bay, indicates the character of the Carboniferous limestone (*c* of the section) and the associated beds:

	Feet.
[Mesozoic:]	
(*g*) Black to dark-gray argillaceous slates	300
(*f*) Covered interval	100
(*e*) Massive or heavy-bedded gray limestone with conchoidal fracture	40
[Carboniferous:]	
(*d*) Light-gray limestone full of small angular cherty masses	80
(*c*) Light-gray cherty limestone in 10 to 30 inch bands, fossils abundant	600
[Age undetermined:]	
(*b*) Red chert in 6 to 20 inch bands	300
(*a*) Black chert in 4 to 10 inch bands, with rarely a brown or red band	550
	1,970

The Mesozoic beds are represented by the two divisions *e* and *g* of the section.

The faunal relations of this limestone are considered by Girty to be rather with the Gschelstufe of Russia, which underlies the Russian Permian, than with that Permian itself. The horizon is, however, the same as that of those formations of Alaska which have been assigned to the Permian. The fauna is unlike any of the faunas of the Mississippi Valley but resembles that of the McCloud limestone of California. (See K 10, p. 376.) Kindle says:

The fauna of the Pybus limestone is the same which has been previously referred to the Permian in Alaska. Dr. George H. Girty, to whom the writer is indebted for the determination of the horizons represented by the Carboniferous collections, states, however, that he finds "that a greater resemblance exists with the Gschelian stage of the Russian section than with the Russian Permian. Provisionally, therefore, I will correlate this horizon with the Gschelstufe, in which occur a great number of equivalent or identical species. This fauna is entirely unlike anything in the Mississippian province of the United States, but some of our western faunas resemble it."

Fossils are usually abundant and well preserved wherever the Upper Carboniferous limestone is found. The character of this fauna is shown by the list of the species collected at Pybus Bay, which has been furnished by Dr. Girty.

* * * * * * * *

In the faunas of the Halleck Harbor section Dr. Girty reports both the upper and lower series of the Gschelstufe or upper Carboniferous faunas to be represented. This section, which is located on the north side of Saginaw Bay, Kuik Island, follows:

	Feet.
(b) Light-gray limestone, locally cherty; fossils abundant	450±
(a) Black carbonaceous shales, with interbedded dark calcareous sandstones, arranged in belts, in which shales and sandstones alternately predominate	125+

At one point the shales and sandstones of division *a* are seen to pass along the bedding directly into cherts similar to those of Pybus Bay. The fauna of this lower division of the section comprises [many species which have been determined by Girty.]

P 6-7. NORTHERN BASE OF THE ST. ELIAS RANGE AND WHITE RIVER BASIN, ALASKA AND YUKON TERRITORY.

Moffit and Knopf[600] describe the Carboniferous of the Nabesna-White River region as follows:

Upper Carboniferous deposits are represented in the headwater region of Copper River by the Mankomen formation.[a] This formation is a series of sediments, between 6,000 and 7,000 feet thick, composed of sandstones, shales, limestones, and tuffaceous beds with included lava flows and intruded sheets. These beds were originally described as Permian but should be correlated, on both structural and fossil evidence, with the beds along White River and would now be called upper Carboniferous. The Mankomen formation, as described by Mendenhall, "falls naturally into two divisions—an upper, prevailingly calcareous division, which includes somewhat more than half the total thickness, and a lower, prevailingly arenaceous and tuffaceous division, over 2,000 feet thick." Two principal limestones are present in the upper part of the Mankomen formation. The lower, a white massive limestone about 500 feet thick, is separated from the upper, which is about 600 feet thick, by several hundred feet of shale. This upper limestone is made up of thin beds and is highly fossiliferous, much more so than any other parts of the section examined. Fossils were collected at several horizons from the base to the top of the Mankomen section, and the correlation with the White River section is made on their evidence. The Mankomen resembles the Nabesna-White Carboniferous section in the presence of much volcanic material, in which respect both differ from the corresponding Yukon Carboniferous.

A massive limestone, having a maximum thickness of more than 2,000 feet, is found in the Chitina Valley and reaches its greatest development on Chitistone River, which heads near Skolai Pass. This formation is known as the Chitistone limestone and was correlated by Schrader and Spencer in their report in 1901 on the geology of the Chitina Valley[b] with the Carboniferous limestone of White River. They found no determinable fossils in the Chitistone limestone, and the correlation was based on stratigraphic evidence and lithologic similarity. After studying the Carboniferous formations of the Upper Copper River valley, Mendenhall[c] questioned this correlation, his objections being based on the seeming absence of fossils in the Chitistone limestone, on its conformable relation to the overlying Triassic sediments, and on its freedom from basic intrusives, all of these features being contrary to the character of the Carboniferous sediments of the Mankomen formation. Later work,[d] however, proved the Chitistone limestone to be of Triassic age, but it is suggested that the Nikolai greenstone, which conformably underlies the Chitistone limestone in the Chitina Valley, may probably

[a] Mendenhall, W. C., The geology of the central Copper River region, Alaska: Prof. Paper U. S. Geol. Survey No. 41, 1906, pp. 40-52.

[b] Schrader, F. C., and Spencer, A. C., The geology and mineral resources of a portion of the Copper River district, Alaska, a special publication of the U. S. Geol. Survey, 1901, p. 46. See also Bull. U. S. Geol. Survey No. 374, 1909, p. 27.

[c] Mendenhall, W. C., op. cit., p. 51.

[d] Moffit, F. H., and Maddren, A. G., Mineral resources of the Kotsina-Chitina region, Alaska: Bull. U. S. Geol. Survey No. 374, 1909, p. 26.

be the equivalent of some of the upper lava flows referred to the Carboniferous in White River valley. Proof for this correlation is lacking and will remain so until the upper limit of the Carboniferous is determined, but the seeming transition, without interruption, from Carboniferous to Triassic deposits in the Yukon Valley suggests the possibility of such a condition holding at the head of White River and that an unconformity between Carboniferous and Triassic deposition may not occur there. Whether the volcanic beds occurring between the massive limestones of the White and Chitina valleys should be referred to the Carboniferous or Triassic may be difficult if not impossible to determine.

Q 3. SEWARD PENINSULA, ALASKA.

Carboniferous limestone has been recognized in Seward Peninsula at Cape Mountain, near York;[a] at Baldy Mountain, in the Kougarok mining district;[b] at Cape Deceit, in Kotzebue Sound;[c] and at Black Mountain, on the lower part of Fish River[d]—in other words, at widely separated localities throughout the peninsula.[166] There is strong reason for believing that in addition to these known mapped localities some of the areas of limestone in the "unclassified Paleozoic" of Seward Peninsula may be of Carboniferous age. In 1909 fossils of either Devonian or Carboniferous age were found by Smith and Eakin[768] in dark-colored limestones on the eastern flanks of the Darby Range at several places. Other limestones associated with schists having characters similar to those of the known Carboniferous areas apparently occur in many places in northeastern Seward Peninsula. In 1908 a very poorly preserved fossil from the large limestone area west of Casadepaga River suggested possible correlation with the Carboniferous.

From the wide distribution of Carboniferous rocks in the peninsula it is probable that many infolded and infaulted remnants occur in such relations to the other members that the structural relations are obscure and involved. All of the known Carboniferous has been subjected to deformation, and in some places it has been intruded by igneous rocks of the granite family, so that under ordinary circumstances fossils are lacking and the original characters are more or less obliterated by secondary structures.

Q 7. UPPER YUKON AND PORCUPINE RIVERS, ALASKA.

Brooks and Kindle,[102] who examined the Porcupine-Yukon section in 1906, distinguish the following section as Carboniferous:

	Feet.
Limestone (youngest Carboniferous)	200
Shales, sandstones, and conglomerates, with a basal member of chert conglomerate	1,600
Probable unconformity by erosion.	
Thin-bedded limestone and shale, containing Carboniferous fossils	1,000
Black shale, classed as upper Devonian but comprising the transition to Carboniferous	1,300

The Carboniferous strata are said to embrace about 2,800 feet of sediment, usually not associated with contemporaneous igneous rocks and thus distinguished from the Devonian.

Details of the sections on Porcupine River are given by Kindle,[497a] who quotes determinations of faunas by Girty and floras by White. They conclude

[a] Collections made by A. J. Collier.
[b] Collections made by A. J. Collier and E. M. Kindle.
[c] Collections made by E. M. Kindle.
[d] Collections made by W. C. Mendenhall, F. L. Hess, E. M. Kindle, and P. S. Smith.

that collections obtained from the Porcupine below the Upper Ramparts, including both faunas and floras, indicate an early or basal Mississippian horizon, and Girty regards it as possible that the whole of Mississippian time is represented. In the Upper Ramparts, 40 miles east of the lower stations, is a belt of Carboniferous rocks which Girty regards as upper Carboniferous (Pennsylvanian).

R 3. CAPE LISBURNE AND CAPE THOMPSON, NORTHWESTERN ALASKA.

The Lisburne formation, once considered to be Devonian, has been shown to be Carboniferous by Collier,[165] who collected fossils and measured the following section:

Section of Paleozoic rocks in Cape Lisburne region, Alaska.

Age.	Formation.	Contact relations.	Thickness (feet).	Lithologic character.
Lower Carboniferous, Mississippian.	Lisburne.	Conformity.........	3,000+	Massive limestones, interstratified with white cherts. Extensive coral and bryozoan fauna.
		Conformity.........	1,000+	Thinly bedded shales, slates, cherts, and limestones. Fauna includes brachiopods, trilobites, cephalopods, and lamellibranchs.
		Conformity?	500+	Thinly bedded black shales, slates, and limestones. Several coral beds. Lower Carboniferous flora. Brachiopod and coral fauna.
Devonian (?).			2,000+	Calcareous sandstones and slates. No fossils found.

Probably the oldest formation of the region consists of heavy calcareous sandstones and interbedded calcareous slates, which occur on the west side of the Lisburne Hills, where they form the sea cliffs for about 15 miles north of Marryat Inlet, and are exposed for about 10 miles along Kukpuk River. The heavy sandstones range in thickness from 1 to 10 feet each, while the slaty beds are usually thinner. The massive members often present schistose phases and contain secondary mica. The total thickness has not been determined, though it is certainly not less than 1,000 feet. * * *

The age of the formation is inferred from its relations to the Carboniferous beds which overlie it with apparent conformity, though no direct paleontologic evidence could be obtained. It is certainly older than the Lower Carboniferous and is tentatively placed in the Devonian. * * *

The Carboniferous rocks lie east of the area of sandstones and slates just described and constitute the mass of the Lisburne Hills. * * *

The contact of these rocks with the supposed Devonian sandstones and slates has been observed at three localities. In two of these localities situated north and south the relation seems to be conformable, while in the third, 2 miles farther south of Cape Dyer, the contact is a well-defined thrust fault, with the sandstone overlying.

* * * The general area of undifferentiated Carboniferous * * * includes a diversity of rocks. Along the coast, where the observations were in more detail, three formations are differentiated, as follows: (1) A lower formation, consisting of slates, shales, and limestones, containing several coal beds and yielding Paleozoic fossil plants. (2) Overlying the coal-bearing beds are black cherts, slates, shales, and cherty limestones containing corals and bivalve fossils, the most common being several species of Aviculopecten. (3) Above these beds is a great thickness of massive limestones, largely made up of coral interbedded with massive white cherts.

The shaly members of the series are usually intensely crumpled, while the more massive beds present broad, open folds complicated by frequent thrust faults, which make the stratigraphy difficult to decipher.

The coal-bearing formation, which is the lowest, * * * is distinguished from the overlying formation by the presence of coal beds and of fossil plants in some of the black shales and clays. It is, therefore, essentially a fresh-water deposit. In one instance marine invertebrates have been found in such position as to suggest a possible interbedding of marine sediments with the fresh-water deposits, but as this relation may be due to the infolding of some of the overlying formations it can not be accepted as conclusive evidence. The beds are usually thin and the formation as a whole is softer than the overlying rocks. * * *

The middle formation of the Carboniferous series * * * consists of thinly bedded black slates, shales, cherts, and cherty limestones and is distinguished from the lower formation, which it resembles in general appearance, by the absence of coal beds or fossil flora of any kind, and from the upper formation of the series, first by its lithologic character and second by its fauna, which consists principally of brachiopods and mollusks, while that of the upper consists principally of corals. * * *

The upper member of this series [Lisburne formation] consists of massive thick-bedded limestones, massive white cherts, and occasional thinner beds of black slate or shale and is distinguished from the underlying Carboniferous formations by its lithologic character and its fauna, which consists mainly of corals. The contact relation of the upper to the middle formation of the series is conformable in an exposure south of Cape Lewis, * * * but in most of the other places where the contact is exposed faulting has occurred. The thickness exposed at Cape Lewis and also south at Cape Lisburne can not be regarded as less than 2,000 feet and may be much greater.

Girty [a] states regarding the age of the Lisburne formation:

The Pennsylvanian probably occurs there, but the greater part of the beds appear to be Mississippian. The Lisburne formation is in the main to be correlated, with little doubt, with the Mountain limestone of Europe and the upper Mississippian of the middle United States. There appears to be an older series, however, which correlates with the lower Mississippian. We have from it a few invertebrates suggesting this conclusion, among them *Leptæna rhomboidalis,* which is not known above the Burlington limestone, of the Mississippian.

The section exposed along the coast south of Cape Thompson was examined by Kindle,[500] who says:

The lowest beds exposed at Cape Thompson outcrop along the beach immediately north of the cliffs. The rocks exposed in these beach outcrops and the accessible or northern portions of the cape cliffs are indicated by the following section:

Section at Cape Thompson.

	Feet.
(*d*) Light-buff or cream-colored limestone with numerous fossils. Strike about north-south, dip variable, mostly E. 25° to 90°, complicated toward the south	500+
(*c*) Black and buff thin-bedded limestone, the former predominating. Productus and large crinoid stems abundant	380
(*b*) Bluish-gray to black fissile shale with abundant plant fragments. Dip E. 80° to 90°, strike N. 15° W	280
(*a*) Very thin bedded lead-gray sandstone, with occasional bands of brown ferruginous chert and films of coal. Plant fragments abundant. Strike N. 15° W., dip E. 86° to 90°	140

The lower 400 feet of the section appears to contain no invertebrate fossils. All or nearly all of these beds represent nonmarine sediments. Plant remains in various stages of maceration occur through most of the shales and sandstones below the limestone. Plant fossils were obtained from both *a* and *b* of the section and numbered respectively lots 5289 and 5290. These were submitted to Dr. David White, whose report follows.

[a] Letter of June 20, 1909, from the field.

"Lot 5289. This lot consists of three fragments of coarse gray sandstone bearing carbonized impressions of pieces of partially decorticated stems. The characters of the very imperfect impressions point toward a close affinity with *Lepidodendron corrugatum*.

"Lot 5290. This lot includes two small packages of wavy, black carbonaceous shale splitting in thin laminæ. This shale contains many fragments of leaves of Lepidodendron, and unidentifiable, decorticated stem fragments of several kinds, together with several imperfect remains in a better state of preservation. The latter represent *Sphenopteris frigida* Heer, twigs of *Lepidodendron veltheimianum* as generally identified in the European and Arctic floras, with a cone fragment possibly belonging to the same species, and portions of a Lepidophyllum very close to *Lepidophyllum fuisseense* Vaff. There are also present several fragments of a cyclopterid type; these are so incomplete that it is not really possible to decide whether they represent (*a*) rachial pinnules of Neuropteris; (*b*) some large, broad pinnuled Aneimites; or, (*c*) pinnules of Cardiopteris. I am inclined to refer them to the latter genus.

"The plant remains from Cape Thompson are so fragmentary and meager as to determinable species as not to permit a close determination of the age of the beds. They appear to be Mississippian and probably represent a stage in the lower part of this division. They may even come from the basal member thereof."

These plants evidently belong to the same horizon as that from which Collier obtained Carboniferous plants at Cape Lisburne. Concerning the Cape Lisburne plants, Dr. White's report[a] contains the following statement relative to their age:

"These fossil plants are evidently of Carboniferous age. Owing to the marked scarcity of filicate elements the testimony of the collection is less direct as to precise age than might otherwise be the case. However, from the evidence in hand I am forced to conclude that the plant-bearing terrane is Mississippian, and it appears probable that it is referable to the lower portion of the Mississippian. The flora * * * is very closely related to that from Bell Sound and Klass-Billen Bay in Spitzbergen. It seems to be slightly younger than the Ursa flora."

Above the plant-bearing beds only marine fossils are seen. The limestones which follow the sandstone and shales carry an abundant fauna. Corals are quite abundant in the upper division of the limestone series.

Dr. Girty furnished a list of fossils from these beds, on which Kindle comments as follows:

While some of the collections are much less numerous than others, it is probably safe to refer them to a single fauna, which is without much question of lower Carboniferous or Mississippian age. It is true that some of the forms appear to be allied to species in the Burlington and Keokuk of the Mississippian section, but I believe that the beds furnishing these fossils should correlate only with the upper Mississippian. Indeed, the faunas are especially suggestive of the well-known fauna of Spergen Hill, which is known to have been rather extensively distributed toward the northwest.

I have long been of the opinion that our upper Mississippian correlates in a general way with the Mississippian limestone of Europe and Asia, but the evidence has been more or less indirect and general in character. The present faunas are especially interesting, because they seem to show to some extent a mingling of the two faunas. The Mountain limestone element is represented by the abundance of Lithostrotion, and other features could probably be pointed out by one familiar with the European faunas. The coral fauna of the Mountain limestone is already known in Alaska, especially at Cape Lisburne, but it has not there, so far as known, the admixture of Mississippian types.

In connection with the interesting resemblance of the Cape Thompson fauna to the Spergen Hill fauna pointed out by Dr. Girty, reference may be made to the minute character of many

[a] Collier, A. J., Geology and coal resources of the Cape Lisburne region, Alaska: Bull. U. S. Geol. Survey No. 278, 1906, p. 22.

of the brachiopods. * * * In this feature the fauna strikingly resembles the depauperate Spergen Hill fauna. The presence in the fauna of a small specimen of Pentremites or a closely allied genus is also worthy of note in this connection. Although extremely abundant in the Mississippi Valley, this blastoid has been recognized at but two localities in the Rocky Mountains, and in both of these occurrences it is associated with a fauna closely resembling the Spergen Hill fauna.

R 5. ENDICOTT RANGE, ALASKA.

The Fickett "series," a very thick sequence of strata comprising a great variety of sedimentary rocks, was observed by Schrader in traversing the Endicott Range, longitude 150°–155° west. Lower Carboniferous fossils occur in pebbles found in gravels derived from it. Brooks [101f] summarizes the observations as follows:

During his exploration of the Anaktuvuk, in northern Alaska, Schrader traversed a belt of phyllites, chloritic schists, limestones, slate, sandstone, quartzite, grit, and conglomerates about 50 miles in width. In spite of the heterogeneity of these rocks and the uncertainty of their interrelations, the hasty character of the field observation made it necessary to group them in one formation, the Fickett series. The only fossils encountered were in the stream gravels and were evidently derived from beds in this series, and on this evidence the entire succession was provisionally assigned to the Lower Carboniferous. The Fickett overlies the Skajit (Silurian ?) on the south by an unconformable overlap, and on the north it is cut off by a fault from the Lisburne (Carboniferous). Schrader states that the Fickett and Lisburne series bear an unconformable relation.

The Fickett series, which may have a thickness of 8,000 to 10,000 feet, has a basal member made up of shale, slate, and limestone, succeeded by quartzite, grit, and conglomerate, and then by slate and micaceous sandstone. It is in this part of the section that the limestone is supposed to occur which yielded the Carboniferous fossils of the stream gravels. A still higher member includes sandstone, limestone, quartzite, schists, slate, and conglomerate, succeeded by quartz schists and green chloritic schists, the latter often cut by quartz veins. It is not made clear why the most highly altered members should occur at the top of the series, for while it is true that these metamorphosed rocks lie near one of the axes of intense folding, it would be expected that the same metamorphic effect would have been noted at the northern limit of the section, where another locus of extreme deformation was observed.

S-T 10-14, T 15, AND U 17-20. BARING (OR BANKS) LAND, PARRY ISLANDS, ELLESMERE LAND, AND GRINNELL LAND.

Haughton's description of the Arctic Carboniferous is quoted by Low [550g] as comprising the principal known facts regarding the Parry Islands:

The southern boundary of the Carboniferous sandstones with their included coal seams crosses the southern part of Banks Island in a north-northeast direction, and they consequently cover the northern two-thirds of that island, while the extreme northwest portion of Victoria Island is also occupied by these rocks. The western Parry Islands, on the north side of Melville Sound, are almost wholly formed of these rocks, whose southern boundary strikes northeast across the northern half of Cornwallis Island. They are found again in Grinnell Peninsula, the northwest portion of North Devon, and again on the western side of Ellesmere, in the vicinity of Store Bjornekap, being probably largely developed in the northeast part of that great island.

These rocks are described as follows by Prof. Haughton:

"The Upper Silurian limestones, already described, are succeeded by a most remarkable series of close-grained white sandstone, containing numerous beds of highly bituminous coal and but few marine fossils. In fact, the only fossil shell found in these beds, as far as I know, in any part of the Arctic Archipelago, is a species of ribbed Atrypa, which I believe to be identical with the *Atrypa fallax* of the Carboniferous slate of Ireland. These sandstone beds are succeeded by a series of blue limestone beds containing an abundance of marine shells, commonly found in all parts of the world where the Carboniferous deposits are at all developed. The line of junction of these deposits with the Silurian on which they rest is northeast to east-northeast (true). Like the former, they occur in low, flat beds, sometimes rising into cliffs, but never reaching the elevation attained by the Silurian rocks in Lancaster Sound."

In regard to Ellesmere Land, Low [550h] quotes Schei [706] as follows:

The Carboniferous rocks of western Ellesmere appear to be isolated areas resting upon the underlying Devonian and in turn covered by Mesozoic rocks. Schei describes the area at Store Bjornekap as consisting in its lowest part of beds of brownish-gray hard fossiliferous limestone; higher up, of a white pure limestone, flinty limestone, and pure flint strata, richly fossiliferous, among the fossils being Lithostrotion sp., Fenestella sp., *Streptorhynchus crenistria*, Rhynchonella (Pugnax) sp., *Spirifer* cfr. *ovalis, cuspidatus, mosquensis, Productus* cfr. *semireticulatus, costatus, punctatus, cora,* etc.

Lists of the fossils collected by various expeditions up to 1860 are given by Haughton [414] and republished in the "Arctic manual," 1875, edited by T. Rupert Jones.[472]

The lower division of the Arctic Carboniferous, which consists of sandstones and shales, has furnished a few plants from localities in Melville and Bathurst islands. Heer assigned the formation to the Ursa stage and correlated it with similar deposits in Bear Island and Spitzbergen. David White, however, regards the typical Ursa as Devonian at latest, and reports that the plants from the Arctic Archipelago represent the lower Carboniferous. The formation is probably related to the Mississippian of the section at Cape Lisburne, Alaska.

The upper division of the Carboniferous in the Arctic is the limestone from which the marine invertebrate fossils have been obtained. Girty has examined the literature and has furnished the following statement:

The most extensive fauna reported was obtained at Depot Point in Grinnell Land. In it have been identified *Fusulina hyperborea, Stylastræa inconferta, Lithostrotion basaltiforme, Zaphrentis ovibos, Clisiophyllum tumulus, Syringopora aulopora, Fenestella arctica, Productus semireticulatus* var. *frigidus,* and *Spirifer keilhavii.*

This fauna, composed as it is largely of corals, is difficult to correlate satisfactorily. A suggestion is found in the fact that Tschernyschew states that the fossil cited by Haughton under the name *Spirifer keilhavii* undoubtedly belongs to *Spiriferella saranæ,* which is a species of the Gschelian fauna of Russia. Some of the other Arctic brachiopods show similar alliances and this is also conspicuously the case with certain of the Alaskan faunas. It seems highly probable, therefore, that the Gschelian fauna was distributed over this region.

Some of the species cited from Depot Point have been found also at other stations, one or two at a time. In addition the following have been identified apparently from the same limestone in the Parry Islands: *Syringopora geniculata, Productus cora, Productus sulcatus* var. *borealis,* and *Spirifer arcticus.*

Still another Carboniferous formation with invertebrate fossils is found in Ellesmere Land. In the preliminary notice Schei refers his fauna to the upper Carboniferous and if his identification of *Spirifer mosquensis,* a leading fossil of the upper Carboniferous of Russia, is to be trusted, the horizon is possibly the Mosquensis zone of the Russian section, which comes in at the base of the upper Carboniferous. The position of the Ellesmere occurrence would then be below the horizon of the Carboniferous limestone of the Parry Islands and above the phytiferous beds. Whether the *Spirifer mosquensis* horizon occurs in the Parry Islands can not be determined from the fragmentary paleontologic evidence thus far obtained. There is yet no clear suggestion of two distinct faunas in the species cited from the Parry Islands and from Grinnell Land, nor does the fauna from those areas present any close similarity with that from Ellesmere Land.

Chapter IX.

MISSISSIPPIAN.

Color, light French blue.
Symbol, 13.
Distribution: Guatemala; eastern North America from Oklahoma to Nova Scotia; present but included in the "Carboniferous undivided" (14) in the Cordillera, Arctic region, and Newfoundland.
Content: "Lower Carboniferous" limestones and their equivalents where they are separated on the map from Pennsylvanian coal measures. In Guatemala the Santa Rosa formation.

Mississippian areas.

I 16. ALABAMA AND TENNESSEE.

In their southern extension into Tennessee and northern Alabama the Mississippian strata were described by Safford [687a] as the "Siliceous group" (regarded by him as equivalent to Burlington, Keokuk, and St. Louis) and the "Mountain limestone" (regarded by him as equivalent to Chester), and these terms were used in Alabama. The latest classification for western Tennessee is that given by Hayes and Ulrich [431b] in the Columbia folio, as follows:

Mississippian formations in western Tennessee.

<table>
<tr><th colspan="2">Generalized time scale for central North America.</th><th>Mappable lithologic equivalents in the Columbia quadrangle.</th><th>Safford and Killebrew (Elements of geology of Tennessee, 1900). Middle Tennessee.</th><th colspan="2">Safford (Geology of Tennessee, 1869). Middle Tennessee.</th></tr>
<tr><td rowspan="5">Carboniferous (Mississippian).</td><td>Chester.</td><td>(Not present.)</td><td>Mountain limestone.</td><td colspan="2">Mountain limestone.</td></tr>
<tr><td>St. Louis.</td><td>St. Louis limestone.</td><td>St. Louis limestone.</td><td>Lithostrotion bed or St. Louis limestone.</td><td rowspan="4">Siliceous group.</td></tr>
<tr><td>Keokuk.</td><td rowspan="3">Tullahoma formation.</td><td rowspan="3">Tullahoma formation.</td><td rowspan="3">Lower or Protean member.</td></tr>
<tr><td>Burlington.</td></tr>
<tr><td>Kinderhook.</td></tr>
</table>

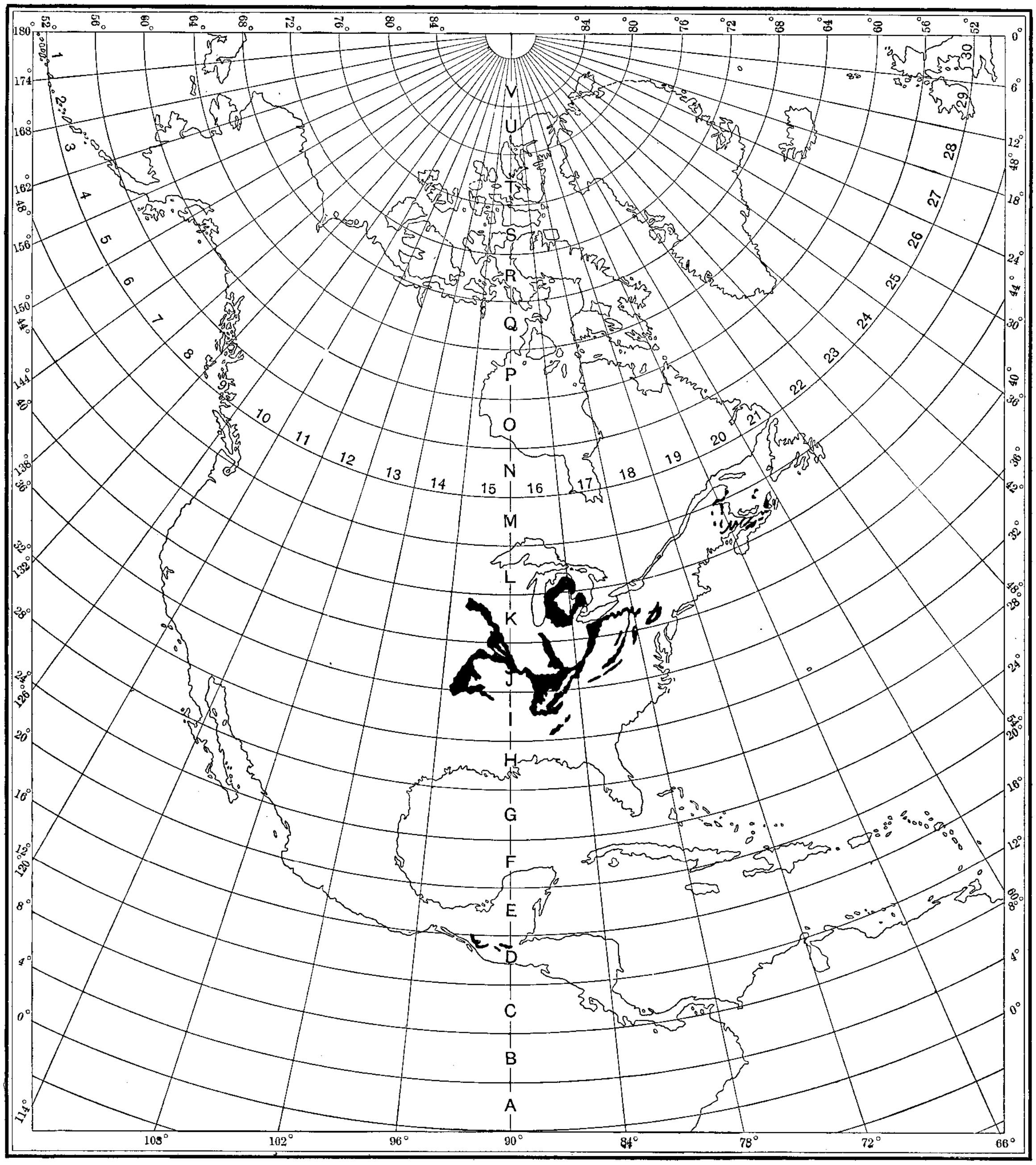

FIGURE 11.—Sketch map showing the distribution of Mississippian rocks that are separately represented on the geologic map of North America and the key to references in the text.

The strata are thus described:

Tullahoma formation.—This formation consists chiefly of siliceous shales and limestones, but the lowest member is a calcareous shale, generally a grayish green or pale blue but occasionally dark, varying from nothing to perhaps 30 feet in thickness. * * * The fossils, though chiefly of undescribed species of Ostracoda, indicate very early Mississippian age. * * *

A strongly siliceous and argillaceous limestone that weathers into a cherty, shalelike material occurs stratigraphically above the calcareous shale but usually constitutes the ordinary base of the formation. Similar strata, in one place more shaly, in another more calcareous, and generally with heavier chert, continue to the top of the formation, which has a maximum thickness of about 250 feet. Usually it is much less, especially in the southeastern quarter of the quadrangle. * * *

Excepting in the basal shales, specifically recognizable fossils are extremely few in this formation. Here and there the heavier chert blocks contain large crinoid stems in abundance, and occasionally a brachiopod cast, indicating the Burlington or Keokuk horizon of Iowa and Illinois.

St. Louis limestone.—This, the latest or youngest formation exposed in the quadrangle, consists in the main of a thick bed of limestone, gray to blue in color, and associated with considerable chert. * * * The fossils are mostly small and consist mainly of Bryozoa and brachiopods more or less characteristic of the "Warsaw horizons" of Illinois, Indiana, and Kentucky, which have been referred to various ages. Above these heavy layers come the more characteristic St. Louis fossils, like Melonites and Lonsdaleia, or as the latter is generally called, *Lithostrotion canadense.*

In 1894 the Alabama section of the Mississippian was thus classified by Smith[746]:

Mountain limestone:
- (*a*) Bangor limestone and Hartselle sandstone.
- (*b*) Oxmoor shale and sandstone.
  (Chester.)

Fort Payne:
- (*a*) Tuscumbia (St. Louis).
- (*b*) Lauderdale (Keokuk, etc.).

This classification has since been revised and modified. The latest statement is by Butts,[107b] as follows:

Overlying the Devonian black shale unconformably are rocks of Mississippian or lower Carboniferous age. At the base of the Mississippian rocks, throughout the whole region, is the Fort Payne chert; this is succeeded in Brown and Murphrees valleys by the Bangor limestone, with the included Hartselle sandstone member, and by an overlying shale which is correlated on stratigraphic and lithologic grounds with the Pennington shale to the north. At the southern end and along the east side of Blount Mountain, and along the east side of Shades Valley, the Pennington shale is overlain by shales and sandstones to which the name Parkwood formation is here given. South of Boyles Gap in Opossum Valley and south of Oxmoor in Shades Valley the Bangor limestone runs out and is replaced by black and gray shales similar to the Floyd shale to the northeast. Because of its stratigraphic position and lithologic similarity this shale will be called Floyd shale in this report. South of Boyles Gap and Oxmoor, therefore, the Mississippian rocks above the Fort Payne chert consist of the Floyd shale (including the Hartselle sandstone, which persists after the thinning out of the Bangor limestone and thus locally becomes a member of the Floyd shale) and the Parkwood formation above the Floyd. The Floyd shale is thus the equivalent of the Bangor limestone and the Pennington shale. In reports of the Alabama Geological Survey the Floyd shale and the rocks comprising the Parkwood formation have been treated together as the "Oxmoor or shale and sandstone phase" of the upper part of the lower Carboniferous rocks, and the Bangor limestone has been called the "Bangor or limestone phase" of the same rocks, the two phases being regarded as contemporaneous.

As a result of the writer's study of the geology of the region, however, the conclusion has been reached that only the Floyd shale and the rocks included by the Alabama Survey in the "Bangor or limestone phase" are contemporaneous. The Parkwood formation of Shades Valley and Blount Mountain is absent from the section in Murphrees and Brown valleys, having been eroded west of Birmingham Valley before the deposition of the Pottsville or "Coal Measures," so that they rest unconformably on the Pennington shale.

The variations in the stratigraphy of the Mississippian formations above the Fort Payne chert are shown in the sections below:

Section of Mississippian rocks above the Fort Payne chert in Brown and Murphrees valleys.

	Feet.
Pottsville formation.	
Pennington shale	100
Bangor limestone:	
Limestone	350
Shale	30
Sandstone (Hartselle member)	100
Shale	50
Limestone	160
Fort Payne chert.	
	790

Section of Mississippian rocks above the Fort Payne chert near Irondale.

	Feet.
Pottsville formation.	
Parkwood formation, shale and sandstone	2,000
Pennington shale, dark, calcareous (?)	292
Bangor limestone:	
Limestone	317
Shale, soft, dark, calcareous (?)	39
Sandstone (Hartselle member)	117
Shale, dark, calcareous (?)	97
Limestone	88
Fort Payne chert.	
	2,950

Still farther south, in the vicinity of Readers Gap, borings show only dark shale, probably calcareous, in the 500 feet immediately over the Fort Payne chert. The well logs are corroborated in the main by all that can be seen of the formation. South of Boyles Gap and Oxmoor good sections and accurate measurements of the rocks under discussion are not obtainable. A compiled section for the region south of Oxmoor, probably a close approximation, is as follows:

	Feet.
Pottsville formation.	
Parkwood formation, shale and sandstone	2,000
Floyd shale:	
Shale, some calcareous, sandstone, and limestone lenses	700
Sandstone (Hartselle member)	100
Shale, dark, calcareous	200
Fort Payne chert.	
	3,000

Sections of rocks below the coal measures.

A. In Murphrees and northern part of Birmingham valleys.

System.	Formation.	Thickness (feet).	General character.
Carboniferous (Mississippian series).	Parkwood formation.	Knife-edge to 2,000.	Prevailingly gray shale and sandstone; no calcareous beds. Fossils very scarce.
	Pennington shale.	60–300	Gray, green, and red shale, with a little chert and some sandstone and conglomerate. Highly fossiliferous.
	Bangor limestone.	700	Prevailingly thick-bedded light-gray crystalline limestone. Hartselle sandstone member and shale in midst. Merges through sparingly cherty limestone into Fort Payne chert below. Highly fossiliferous.
	(Hartselle sandstone member).	(100)	(Prevailingly fine-grained firm sandstone, locally coarse and friable.)
	Fort Payne chert.	200	Mostly thin-bedded chert; locally thick bedded at bottom. Generally fragile. Fossiliferous.
	Unconformity		
Devonian.	Chattanooga shale and Frog Mountain sandstone.		Black carbonaceous shale, locally sandstone below, with phosphate nodules and fossils.
	Unconformity.		

B. In southern part of Birmingham and Shades valleys.

[Section below Floyd shale is same as in A.]

Formation.	Thickness (feet).	General character.
Parkwood formation.	1,500–2,000	Same description as in A.
Floyd shale.	1,000	Gray, dark, and black shale, calcareous at horizons. Contains beds of sandstone and lenses of limestone. Highly fossiliferous throughout. Equivalent to the Bangor and Pennington formations. Hartselle sandstone member.
Fort Payne chert.	200±	

Stevenson[794e] comments on the fact that the formations represented in Alabama are recognizable far to the north and northeast, although they undergo very material lithologic changes, and he thus sums up the relations:

Beginning at the south, on the western outcrop, one finds, ascending, the Tuscumbia, limestone and markedly siliceous; the Hartselle, sandstone with shales and limestones; and the Bangor, limestones more or less argillaceous. These three divisions retain their characteristics across Tennessee into Kentucky, the Bangor meanwhile becoming more argillaceous in northern Tennessee, where its upper portion has been identified with the Pennington shale. In Kentucky the Tuscumbia and Hartselle are taken together as the St. Louis, but they retain the Tennessee features, one of the Hartselle sandstones being persistent. The Bangor becomes very shaly and, like the Tuscumbia, thins out northward more rapidly than the Hartselle, so that the last alone is present in central Ohio, where Prof. Andrews called it the Maxville.

Along the eastern outcrop one finds greater variation, for outlying areas toward the southeast reveal something of the conditions existing along the old shore line. But those areas may be neglected in this connection. Following the border of the principal areas, one finds the Tuscumbia, Hartselle, and Bangor sharply defined in Alabama, with the same features as on the western side. In Tennessee the Tuscumbia is easily recognized in the upper portion of Mr. Hayes's Fort Payne, while at least one of the Hartselle sandstones is persistent in southern Virginia; but the Bangor, the upper portion of Mr. Hayes's Bangor limestone, becomes increasingly argillaceous northward, so that frequent reference is made to its tendency to weather into shale. Toward the Virginia line it becomes almost wholly shale and sandstone, while it increases greatly in thickness, so that Mr. Campbell has separated the Pennington shale from the limestone which he calls Newman. The enormous increase in thickness of the section, due to increase of land detritus, renders exact tracing difficult for a little way in southwest Virginia, the more so since detailed descriptions have not been published. The Bangor evidently becomes wholly shale and sandstone before New and Greenbrier rivers are reached, where Fontaine and Campbell found so great a mass of shales with insignificant streaks of limestone. The persistence of the Hartselle sandstone at the bottom of the shales or near the top of the limestone is shown by many of the oil records and along the outcrops almost into Pennsylvania. The upper limestone of Virginia, Maryland, and Pennsylvania is the Hartselle. The Tuscumbia retains its siliceous character throughout, though losing its chert in Virginia and becoming merely a siliceous limestone; this feature, along with a curiously current-bedded structure and a peculiar whiteness when crushed, characterizes it thence into Pennsylvania, where by several of the geologists it was termed the Siliceous limestone.

The correlation seems to be:

Shenango [*shale*].—Bangor of McCalley in Alabama; upper portion of Bangor of Hayes in Tennessee; upper portion of Safford's Mountain limestone in Tennessee; Chester of Kentucky geologists (Second Survey); Pennington and top of Newman of Campbell in Tennessee and southwest Virginia; Umbral shales of Fontaine; Canaan shales of Darton; Greenbrier shale of W. B. Rogers; Mauch Chunk shale of Maryland; Mauch Chunk of Pennsylvania in part; absent from most of Ohio; Shenango shale of I. C. White in northeast Ohio and northwest Pennsylvania.

Maxville.—Hartselle of Alabama; greater part of Bangor in Tennessee; lower part of Mountain limestone in Tennessee; greater part of upper Newman and of upper Greenbrier in Virginia; upper Umbral and upper Mauch Chunk limestones in Pennsylvania; Maxville of Ohio; upper St. Louis of Kentucky.

Tuscumbia.—Tuscumbia of McCalley in Alabama; Lithostrotion of Safford in Tennessee; upper part of Fort Payne in Tennessee; lower part of St. Louis in Kentucky; lower Newman and Greenbrier in Virginia; lower [part] of Greenbrier in Maryland; Siliceous limestone of Pennsylvania; absent in Ohio except at Kentucky border.

The term Shenango is the earliest applied definitely to the latest division. Though Dr. White's Shenango shales have been spoken of as representing the whole of the Mauch Chunk sedimentation, it will be shown in the next chapter that they represent practically only the sedimentation of the closing epoch. The name Maxville was given by Prof. Andrews in 1870 and therefore antedates Hartselle by many years. Tuscumbia, being a geographical term, will have to replace the much older Lithostrotion of Prof. Safford.

The fossils from the Shenango appear to be those characteristic of the Chester of the Mississippi basin. Forms belonging to that epoch have been collected in Pennsylvania, Virginia, Kentucky, and elsewhere. Fossils collected by Andrews in 1869 from the Maxville localities in Ohio and by Stevenson in 1870 from the same limestone in West Virginia were submitted to Mr. F. B. Meek, who pronounced them distinctly Chester. Prof. R. P. Whitfield afterward figured and described the Ohio forms, referring them practically to the same horizon. Still later, in 1901, Stevenson collected carefully at a locality in Fayette County of Pennsylvania and submitted the specimens to Mr. Weller, who found that the fauna contains some St. Louis as well as the Chester forms. There is, however, practically no change in the fauna from the bottom to the top of this locality, the same forms, with two or three exceptions, being found throughout. The Chester forms predominate, and of those belonging to the St. Louis some lived on into the Chester at typical localities within the Mississippi basin. The same fauna occurs in Randolph County of east-central West Virginia and in Washington County of Virginia at the Tennessee border. In Tennessee and Alabama the Maxville (Hartselle) is clearly Chester. The Kentucky geologists of the Second Survey make the Maxville the upper part of their St. Louis, but it overlies the Lithostrotion bed, the lower part of their St. Louis. No list is given of the fossils which lead to classification of the limestone as St. Louis.

The Tuscumbia is practically nonfossiliferous at most localities in Pennsylvania. In Tennessee and Alabama, as well as in Kentucky, *Lithostrotion canadensis* is the characteristic fossil, and it is associated with other forms belonging to the St. Louis.

Girty [a] comments on the correlation which Stevenson thus suggests as follows:

In the correlations quoted from Stevenson there appears to be an error. Stevenson there places the Shenango above the Maxville and the Tuscumbia, whereas on page 42 he assigns the Shenango to the horizon of the Burlington and Keokuk and correlates it with the Logan which underlies the Maxville in the Ohio section. It seems almost certain that in the former case he is speaking of the Shenango shale of White and in the latter of the underlying Shenango sandstone of the same author. There can hardly be a doubt that the Shenango sandstone is the same in part at least as the "Logan group" of Ohio (now the Blackhand and Logan formations). The correlation of the Shenango sandstone with the Blackhand and of the Logan with the Shenango shale is suggested by the lithologic sequences. Professor Stevenson, however, appears to consider the Shenango shale as occupying a much higher position. He places it equivalent to the upper Mauch Chunk and above rather than below the Maxville. If this is so, there must be an important interval between the Shenango shale and the Shenango sandstone representing the lower and middle Mauch Chunk, so that it would be inadvisable to include the shale and sandstone under the same formation name. If Stevenson is right, the sandstone alone should be called Shenango.

Some doubt also is involved in the use of the name Tuscumbia for the lowest of these three formations, with which he aligns the Fort Payne of Tennessee. I have good faunas of both the Fort Payne of Alabama and the overlying Hartselle of the same area and I also have a collection from the limestone at Tuscumbia, Ala., which is without much question the Tuscumbia limestone. The Tuscumbia fauna is decidedly different from either the Fort Payne or Hartselle faunas and much more closely allied to that of the overlying Bangor.

J-K 15. IOWA, ILLINOIS, MISSOURI, ARKANSAS, AND OKLAHOMA.

The region here comprised is that in which the Mississippian is typically developed as a great limestone, which is divided locally into several formations according to the nature of the strata, and these are grouped according to their fossil contents.

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[a] Comment on manuscript.

In originally defining the Mississippian Williams [932] discussed previous attempts at correlation and proposed the following classification:

Recent studies of the fossils, their original grouping into local faunas, and their association in other parts of the province have led me to recognize three fairly well differentiated faunas in the Mississippian series, the subdivisions of which are believed to be local and therefore very unsatisfactory for purposes of correlation.

The following table sets forth the proposed classification and nomenclature:

	Structure scale.		Time scale.
Mississippian series	Chester stage St. Louis stage Warsaw stage		Genevieve age.
	Keokuk stage Burlington stage		Osage age.
	Kinderhook stage, including	Chouteau limestone Vermicular shale and sandstone Lithographic limestone	Chouteau age.

The Chouteau age is the age of the Chouteau group of Broadhead. The Osage age is the age of the fauna of the Burlington and Keokuk formations, which are locally distinguishable but in the sections on the northwestern, western, and southwestern flanks of the Ozark uplift are so blended that it seems impracticable in most cases to differentiate them. The name is suggested by the fact that the Osage River drains the region in which this confusion of the two faunas is clearly exhibited. The Genevieve age is the age of the fauna of the Archimedes group of Shumard.

The name is suggested by the fact that Shumard first called attention to the union of the several formations in which the common fauna prevails in his description of the geology of Ste. Genevieve County, Mo. The name he applied was Archimedes group, but this is not a satisfactory name, and in the county of Ste. Genevieve and on the eastern and northeastern margins of the Ozark uplift, above and below this county, are found the typical outcrops of the individual formations included in the group.

The term Mississippian is now generally used for the lower Carboniferous in North American stratigraphy, but the definition of its limits and the classification of its subdivisions have been subjects of continued research and discussion. Chamberlin and Salisbury [134] give the following list of divisions in the Mississippian province, together with those of other sections of the eastern interior:

Subdivisions of Mississippian series.

Mississippi River States.[a]	Ohio.[b]	Pennsylvania.[c]	Maryland.[d]
	7. Maxville.		
4. Kaskaskia or Chester.	6. Logan.		3. Mauch Chunk.
3. St. Louis.	5. Blackhand.	2. Mauch Chunk.	
2. Osage or Augusta (including the Burlington, Keokuk and Warsaw).	4. Cuyahoga.		2. Greenbrier.[e]
	3. Sunbury.		
1. Kinderhook or Chouteau.	2. Berea grit.		
	1. Bedford.	1. Pocono.	1. Pocono.

[a] Williams, Bull. U. S. Geol. Survey, No. 80, p. 169. St. Genevieve was the term applied by Williams to the upper part of the Mississippi system.

[b] Prosser, Jour. Geology, vol. 9, p. 215; vol. 11, p. 520. See also Am. Geologist, vol. 34, p. 335.

[c] Pennsylvania Repts. and folios of U. S. Geol. Survey.

[d] O'Harra, Maryland Geol. Survey, Allegany County, pp. 109–113.

[e] The Greenbrier is absent in eastern Pennsylvania. It comes in as a lentil of limestone farther west, and thickens southward, becoming an important formation in Virginia, largely replacing the Mauch Chunk shale. See Brownsville-Connellsville folio, U. S. Geol. Survey (Campbell).

The latest statement on the Mississippian is by Weller,[886] whose full discussion may be abstracted as follows:

Weller distinguishes (1) a "southern Kinderhook or Chouteau fauna," partly derived from the Devonian (showing relationships to the Hamilton fauna) and partly composed of "a new element from some unknown region." "The return of this fauna into the Mississippi Valley basin marks the opening of the Kinderhook epoch and the Mississippian period." This southern fauna is well developed in southern Indiana and Illinois, in the Rockford limestone of the Indiana State reports.

(2) A northern Kinderhook fauna, differing markedly from the southern, typified by the "Chonopectus" sandstone and developed in Iowa and northern Illinois, north of the "Kankakee peninsula." This northern fauna is related to the Chemung faunas of the eastern upper Devonian. The southern and northern Kinderhook faunas, though apparently contemporaneous within comparatively narrow limits, occupied distinct faunal provinces as regards invertebrate life. A fish, *Ptyctodus calceolus*, was common to both.

> During the progress of Kinderhook time the sea was encroaching from both the north and the south, until before the close of the epoch free communication was established between the earlier separated provinces, and the fauna of the southern province became the dominant type throughout the entire Mississippi Valley basin. * * * It is evident that the arrangement of the Kinderhook formations into three successive divisions, the Louisiana, Hannibal, and Chouteau, as has usually been done, does not express the proper relationships of the faunas. The Chouteau fauna, in some of its expressions, is without doubt as old as the Louisiana fauna, and it is as impracticable to make one continuous section to contain all of the Kinderhook formations as it would be to make a standard Devonian section to include the formations of New York and Iowa.

East of the Cincinnati arch the early Mississippian formation (Bedford shale) carries a fauna which resembles that of the southern Kinderhook. The succeeding formations of the Waverly group in Ohio are similarly related, but in the north occur forms (*Paraphorhynchus*) which suggest connection with the northern Kinderhook also.

West of the Cincinnati axis the union of the northern and southern provinces gave rise to an extended sea and conditions favorable to the deposition of limestones (Burlington and Keokuk) forming the Osage group, characterized by its crinoids. Succeeding formations in the Mississippi Valley basin constitute the Warsaw, Salem [Spergen], St. Louis, and Ste. Genevieve limestones. Unconformities follow the Salem [Spergen], and more extensively the Ste. Genevieve, over the northern part of the Mississippi Valley basin. Southern Illinois, where the Ste. Genevieve comprises the Fredonia limestone, Rosiclare sandstone, and Ohara limestone members, was the northern limit of continuous deposition. On the other hand, faunal relations with the faunas of the far West indicate marine connections, of which that established during the Ste. Genevieve was one of the most extensive.

The closing epoch of the Mississippian in the typical province, the Mississippi Valley basin, was that of the Chester group.

Comparing the classification of the formations of the Appalachian Basin (east of the Cincinnati arch)—that is, those of the Waverly group—with the divisions of the typical Mississippian, Weller accepts Stevenson's conclusion[a] that only the upper part of the Pocono is of Mississippian age and that this upper part is stratigraphically continuous with the Waverly. "The most definite point of faunal contact between this basin and the Mississippi Valley basin is found in the Maxville limestone, whose fauna is to be correlated essentially with the Ste. Genevieve of southern Illinois and Missouri."

The Iowa section of the Mississippian as compiled by Chamberlin and Salisbury[134c] from the reports of the Iowa State Survey is as follows:

Mississippian formations in Iowa.

	Formation.	Thickness (feet).	Characteristics.
Mississippian.	Unconformity. St. Louis limestone.	100	Light ash-colored limestones and marls, with thin beds of sandstone. Good building stone.
	Osage (Augusta) formation.	200–300	Buff limestone and shales, underlain by coarse-grained encrinital limestone; basal portion usually ferruginous; prominent chert beds.
	Kinderhook formation.	150–200	Bluish or greenish clay shales, fine grained; buff, compact, more or less argillaceous limestones; sandstones.
Devonian.	Lime Creek formation.	80	Dark-colored argillaceous shales, highly fossiliferous, and locally calcareous.

In northern and central Iowa, owing to the effects of elevation and erosion during the later part of the Mississippian epoch, the higher divisions of the series are unrepresented; they are restricted to the southern portion of the State and the Kinderhook alone extends across it.[701]

On each side of Mississippi River between Burlington, Iowa, and southern Illinois occur the typical sections of the Mississippian. The deposits are chiefly limestone, but in both the lower and the upper portions occur shales and sandstones, which mark the advance and retreat of the Mississippian sea. The basal formations (Kinderhook group) are irregular in occurrence, varying lithologically and faunally, and there are unconformities by erosion, particularly at the base of the Kaskaskia.[490, 492, 881]

In southwestern Missouri and northern Arkansas, on the southwestern shore of the Ozark land, the Mississippian formations are, according to Adams and Ulrich,[5a] as follows:

[a] "The lower portion of the Pennsylvania Pocono * * * decreased rapidly in the southwestern part of the State [Virginia] until it disappeared or was merged into the Grainger [Devonian] shales of M. R. Campbell." Stevenson, J. J., The Lower Carboniferous of the Appalachian Basin: Bull. Geol. Soc. America, vol. 14, 1903, p. 35.

"His [White's] Shenango shales, Shenango sandstone, and Meadville shales, down to and including the upper Meadville limestone, are undoubtedly Lower Carboniferous, while the underlying divisions—the lower part of the Meadville shales, the Sharpsville sandstones, the Orangeville shales, and the Oil Lake group—are evidently later Devonian." Idem, p. 40.

Correlation table of the Paleozoic formations in northern Arkansas [*in part*].

<table>
<tr><th colspan="5">A standard time scale of the Ohioan province.</th><th colspan="2">Mappable lithologic equivalents in northern Arkansas.</th></tr>
<tr><td rowspan="11">Carboniferous.</td><td rowspan="11">Mississippian.</td><td rowspan="5">Chester.</td><td rowspan="3">Kaskaskia.</td><td rowspan="2">Birdsville.</td><td colspan="2">Pitkin limestone.</td></tr>
<tr><td colspan="2">Wedington sandstone.</td></tr>
<tr><td>Tribune.</td><td colspan="2">Fayetteville formation.</td></tr>
<tr><td colspan="2">Cypress.</td><td colspan="2" rowspan="2">Batesville sandstone.</td></tr>
<tr><td colspan="2">Ste. Genevieve.</td></tr>
<tr><td rowspan="3">Meramec.</td><td colspan="2">St. Louis.</td><td colspan="2">Moorefield shale (including Spring Creek limestone).</td></tr>
<tr><td colspan="2">Spergen Hill.</td><td colspan="2" rowspan="2">(Wanting.)</td></tr>
<tr><td colspan="2">Warsaw.</td></tr>
<tr><td rowspan="2">Osage.</td><td colspan="2">Keokuk.</td><td rowspan="2">Boone limestone.</td><td>Cherty limestone.</td></tr>
<tr><td colspan="2">Burlington.</td><td>Gray subcrystalline limestone.
St. Joe limestone.</td></tr>
<tr><td colspan="3">Kinderhook.</td><td colspan="2">Noel shale.</td></tr>
</table>

Adams [5] describes these formations as follows:

The Noel shale [now called the Chattanooga shale] has been previously described by the Arkansas State Survey under the name of the "Eureka shale;" but this name is preoccupied by the Eureka quartzite of Nevada, and accordingly it has been renamed, from the town of Noel, in southeastern Missouri, where it has been studied and at which place it is typically exposed. It consists of a bed varying from a few feet, and in some cases a few inches, up to 70 feet in thickness. Usually it averages from 15 to 30 feet. Its color is often black, although not infrequently it has a greenish and sometimes a yellowish appearance, according to the conditions of weathering or the amount of carbonaceous material contained in it.

* * * * * * * * *

The Noel shale is succeeded by the Boone formation, which appears to be conformable with it and represents merely a change in the character of sedimentation. Over a large area its basal member is an even-bedded limestone, free from chert and showing in a distinct ledge, sometimes shelly and thin bedded. It is known as the St. Joe limestone member. Its thickness in northern Arkansas varies from a few feet up to 50 feet. * * *

The remaining portion of the Boone formation consists of beds of cherty limestone and beds of chert, which vary in their lateral and vertical extent in such a way that it has been impossible to divide this part of the formation into members which can be generally recognized. The thickness of the formation is about 325 feet.

The limestones of the upper portion of the Boone formation are often coarsely crystalline and have usually a light-gray color. They contain numerous well-preserved fossils, but crinoid stems are perhaps the most conspicuous.

Generally the upper portion of the formation is heavily bedded, and the lower portion contains a large amount of flint. The line separating the St. Joe member from the remaining portion, although not marked by any very evident stratigraphic break, has been drawn at the point where the chert appears and is at a definite horizon.

In the vicinity of Batesville there is a bed of shale lying upon the Boone limestone and chert. It is well exposed around Moorefield, from which place it is named. In that locality it has a thickness of from 50 to 75 feet. To the west, at Marshall, it is not over 35 feet thick, and evidently it does not extend much farther westward. The shale has a light-grayish or bluish color, and is very friable. In places it is sandy.

The Moorefield shale is succeeded at Batesville by sandstones with some interbedded shale. In certain localities to the west the formation contains interstratified limestones, which, where they are weathered, appear sandy. Where the Moorefield shale is absent this formation rests directly on the Boone formation and is usually found in this position between Marshall and Fayetteville. The thickness of the formation in the Yellville quadrangle is about 75 feet. The conspicuous portion of it is an even-bedded yellowish-brown sandstone.

The conspicuous portion of the Fayetteville shale is a bed of black carbonaceous shale, which is usually thinly laminated. It frequently exhibits a jointed structure and upon disintegration falls into small fragments. Its thickness varies from about 50 feet up to 200 feet. It is named from exposures around Fayetteville, where it is conspicuous in the valley of the West Fork of White River. This formation rests upon the Batesville sandstone or, where that formation is absent, upon the Boone formation. The lower portion of the black shale in the Fayetteville formation contains lenses of dark-blue siliceous limestones at some places.

Southeast of Fayetteville and westward to the State line the Fayetteville shale is succeeded by a sandstone formation varying in importance but usually having a thickness of between 50 and 150 feet. It is thin bedded and heavy bedded and carries some interstratified shale.

Succeeding the Fayetteville formation in the lead and zinc region there is nearly everywhere a bed of limestone. It is not always conspicuous, since it frequently occurs on slopes and is covered with débris of sandstones and shales from the higher formation. Its thickness where well developed is usually from 10 to 40 feet. In exceptional cases it is thicker. It sometimes has associated with it sandstone beds which contain the same fossils found in the limestone. The Pitkin limestone has been called the "Archimedes limestone" by the Arkansas Survey, because of the presence of this easily recognized bryozoan, the screwlike stems of which are seen in the weathered surface of the rock. In the northwestern part of the State, around Fayetteville, the limestone thins out to a pebbly stratum and disappears from the section. Along the north front of the Boston Mountains, however, it is a very persistent ledge, and the beds are frequently massive and give rise to an escarpment, a bench being developed on its upper surface. This formation is regarded as the highest one of the Mississippian series. It is probable that the thinning to the north and west is due to shore conditions, and its absence in some cases may be due to erosion previous to the deposition of the Pennsylvanian series which succeeds it.

J-K 16. KENTUCKY AND INDIANA.

Along the west side of the Cincinnati axis the Mississippian presents a section similar to that of the series along Mississippi River. At the base the strata lie conformably upon the Devonian and are somewhat sandy and shaly. The bulk of the deposit is limestone. The top part, which includes sandstone, is limited above by an unconformity. The local section for Indiana, as given by Blatchley and Ashley [86] and substantially quoted by Chamberlin and Salisbury,[134b] is as follows:

Generalized section for Indiana.

	Formation.	Thickness (feet).	Characteristics.
Mississippian.	Unconformity.		
	Kaskaskia or Chester group	120	Sandstone and limestone.
	Mitchell limestone	0–250	Massive impure limestones and calcareous shales.
	Bedford oolitic limestone	20–80	Excellent building stone.
	Harrodsburg limestone	60–90	Limestones and shales.
	Knobstone formation	40–600	Arenaceous shales and sandstones. Not included in Knobstone by Blatchley and Ashley.
	Rockford goniatite limestone	....	Thin bed of limestone and calcareous shale.
Devonian.	New Albany black shale	70–120	

The detailed stratigraphy of the foregoing section has been described by Hopkins and Siebenthal,[464] Ashley,[38] and Newsom,[615] and the faunal relations have been discussed by Kindle.[493]

The Mississippian of Kentucky has been classified by Ulrich [824] in a manner differing in several respects from any arrangement previously published. It is as follows:

Formations in the Kentucky-Illinois fluorite district.

				Names of formations and members used in this work.		Synonyms and equivalent formations in the Mississippi and lower Ohio valleys.[a]	
Carboniferous.	Pennsylvanian.		Pottsville group.	Mansfield sandstone.		Mansfield sandstone of Indiana. Coal Measures conglomerate of western Kentucky.	
	Mississippian.	Tennesseean.	Chester group.	Kaskaskia limestone.	Birdsville formation.	Kaskaskia limestone of Hall. Chester limestone of authors. Huron formation of recent Indiana reports is same as Birdsville formation.	
					Tribune limestone.		
				Cypress sandstone.		Aux Vases sandstone of Keyes. Probably also Big Clifty sandstone of Norwood.	
				Ste. Genevieve limestone.	Ohara limestone. Rosiclare sandstone. Fredonia oolitic limestone.	Two upper members referred to as lower Chester by Worthen and Engelmann. Entire formation referred to as St. Louis by Norwood.	
			Meramec group.	St. Louis limestone.		St. Louis limestone of most authors, but not of Engelmann, Shumard, and Swallow, who do not include two lower formations in the St. Louis limestone. The two upper formations equal, respectively, the Mitchell limestone and the Bedford oolitic limestone of recent Indiana reports.	
				Spergen limestone.			
				Warsaw formation, lacking.			
		Waverlyan.	Osage group.	Tullahoma formation.		Keokuk limestone. Burlington limestone.	Harrodsburg limestone (typical) and Knobstone of Indiana.
			Kinderhook group.			Various formations of the Kinderhook group.	
Devonian.			Chemung group.	Ohio shale.		New Albany shale of Indiana reports. Chattanooga shale. Grassy Creek shale of Keyes.	

[a] The matter in this column is generalized and incomplete. It will be given in greater detail in a work on the Paleozoic section in the Mississippi Valley soon to be published by the writer.

J-K 17. OHIO AND EASTERN KENTUCKY.

The Mississippian series on the east side of the Cincinnati arch consists chiefly of argillaceous and sandy deposits which are in contrast to the limestones of the west (Indiana) side. They have been described under the name Waverly since 1838 (Briggs) and 1869 (Newberry), but with various classifications. Above these strata occurs a thin limestone which also belongs to the Mississippian and upon which the Pottsville (Pennsylvanian) was laid down unconformably. Prosser [645, 649] has recently reviewed the literature and sequence of formations and his arrangement has been in general followed by Chamberlin and Salisbury [134a] in the following table, but Prosser called the Logan exclusive of the Blackhand a formation, and not a group, the old "Logan group" including both the Logan formation and the Blackhand.

Generalized section for Ohio.[a]

		Formation.	Thickness (feet).	Characteristics.
Mississippian.		Unconformity.		
		Maxville limestone	25±	Fossiliferous limestone often brecciated.
	Waverly series.	Logan group	100–150	Sandstone, massive conglomerate and shale.
		Blackhand conglomerate.	50–500	Sandstone and fine conglomerate.
		Cuyahoga shale	150–300	Light-colored argillaceous shales, with thin beds of sandstone. Shales characterized by ferruginous nodules.
		Sunbury shale	5–30	Black bituminous shale.
		Berea grit	5–175	Sandstone, used for building stone and for grindstones; locally carries oil, gas, and brine.
		Bedford shale	50–150	Thin-bedded shales; occasional thin beds of sandstone.
Devonian.		Ohio shale	300–2,600	Mainly black or dark-brown shale.

[a] Prosser, Jour. Geology, vol. 11, 1903, pp. 520, 521. Geol. Survey Ohio, vols. 6, 7; Bull. No. 7, 4th ser., 1905.

The correlation of this section with that of the typical Mississippian section and the Appalachian equivalents on the east is discussed by Girty as follows: [361]

> In 1900 an effort was made to trace eastward into Pennsylvania the members of Newberry's Waverly section in northern Ohio. The Berea grit of the Waverly group was found to be the equivalent of the Cussewago sandstone of northwestern Pennsylvania. The Orangeville shale of that region is the basal third of the Cuyahoga shale, in part equivalent to Orton's Berea shale. The Sharpsville sandstone, representing the middle portion of the Cuyahoga, is probably the stratum producing the lower falls at the village of Cuyahoga Falls. The Meadville shale can with little doubt be correlated with the upper portion of the Cuyahoga, and it seems probable that the Shenango sandstone and shale are the equivalents of the Logan group. It is doubtful if the Corry sandstone is represented in Ohio, while the Bedford and Cleveland shales probably die out before reaching the Pennsylvania line.

The relations of the Waverly to the clastic formations of Pennsylvania and West Virginia have been traced by Stevenson,[794a] who uses the term Logan in the sense given to it by Orton, rather than as restricted by Andrews and Prosser. "Logan" in the following quotation thus comprises the original Logan formation and the Blackhand formation.

The Shenango sandstone has been followed by Dr. White into Trumbull County of Ohio, where it is about 15 feet thick and rests on 80 feet of Meadville shales. Prof. Orton regards the Logan sandstone of Ohio as the Shenango sandstone but includes also in the equivalence the overlying Shenango shales of White, which, as will appear in the second chapter, must be considered with the Mauch Chunk.

The Logan, in Ohio, is double, sandstone above and conglomerate below, at the typical localities. Followed into Ohio from Pennsylvania the rock becomes finer, the sandstone becoming shale and the conglomerate sandstone. In the counties of Knox, Holmes, Richland, and Coshocton the sandstone is represented by the Olive shales of M. C. Read, which are upward of 200 feet thick, but farther south the mass becomes a fawn-colored even-bedded fine-grained sandstone. The conglomerate gains in coarseness westward and southward, being a coarse rock in Wayne, Holmes, Coshocton, Knox, Licking, Fairfield, Hocking, Vinton, and Ross counties, which, as Prof. Orton observes, mark "the northwestern arc of the sea boundary in Sub-Carboniferous time." The conglomerate is not always continuous, there being usually, as Prof. C. L. Herrick has shown, two beds of conglomerate separated by layers of fine sandstone or even of shale. The pebbles are usually flat, small, and of practically uniform size. Southward from Ross County, along the western outcrop, the rock is less coarse and it ceases to be conglomerate before reaching the Ohio River, where it is the upper portion of the Kentucky Knobstone. The Logan rests upon the Cuyahoga shales of Orton, varying from 150 to 400 feet, with the Buena Vista sandstone at the base, a persistent bed, identified with the Sharpsville of White and continuous from the Pennsylvania line around the outcrop to the Ohio River at Buena Vista. Below this is the Berea shale, regarded as the equivalent of White's Orangeville, and at the base is the Berea grit, continuous from Lake Erie to the Ohio River, 50 to 75 feet thick, a fine sandstone at the north but somewhat argillaceous at the south. This ripple-marked sandstone is thought by Prof. Orton to be equivalent to the upper part of White's Oil Lake group.[a] This rests on the Bedford shales. Herrick has shown that the Logan does not extend so far northward as do the Cuyahoga shales.

At this point may be inserted a table of approximate correlations worked out by Stevenson,[794b] between the Appalachian Basin and the Mississippian section of the Mississippi Valley:

Lower Carboniferous:		
Shenango and Upper Meadville	Northwestern Pennsylvania	Keokuk, Burlington, and Kinderhook.
Logan, including Waverly shales	Ohio	
Upper 400 feet of Bedford and Huntingdon	Eastern Pennsylvania	
Coal-bearing shales and sandstone	Virginia	
Upper plate of Big Injun	West Virginia	
Upper Knobstone of	Kentucky	Keokuk and Burlington.
Protean of Safford	Tennessee	Keokuk.
Lauderdale of McCalley	Alabama	
Lowest Fort Payne of Hayes	Georgia and eastern Alabama	Undetermined.
Lowest Newman of Campbell	Tennessee and Virginia	

The Waverly group of Ohio has recently been traced across Ohio River into Kentucky and certain variations of stratigraphy have been described by Morse and Foerste,[605] who recognize the formations distinguished in Ohio (Bedford, Berea, Sunbury, Cuyahoga, Blackhand, and Logan, in ascending order) but find that the strata below the Cuyahoga thin out toward the south and west and also lose such arenaceous partings as they had at the Ohio. The littoral formations of the Waverly

[a] Orton, E., Ohio Survey Repts., vol. 7, 1893, pp. 28 et seq.

gulf thus diminish southward toward the Mississippian sea. A typical section at Vanceburg, Ky., is stated by Morse and Foerste as follows:

Section of Alum Rock, Vanceburg.

	Ft.	in.	Feet.
5. Cuyahoga formation			39
Interval covered except a thick layer of argillaceous sandstone at the top. The sandstone contains Taonurus. Small phosphatic nodules are found in the basal part of the interval.			
4. Sunbury shale, total thickness			15½
Black fissile carbonaceous shales, which can not be distinguished lithologically from the Ohio shale.			
3. Berea grit, total thickness			22¼
Thick layer of gray sandstone	2	6	
Heavy layer of rather coarse grained gray sandstone, the upper surface excellently ripple marked	3		
Medium to thick bedded, rather coarse grained gray sandstones, beautifully ripple marked	15		
Arenaceous shales	1		
Layer of fairly coarse grained gray sandstone		9	
2. Bedford formation, total thickness			95⅚
Blue arenaceous shales and shaly sandstones; lower part slightly covered	35		
Arenaceous shales with thin sandstone partings	7		
Layer of thick-bedded gray sandstone	1	8	
Arenaceous shales with two layers of sandstone	6	9	
Heavy layer of gray sandstone, with lower surface contorted	2	4	
Arenaceous shales with two layers of gray sandstone	6	6	
Layer of thick-bedded buff sandstone	1	9	
Medium-bedded gray sandstones with shaly partings	2	10	
Arenaceous pink shales with sandstone partings	2	6	
Covered interval	5		
Layer of thick-bedded buff sandstone	2		
Practically covered interval with some argillaceous shales	22	6	
1. Ohio shale			242
Black fissile carbonaceous shales. About 10 feet from the top one or two linguloid shells occur. Near the central part the shales become softer and lighter in color and resemble a similar zone in the Ohio at Columbus (Ohio). The interval (242 feet) is mostly exposed and extends to the level of the Chesapeake & Ohio Railway. At "Slate Point," however, the top and bottom contacts are shown and the total thickness is 301¼ feet.			

At Petersville, Ky., southwest of Vanceburg, the Bedford and Berea are, according to Morse and Foerste, no longer separable and have together a thickness of 46½ feet only. Several successive sections are cited by them. At Irvine, Ky., southwest of Petersville, they measured the following:

Section of Minerva Mountain, Irvine.

	Ft.	in.	Feet.
6. Subcarboniferous limestone			1
Yellowish sandy-like limestone, lying at the extreme top of the hill.			
5. Upper Waverly series, not divided			344
Covered interval	60	6	
Thin-bedded buff argillaceous sandstones, which weather to thin shaly pieces; Taonurus	17		
Layers of massive buff argillaceous sandstone, Taonurus abundant	24		
Buff argillaceous sandstones, weathering to shales; Taonurus	17		
Covered interval	225	6	
4. Cuyahoga formation, top not determined			144
Brownish ferruginous and calcareous nodular layer of sandstone		6	
Indurated bluish to pinkish argillaceous shales with ferruginous nodular layers.	69	6	
Soft bluish argillaceous shale with ferruginous nodular layers, slightly covered (top of Linietta clay)	63	6	
Layer of brownish argillaceous sandstone, which breaks up into shaly layers	2		
Soft bluish to pinkish argillaceous shales and small phosphatic nodules	8	6	

	Ft. in.	Feet.
3. Sunbury shale, total thickness		3
Black fissile carbonaceous shales.		
2. Bedford-Berea, total thickness		1½
Argillaceous shales with phosphatic nodules	2	
Black fissile carbonaceous shales	3	
Dark argillaceous shales, with some carbonaceous material	6	
Gray calcareous and argillaceous shales, slightly fossiliferous	2	
Yellowish calcareous and argillaceous shales, the upper part very fossiliferous	5	
1. Ohio shale		94½
Black fissile carbonaceous shales, with an occasional softer argillaceous layer. Practically all exposed to the highway.		

In the Irvine section the Bedford and Berea are stated to be represented by 1½ feet of fossiliferous shale and the Sunbury by but 3 feet of black carbonaceous shale. Morse and Foerste conclude:

The Bedford and Berea formations thin rapidly southwestward from the Ohio River and this horizon, even after it has been reduced to a thickness of only a few inches, can be traced to near the crossing of the Cincinnati geanticline by the Waverly series.

The Sunbury shale, on the contrary, suffers but little decline, at least until Indian Fields is reached.

The Ohio black shale of the Kentucky reports or the Chattanooga shale of United States reports, south of Petersville, is not of Devonian age alone but of Devonian and Carboniferous—that is, is composed of both the Ohio and Sunbury shales and a thin zone representing the Bedford and Berea.

The sandstones which are extensively quarried about Rockville station belong to the Buena Vista member of the Cuyahoga formation rather than to the Berea grit.

The Buena Vista sandstones begin to disappear from Olympian Springs southwestward except a single layer which, if not always the same, at least occupied the position of the lowest and which persists as far south as Stanton if not to Irvine.

The Linietta clays belong to the lower part of the Cuyahoga formation.

The so-called Waverly of at least the Richmond folio includes only the upper part of the Waverly, beginning with the base of the Cuyahoga.

J-K 17-18. PENNSYLVANIA, MARYLAND, WEST VIRGINIA, AND VIRGINIA.

The area considered under the above heading covers that restricted part of the ancient bay of New York and Pennsylvania which was occupied by the sea at intervals during the Mississippian epoch and within which were laid down the coarse clastic sediments of the Pocono, at the base of the series, and subsequently the shaly, sandy Mauch Chunk formation. The Pocono is commonly a sandstone which includes also strata of conglomerate shale, and thin coal beds. Its thickness is 1,800 feet in West Virginia and 2,000 feet in a section on the Susquehanna. It thins out to the north and south, to 500 feet in the Wyoming anthracite field, Pennsylvania, and to 100 feet or less in West Virginia. In western Pennsylvania, Ohio, Kentucky, and Tennessee its equivalents are shales and sandstones whose precise stratigraphic and faunal relations are still matters of doubt; but they, together with the Pocono, are referred in general terms to the position of the Kinderhook, Burlington, and Keokuk of the Mississippi River section.[794]

The lower part of the Pocono is regarded as Devonian by Stevenson.

The Mauch Chunk formation is dominantly a red sandy shale, which in Pennsylvania is chiefly a subaerial flood-plain deposit, according to Barrell.[56]

It attains a maximum thickness of 3,000 feet in the southern anthracite fields and thins away toward the north, west, and south, as shown by Barrell and Stevenson. In southern Pennsylvania, Maryland, and West Virginia the lower part of the shales gives way to the sandy Greenbrier limestone. Stevenson[794d] sums up the stratigraphic relations and nomenclature as follows:

> The Mauch Chunk is represented only by shales, or by shales and sandstones, along the northerly border in Pennsylvania, but southward limestone is found with shale above and below it. This limestone, in the Allegheny Mountain region, reaches to within 30 miles of the northern outcrop, while traces of it are present still farther north in the anthracite region. In southern Pennsylvania it is double, with a siliceous division below and a more or less argillaceous division above. The former is the more persistent at the north and in the central part of the basin, but it is wanting in Ohio except in the extreme southeast. Both divisions persist in Virginia, Tennessee, and Alabama, as well as in the greater part of West Virginia and Kentucky. The lower shales become indefinite southward and the upper shales extend as shales little beyond the northern line of Tennessee.
>
> The whole series has been termed Mauch Chunk in Pennsylvania, and no special geographical term has been applied there to any of the subdivisions except in the northwestern part of the State, where Dr. I. C. White gave the name Shenango to the shale which there is the sole representative of the Mauch Chunk. In Maryland the upper shales have been termed Mauch Chunk and the limestone Greenbrier; in Virginia Prof. W. B. Rogers used the names Greenbrier shale and limestone; the United States geologists in that State have applied the names Canaan and Pennington to the shales, Greenbrier and Newman to the limestone; Prof. Safford in Tennessee divided the limestone into Mountain limestone above and the Siliceous group below, the latter into the Lithostrotion and the Protean, of which the former belongs to the Mauch Chunk; to Prof. Safford's divisions Mr. Hayes applies the designations Bangor and Fort Payne, with, in the southeastern areas, Floyd as equivalent to the lower portion of the Bangor; in Alabama the limestone is divided by Smith and McCalley into Bangor, Hartselle, and Tuscumbia; in Kentucky the divisions are Chester and St. Louis; and in Ohio Andrews termed it Maxville.

Regarding the Mississippian of the Meadow Branch Mountains area of West Virginia, adjacent to the Potomac, Stose[803] points out that these rocks are structurally the southeasternmost occurrence of Carboniferous rocks in the northern Appalachians, outside of the anthracite region. They are widely separated from the main body of Mississippian sediments in western Maryland and Pennsylvania, and the formations which he maps have not been positively correlated with those of the broader area. These formations, which he regards as subdivisions of the Pocono group, comprise the Rockwell formation, Purslane sandstone, Hedges shale, Myers shale, and Pinkerton sandstone.

Stose describes the Rockwell formation—the basal Carboniferous deposit—as composed of coarse arkosic sandstone, fine conglomerate, and buff shale, with some dark shale containing locally thin coal beds, and gives a section of this formation as seen at Sideling Hill, on the north bank of the Potomac, showing a thickness of 541± feet.

The Purslane sandstone he describes as the ridge-making rock of the Meadow Branch Mountains, Sideling Hill, Spring Gap Mountain, and the higher parts of Town Hill, and as composed largely of heavy-bedded coarse white sandstone with bands of quartz conglomerate and some soft white sandstones containing locally thin coal seams. Sections of the Purslane sandstone show that the thickness varies from 180 to 310 feet.

The Hedges shale is described as a dark coal-bearing shale overlying the Purslane sandstone in the Meadow Branch syncline. Because of its soft and unresistant character it is exposed in but few places. The best estimate of its thickness, obtained from a section south of Devils Nose, is 170 feet.

The Myers shale is distinguished by its bright-red color. The basal 60 feet is composed of cross-bedded reddish-gray gritty arkosic sandstone. At the top thin reddish-stained sandstone merges into the overlying Pinkerton sandstone. The thickness is estimated at 800 to 900 feet.

The Pinkerton sandstone appears in only two small areas, one at Pinkerton Knob and the other in the northern part of Third Hill Mountain. At the base are gray platy sandstone and white quartz conglomerate, with soft crumbly sandstone above. The upper layers, however, are very massive cross-bedded coarse white sandstone. The thickness of the formation on Pinkerton Knob is given as about 125 feet.

Plant remains found in the Rockwell formation, the Purslane sandstone, and the Hedges shale are definitely referred by White to the Pocono group of the Carboniferous, and the few fragments from the Pinkerton sandstone are tentatively regarded by White as of the same age, certainly not younger than the Mississippian.

No fossils were found in the Myers shale, but as it lies below the Pinkerton sandstone, it is older than that formation.

Stose quotes from Stevenson, Ashburner, and I. C. White four sections of the Pocono and arranges them geographically from west to east, in comparison with a composite section in the Meadow Branch syncline in the Hancock quadrangle, as follows:

Summarized sections of the Pocono group.

	Riddlesburg (I. C. White).	Shoups Run (I. C. White).	Juniata River (Stevenson).	Sideling Hill tunnel (Ashburner).	Meadow Branch Mountains (Stose).
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Massive and flaggy sandstone and shale, some red	609	730	620	610	825
Dark shale containing thin coal seams in massive and thin-bedded sandstone	50	100	70	313	170
Massive sandstone and conglomerate generally cross-bedded	85	55	45	380	310
Red to green or gray shale and flaggy sandstone	698	495	630	830	541
	1,442	1,380	1,365	2,133	1,846

All the above sections show in general the following fourfold divisions; a lower group of shales and soft sandstones, generally reddish in color where weathered; a middle heavy sandstone and conglomerate, usually cross bedded; a variable thickness of black shale with thin coal seams and sandstone; and an upper series of shales, usually red, and thick sandstones. The thicknesses in the first three columns of the table correspond rather closely, the total thickness varying from 1,365 to 1,442 feet. The Sideling Hill tunnel section is much thicker, all the members except the top sharing in the increase. * * *

It is concluded from the above comparison that all the Carboniferous strata now remaining in the Meadow Branch Mountains are Pocono in age and correspond to the rocks in the Broad Top coal field below the Mauch Chunk. * * *

As pointed out by Stevenson, the thickening of the Pocono eastward is progressive. From 300 feet in Laurel Ridge, Fayette County, the Pocono increases to 1,030 feet in the southeastern part of Cambria County, to 1,400 feet in the western side of the Broad Top syncline, and to 2,133 feet in Sideling Hill, Pa. If these measurements are correct, it apparently reaches its culmination in Sideling Hill and decreases eastward to 1,850 feet in the Meadow Branch Mountains.

K-L 16-17. MICHIGAN.

According to Lane [519a] the Carboniferous of Michigan consists of the formations tabulated as follows:

Carboniferous formations of Michigan.

System.	Series.	Formation.	Thickness (feet).	Character of rock.
Possibly later.	Conemaugh.	Woodville.	0–110	Light-reddish sandstone and sandy shales.
Carboniferous.	Pennsylvanian (Upper Pottsville).	Saginaw.	400	White sandstone, coal seams, black and white shales; then bands of limestone and of siderite rare, rarely broken up and found in fragments of the sandstone.
		Parma.	0–170	White sandstone and conglomerates, of small white quartz pebbles; brine and sulphates.
	Mississippian.	Bayport or Maxville. Upper Grand Rapids. Upper St. Louis.	50–235	Limestones, light and bluish, cherty; also calcareous sandstones.
		Michigan. Lower Grand Rapids. Lower St. Louis. Osage or Augusta.	0–300	Dark or bluish limestones and dolomites with gypsum and blue or black shales; rarely reddish or greenish shales and dark or red sandstones.
		Napoleon. Upper Marshall.	260–560	White sandstone, often pyritic; brine or fresh water; sulphates low.
		Lower Marshall.		White and red sandstones, peanut conglomerates, sandy shales, whetstones and blur shales, much carbonate of iron and mica in the formation; generally a red shale at the top and bottom.
		Coldwater. Buena Vista.	800–1,000	Blue shale, with nodules of carbonate of iron, especially at the top; sandstone; very subordinate streaks of fine-grained limestone, especially on the west side; black shales at the base.
		Sunbury or Berea.		
		Berea.		White sandstone; brine and salt even near the surface.
Devonian.	Neo-Devonian.	Bedford. Antrim (Senecan).	140+480	Shale, mainly black and always at the base, with huge round balls of calcite; toward the top, blue and black shales.

The formations are deeply covered by drift and are known chiefly by drill records. Lane comments on the sequence according to the sections drilled in many localities.

The base of the Carboniferous in Michigan is usually drawn in practice at the top of the Antrim shale, between it and the overlying Berea sandstone, although it is theoretically drawn in the Antrim shale itself, so as to separate from it a portion equivalent to the Bedford shale of Ohio, regarded as the lowest Carboniferous of that State. Ulrich would draw the line below the Antrim, removing that formation entirely from the Devonian to the Carboniferous. Where the Berea sandstone is not present the Antrim shale is succeeded by the Coldwater shale (Carboniferous) and a practical distinction is not possible.

With reference to the line between Devonian and Carboniferous, G. H. Girty has prepared the following discussion [a] for this paper:

In northwestern Pennsylvania I have discriminated a group of rocks between the Berea ("Corry") sandstone and the top of the typical Chemung under the name "Bradfordian." In Ohio I am tentatively assigning to this group the Bedford shale, the Cleveland shale, and the Chagrin ("Erie") shale, or at least the upper portion of the Chagrin shale, from which our fossil faunas are obtained. Because the "Bradfordian" faunas were very different from the Waverly faunas (inclusive of the Berea sandstone but exclusive of the Bedford shale), I originally assigned the "Bradfordian" without hesitation to the Devonian. After comparing the "Bradfordian" faunas with the typical Chemung, however, I find that there exists a difference, almost equally marked, and feel somewhat doubtful whether the "Bradfordian" would not better be placed in the Carboniferous.

In northern Ohio the most convenient horizon at which to draw the base of the Carboniferous would doubtless be immediately below the Berea sandstone. If the Bedford shale is included in the Carboniferous, so must also be the Cleveland. A more or less conspicuous change of fauna occurs in passing from the Chagrin into the Bedford.

If the Berea sandstone is taken as the earliest formation of the Carboniferous in Ohio, then in Michigan the Devonian would naturally close with the top of the Antrim. If the Bedford and the Cleveland of Ohio are included in the Carboniferous, then probably a corresponding portion at the top of the Antrim would have to be taken out of the Devonian. If the entire "Bradfordian" is assigned to the Carboniferous (on the assumption that that term includes in Ohio the whole of the Chagrin shale), then more or possibly all of the Antrim would have to be placed in the Carboniferous.

Regarding the Berea sandstone, Lane [519b] states:

This is an Ohio formation and has never been seen at the surface in Michigan, but may be traced very well along the flanks of the Cincinnati anticlinal, from near Adrian north. Westward it seems soon to disappear and to be spotty in occurrence. Eastward it is persistent in Ohio, but thin, about 50 feet or less.

It continues to the northeast and north, as determined in wells at several points cited by Lane.

Its thickness is usually about 100 feet and, as is well shown in Huron County, it thickens gradually from about 40 feet until it is thickest near its western margin (over 200 feet), where it disappears suddenly * * *. It is generally fine grained, micaceous, a grindstone, and overlain by a black shale (the Berea or Sunbury shale).

The Coldwater shale of Michigan directly overlies the Berea sandstone where that formation is present; elsewhere it succeeds the Antrim shale. The base of the

[a] Notes, December, 1910.

Coldwater is the black shale which Lane refers to in the above quotation as the equivalent of the Sunbury. The Coldwater comprises further the representative of the Cuyahoga shale and possibly that of the Blackhand formation.[519c] Lane cites the following section from Huron County:

	Feet.
Blue and sandy shales	172
Light House Point conglomerate	4
Blue shales with carbonate of iron, with *Chonetes scitulus* cf. *pulchella* common throughout	720
Black shale (Sunbury), with *Lingula melie* and *Orbiculoidea newberryi* in Ohio	103
	1,000±

The Coldwater shale thus represented and as originally defined covers the interval between the Berea sandstone below and the Marshall formation above. Among the subdivisions, the conglomerate in the above section is tentatively correlated by Lane with the Blackhand of Ohio, and beneath it should come the representative of the Cuyahoga shale. Lane gives a number of well sections showing variations in color, composition, or thickness of the several subdivisions, and the strata have also been described by earlier writers.

The Coldwater shale is succeeded by the Marshall formation, into which it passes by increasing sandiness without distinct plane of division.

The Marshall formation as known in Huron County comprises, according to Lane,[519d] the following beds:

	Feet.
Napoleon (Upper Marshall) sandstone	300
Lower Marshall (original Marshall):	
Hardwood Point shales and sandy flags, fossiliferous ("typical Marshall" fauna)	85
Port Austin sandstone	23
Sandy shale	68
Point aux Barques sandstone	18
Shales and flags with *Romingerina julia*	41
Grindstones with bands of peanut conglomerate and broken goniatite shells	25
	560

Lane comments:

The facies with the battered shells, chip pebbles (now coal), Solens, and lamellibranchs is a real shore facies. As we go toward the center of the basin the sandy facies of the Lower Marshall seems to disappear, especially the clear white sandstone, nor is the upper sandstone so thick.

The Michigan formation, a sequence that carries brine and gypsum and is of smaller extent, succeeds the Marshall. Lane regards it as the deposit of an inclosed sea, like the Caspian. Its thickness is generally about 200 feet. At Mount Pleasant, where it is thickest, the section is as follows:[519f]

	Feet.
Shale	5
Sandstone	20
Dolomite and shale	75
Anhydrite and dolomite	100
Anhydrite	45
Dolomite, shale, and anhydrite	103
Sandstone	8
Shale	5
Sandstone	4
Shale	15
	380

The shales are dark or even black and the dolomites blue or dark and impure. The general association of dolomite and gypsum is like that in the Salina, but the deposits contain more clastic mud in proportion to the lime salts.

According to Lane the deposition of the Michigan formation went on until "a depression to the west opened connection with the wide ocean at the time of the Maxville limestone of Ohio." Deposition appears to have gone on continuously with change to the formation of limestone.

The Bayport (Maxville?) limestone succeeds the Michigan formation, the two formations composing the Grand Rapids group. The Bayport is a hard light-colored limestone with chert. It was deeply eroded before the deposition of the overlying Parma sandstone, of Pottsville age. The thickness remaining is usually only 50 to 75 feet, but in the well at Mount Pleasant Lane[519g] recognizes as Maxville (Bayport):

	Feet.
Shale and red limestone (weathered?)	30
White limestone	30
White sandstone, very salt water	120
White limestone	55
	235

The erosion of the Bayport limestone was general and at some points is complete. The formation is taken as the plane of division between the Mississippian and Pennsylvanian.

L 20. NOVA SCOTIA AND ADJACENT NEW BRUNSWICK.

For discussion of this area by Ells and Bailey see Chapter VIII, pages 384–386.

M 20. BONAVENTURE COUNTY, QUEBEC.

The "Lower Carboniferous" (Mississippian) is represented by the Bonaventure conglomerate along the north shore of Chaleur Bay and the extremity of the Gaspe Peninsula. The Bonaventure, as described by Logan,[544v] is a basal conglomerate, in places remarkably coarse, composed of pebbles, bowlders, and blocks derived from the underlying Silurian limestones and igneous rocks intrusive in them; all embedded in a red sandstone, which constitutes also an upper and more continuous member. Ells[307a] distinguishes between the basal conglomerate and the upper red sandstone, more particularly on the south shore, near Restigouche Harbor, where the lower conglomerates are interstratified "with gray beds containing Psilophyton and other Devonian fossils," and are unconformably overlain by the upper beds.

The relations of the Bonaventure conglomerate in the eastern exposures of Gaspe Peninsula have recently been studied by Clarke,[157d] who describes them as follows:

Over the tops of the broken and decapitated folds of sand, limestone and conglomerate in Gaspe County lies a mantle of coarse clastic material, partly sand but chiefly jasper and limestone conglomerates. These strata do not appear north of Gaspe Bay and are chiefly confined to the mountains about Perce and to Bonaventure Island. Sandstones and conglomerates together may attain an elevation of 1,500 feet represented by the Perce Mountain and they have a gentle and apparently uniform dip to the north, not often exceeding 10° and generally less. These constitute the Bonaventure formation of Logan and were regarded by him as of early Carbonic age.

At places, as south of the Robin beach at Perce, the lower beds are fine feldspathic red, green, or gray sandstones, but even these carry pebbles, and the prevailing character of the formation is conglomeratic. South of this region under immediate consideration, sweeping along all the country on the north shore of Chaleurs Bay and into New Brunswick, these deposits are widespread.

It is by no means easy, with present knowledge, to determine the true age of these deposits. In considering the commonly accepted view of Logan and his successors expressed above, we are confronted by phenomena at Perce and thence north to Point St. Peter, which seem to us to render this conclusion less secure than the observation of the more southerly outcrops would induce. Strata of conglomerates composed of pebbles carrying Siluric and Devonic fossils from the beds beneath and included by Logan in the Gaspe sandstone group, are found at various inclinations from Chien Blanc, on Gaspe Bay, all the way around Malbay to the Grande Coupe at Perce; at places these beds are nearly horizontal; from Cannes de Roche to Corner of the Beach, on the south shore of Malbay, they are nearly vertical and their color varies from red to ashen gray. In lithologic composition, the nature of the component pebbles, and in the general aspect of this northern series there is no distinction from that comprising Perce Mountain and Bonaventure Island. This latter, the typical expression and section of the Bonaventure conglomerates, stands with abrupt and sheer escarpments on the east and north, telling, like the Catskills, of a widespread further extension. The stratigraphic distinction between these higher Bonaventure conglomerates and the lower conglomerates of Malbay is only the apparent unconformity between the two. The gently sloping higher mass of Perce Mountain seems to lie directly on the vertical conglomerates of Canne de Roche, and it is the indication of this sharp unconformity that has been regarded as evidence of the distinction in age in the two parts of this great homogeneous mass of conglomerates. My examination of the sea wall from the Murailles at Perce to Corner of the Beach leads me to the impression that the erect conglomerates at the latter place, cut off as they are, to a narrow shore belt by the Siluric limestones behind, have been downthrown from their normal position along the zone of great disturbance which has involved the Murailles, Cape Barre, the sea floor outside the North Beach, and Perce Rock. No fact impresses the casual observer more forcibly than the apparent presence of extensive unconformity between these Bonaventure beds and the lower conglomerates, but the appearance is, I am confident, illusive and the Bonaventure conglomerates seem to represent a southern slightly undulated part of the same conglomerate mantle which appears more highly faulted in the anticlines farther north. Such an interruption involves several important conceptions.

1. These conglomerates were certainly laid down unconformably on the vertical edges of the Devonic and Siluric strata about Perce.

2. As the Gaspe sandstones of the Gaspe Basin have been folded up together with the Devonic limestones of the Forillon, either the Gaspe sandstones of the north are older than the entire series of conglomerates or the folding at the south, which involves the Devonic limestones and the Siluric strata together, was earlier than the upturning of the Devonic limestones at the north with which the older strata were not involved; or both conclusions are probable.

3. While the sandstones constituting the lower part of the "Gaspe sandstone series" and their presence in the higher beds are indicative of barachois or lagoon conditions, the conglomerates themselves are clearly open coast deposits formed under such circumstances as prevail to-day wherever these very rocks are exposed to the play of the sea.

4. That the Bonaventure conglomerates of this typical section, either in whole or in part, are of Carbonic age is probably only in a sense that their formation began in late Devonic time and continued without effectual interruption into that of the subsequent era, in the same sense perhaps as the upper beds of the Catskill group of New York seem to be of a post-Devonic age.

These strata constitute the latest of the rock deposits in Gaspe.

CHAPTER X.

PENNSYLVANIAN.

Color, dark gray.
Symbol, 12.
Distribution: Guatemala, central and eastern United States, New Brunswick, and Nova Scotia. Present though not distinguished from Mississippian throughout the Cordillera, the Arctic region, and Newfoundland.
Content: "Coal Measures" (Pottsville to Monongahela inclusive) of eastern North America and their equivalents where distinguished; Carboniferous limestone of Guatemala. Mapped elsewhere with Carboniferous undivided.

Pennsylvanian areas.

D 15–16. GUATEMALA AND CHIAPAS.

The Carboniferous of Guatemala and Chiapas was recognized by geologists who preceded Sapper, but has been more accurately determined by him. He has described it in two works.[694, 695] From the later one we quote:

In Alta Verapaz one may distinguish two series or formations—a lower, which consists of quartz, conglomerates, sandstones, clay slates, and graywacke, which has been called the Santa Rosa terrane by Dolfus and Mont-Serrat, and an upper series of limestones, dolomites, and conglomerates or breccias, which consists of both these rocks. These limestones and dolomites are both of very dark color and often strongly bituminous. The graphitic limestone occurs near Tucuru.

In the older rocks of the Santa Rosa terrane are quartz conglomerates and puddingstones. They rest directly upon the Archean. In many places they contain pebbles of crystalline schists as large as nuts. The higher beds consist of sandstones, slate, shales, and graywackes which are sometimes interbedded and also show gradual transitions and even pass through coarse sandstones into conglomerates. The Santa Rosa strata also include limestones which contain crinoids and also *Fusulina granum avenæ*. [Sapper mentions local occurrences of gypsum, yellow shales and slates and clay slate, and other rocks.]

The age of the Santa Rosa terrane is definitely fixed by the discovery of typical Carboniferous fossils which were determined by Stolley under the direction of Zittel. They are *Syncladia biserialis* Swallow, *Lonsdaleia floriformis* Fleming, Fenestella sp., *Nucula* cf. *ventricosa*, Leda sp. n., Natica sp. [lower Pennsylvanian or possibly upper Mississippian—G. H. Girty].

The fossils have been found only in the upper horizons of the Santa Rosa and consequently the age of the lower horizons is not fixed. The thickness of the Santa Rosa in some places rises to as much as 200 or 300 meters but is very different in different localities.

The upper terrane of the Carboniferous formations has a thickness of 600 to 800 meters and is shown by abundant fossils to belong to the upper Carboniferous [Pennsylvanian—Girty]. The fossils are *Fusulina granum avenæ* Roemer, *Bellerophon* cf. *costatus* Sow., *Athyris ambigua*, *Athyris sublamellosa* Hall, *Productus semireticulatus* Martin. In the vicinity of Senahu the rocks are chiefly dark-gray dolomites which readily decompose into a sand and show no traces of

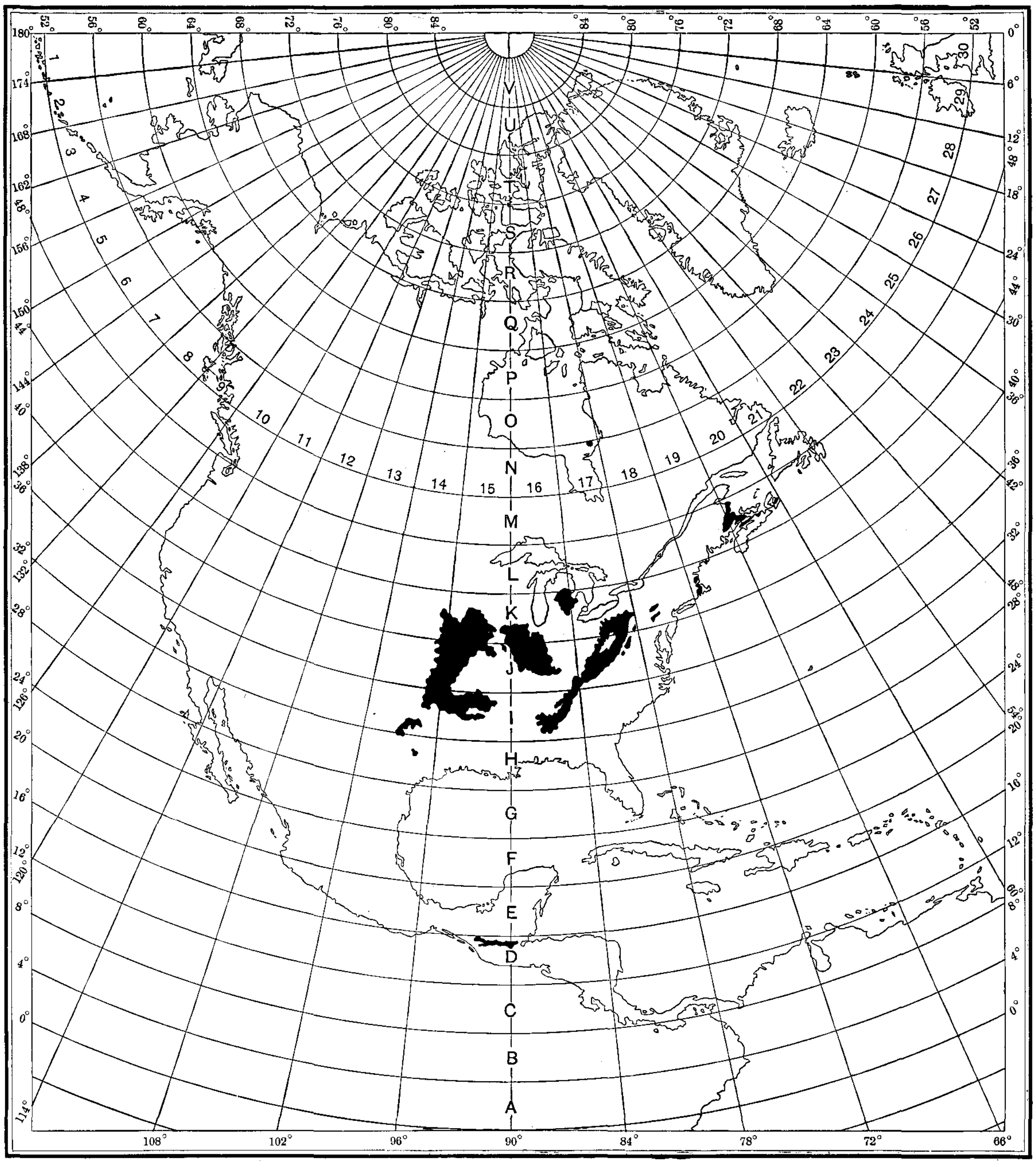

FIGURE 12.—Sketch map showing the distribution of Pennsylvanian rocks that are separately represented on the geologic map of North America and the key to references in the text.

fossils. In the western part of Alta Verapaz these dolomites are, it is true, not entirely wanting, but limestones, limestone conglomerate, and breccia greatly predominate. The limestones rest conformably upon the Santa Rosa terrane.

Complete lists of the Carboniferous fossils identified for Sapper by Stolley are given in an earlier paper by Sapper.[697]

H 14. CENTRAL TEXAS.

The following notes are selected from the forthcoming Llano-Burnet folio and from a bulletin[626] on the mineral resources of the region, both by Paige:

The Carboniferous of the Llano-Burnet district is represented by limestone and shale formations of lower Pennsylvanian age. The limestone forms the lower portion of the system and has been mapped as the Marble Falls limestone. The shale, in which are included sandstone lentils, overlies the limestone and is mapped as the Smithwick shale.

The Marble Falls limestone is separated from the underlying Ellenburger limestone (Cambrian and Ordovician), by a thin limestone conglomerate, though in one place a very coarse angular conglomerate or breccia was observed. There are some localities, however, where little or no discordance could be noted, as, for example, in the small basin 5 miles northeast of Blufton. The boundary at the top of the formation is sharp, and the Smithwick shale succeeds with perfect accordance in dip.

The Marble Falls limestone is believed to be not more than 450 feet in thickness. It is composed of alternating beds of dark and light gray, dove-colored, and dark blue to black limestone. Many beds carry an abundance of cherty nodules, largely of a decidedly dark or black color. The color of this chert is diagnostic in distinguishing this formation from the underlying Ellenburger limestone, in which the chert is of a decidedly lighter color. The formation usually may also be distinguished by the petroliferous odor which it emits on being struck a sharp blow with a hammer. The Marble Falls limestone is confined largely to the southeast quarter of the Burnet quadrangle, but a small patch occurs northeast of Blufton and there are considerable areas in Riley Mountain.

The two following sections will illustrate the lithology of the formation:

Section of Marble Falls limestone in Riley Mountain, in stream 7⅘ miles north of south edge and 4 miles west of east edge of Llano quadrangle.

	Feet.
Very hard, compact, nearly black limestone; some chert; nonfossiliferous.	
Thin, dark, very hard limestone; conchoidal fracture; weathers buff; platy and considerable black chert	10
Rather massive gray limestone; some black chert	10
Thin-bedded, very fine grained black slaty limestone	20
Rather massive dove-colored limestone	20
Thin-bedded slates or slaty limestone, black or dark gray; weathers yellow; apparently no fossils	35
Massive, coarse brown limestone	5
Thin-bedded limestone with cherts, gray-browns; marly in some places; weathers light yellowish; few fossils noted in talus slopes	50
Crystalline grayish-brown limestone; some fossil fragments	12
Massive brown limestone with large amount of chert	7
Coarse-grained brown limestone containing considerable light chert; weathers into a slope of talus	9
Irregular limestone, gray to brown, fine grained, nonfossiliferous	32
Thin-bedded, very dark fine-grained limestones with a large quantity of black chert; a few fossils.	
Irregularly bedded fine-grained brown and gray limestone; very fossiliferous at base; bituminous odor strong; some parts of base are mostly Productus remains	22
Mostly thin-bedded fine to coarse grained brown and dark-gray limestone, highly fossiliferous	8
Thin-bedded hackly limestone, brownish, sugary; bituminous odor	6½
Conglomeratic limestone containing pebbles of white chert and fine-grained light limestone	2
Ellenburger limestone (Cambrian and Ordovician).	
	248

Section of Marble Falls limestone along north bank of Colorado River from dam to point above bridge at Marble Falls.

	Feet.
Smithwick shale.	
Thin-bedded black limestone	20
Fine-grained dark-gray limestone	15
Thin-bedded and massive black limestone	30
Brownish-gray subvitreous to crystalline limestone	30
Thin-bedded dark-gray or black fossiliferous limestone with Productus and crinoids	4
Fine-grained crystalline gray limestone	4
Fine-grained gray limestone with molluscan fossils	20
Dense black or dark-gray limestone	2
Light and dark gray mottled limestone with chert nodules	5
Mottled gray limestones with crinoid stems 26 inches long	5
Limestone conglomerate	1
Gray limestone without chert	2
Gray cherty limestone	8
Black limestone with cherty layers	8
Black, evenly bedded limestone with cherty layers	9
Massive gray crystalline limestone	8
Gray cherty limestone	25
Gray crystalline limestone	6
Fault.	
Irregular-bedded gray limestone	17
Black shaly limestone with chert layers and lenses	22
Massive gray limestone; crinoid stems	60
Fault.	
Dark cherty limestone	7
Dove-colored limestone with black bands and lenses	40
Conglomerate	20
Ellenburger limestone (Cambrian and Ordovician).	
	368

The Smithwick shale consists of a soft, very dark to nearly black carbonaceous shale in which are included a number of sandstone lentils. Because of its soft nature the formation was not observed in such attitude as would permit its measurement. Moreover, its top is overlapped by Cretaceous sediments. Probably the beds exposed in Burnet County do not exceed 400 feet in thickness. The basal boundary of the formation is always sharp, the change to limestone occurring very abruptly. The formation represents the youngest Paleozoic sedimentation in the region and the erosion surface, represented by its beveled beds, marks the great unconformity between Paleozoic and Cretaceous sedimentation. The formation is confined to the southeast portion of the Burnet quadrangle and to a small area in Riley Mountain, in the Llano quadrangle.

I 14. NORTHERN TEXAS.

Northern Texas is geologically almost completely separated from the areas to the north by the uplift of the Arbuckle Mountains. There is a possible connection around the west end of this uplift by "Red Beds" strata as yet unclassified. The stratigraphy of the Pennsylvanian of northern Texas was summed up by Taff[807] as follows:

The north Texas coal field extends from the south side of the Colorado River valley between Lampasas and Concho counties northward to Red River in Montague County. It is nearly 250 miles in length, with an average width of about 45 miles, and has, therefore, an approximate area of 15,000 square miles. * * *

The north Texas coal field is limited on the east by the Cretaceous rocks, which rest unconformably upon Coal Measures. At the south end of the field the Coal Measures lie unconformably upon the Mississippian (Lower Carboniferous) and are in part concealed by Cretaceous strata. Upon the west and northwest sides the Coal Measures are bounded and succeeded stratigraphically by the Permian. * * *

The Coal Measures of north Texas were separated by Mr. Cummins [a] into five divisions or groups, as follows, in descending order: Albany, Cisco, Canyon, Strawn, Millsap.

Millsap division.—This group of strata has not been recognized south of northern Erath County, though, according to the structure of the rocks, it should occur in the basin of Leon River in Comanche County. According to the Texas Survey it thins southward and does not occur in the Colorado River valley. North of Trinity River valley in Wise County it is concealed by the overlap of Cretaceous rocks. The top of the formation includes coal bed No. 1, whose outcrop is located upon the map and which is mined at Thurber, Gordon, Rock Creek, and Bridgeport. The strata of this group occur at the surface between the coal outcrop referred to above and the Cretaceous border. The base is not exposed, and much of the section, which has a thickness of about 1,000 feet, is concealed. The complete section was obtained by diamond drill, penetrating the strata at Thurber.

It is composed of blue and black shale, interstratified with occasional limestone and sandstone strata.

The deep wells at Gordon and Thurber produce gas and salt, but no coals were encountered below coal No. 1.

Strawn division.—This is composed of nineteen separate members of sandstone and shale, making an aggregate thickness of 3,700 feet in the southern part of the field, where the members of the group rest unconformably upon the massive shale and limestone of the Mississippian, and in many cases are unconformable with regard to each other.

In the northern part of the field the aggregate thickness decreases to 950 feet. Coal is not known to occur in this division.

Canyon division.—This group is composed chiefly of limestone and shale, with local beds of sandstone and conglomerate. The thicker beds of limestone occur near the base and in the upper part of the series. The limestones are generally thick or massive and hard, making escarpments or outcropping in prominent ledges. In the northern part of the field the group contains twelve separate members of limestone and shale and one conglomerate, making an aggregate in all of 800 feet of strata. Unlike the Strawn, this division increases in thickness northward. In the northern part of the field it contains 930 feet of strata. No coal is reported to occur in these rocks.

Cisco division.—There are nineteen different members of this group, each of which is found to be variable in lithologic nature. Some of the members contain limestone, shale, coal, and sandstone, and several contain conglomerate, while a few are composed almost entirely of limestone and shale. Throughout the section there are not fewer than twenty separate beds of limestone, which are usually thin. The shale as a whole is much thicker than all the other strata together, and the whole group aggregates about 800 feet from end to end of the field.

Several of the members which contain conglomerate rest upon eroded surfaces of lower beds and in some instances have been found to overlap and displace beds of coal. The heterogeneous nature of this group of strata indicates many repeated changes in sedimentation. Several thin beds of coal have been recognized near the top and in the lower middle part of the group, besides two beds of workable thickness. These workable beds occur 200 and 300 feet above the base of the division.

Albany division.—The class of sediments making this group is generally a repetition of that found in the Canyon division. They are thick beds of limestone generally separated by shaly members.

According to Mr. Cummins's report the Albany division thins northward from 1,180 feet at the south end of the field to zero on the Brazos River.

It contains two shaly members which bear thin coal strata, none of which, however, have been found to exceed a few inches in thickness.

This group is succeeded by the Permian, which overlaps upon the Cisco division between Brazos and Red rivers.

[a] Cummins, W. F., Report on the geology of northwestern Texas: Second Ann. Rept. Texas Geol. Survey, 1890.

According to Cummins,[199] later studies have shown that the beds to which the name "Albany" formation was applied are the same as the Wichita formation, with which they are stratigraphically continuous, the "Albany" being simply deposits in deeper water.

I 16. ALABAMA.

Plant remains, probably of Pennsylvanian age, are recorded by Smith [747] from the metamorphosed rocks near Moseley (now Erin), Clay County, Ala., which have heretofore been regarded as a part of the Ocoee group of Safford. (See Chapter III, p. 88.)

I–J 16, J–K 17–18. APPALACHIAN COAL FIELD.

The following statement on the Appalachian coal field was prepared for this work in 1910 by David White:

GENERAL FEATURES OF THE PENNSYLVANIAN IN THE APPALACHIAN PROVINCE.

Conditions of deposition.—The Pennsylvanian (upper Carboniferous) rocks of the Appalachian trough or province lie unconformably upon a portion of the eroded and somewhat warped Mississippian surface. The initial invasion of the old basin by the Pennsylvanian sea formed a relatively narrow and elongated estuary extending from the southern anthracite field in Pennsylvania southwestward along or near the eastern margin of the central and southern Appalachian coal fields [898] to the Gulf region in southern Tennessee or northern Alabama, where, becoming confluent with the eastern interior lobe, it opened into the broader sea to the southwest.

Later the basin expanded both to the north and the west, broadening out in these directions to and beyond the limits of the present coal fields. There was, therefore, encroachment of the sea on the land and overlapping of the terranes during at least the earlier divisions of Pennsylvanian time. Nearly everywhere the Pennsylvanian-Mississippian contact exhibits sharply contrasting sediments, though at a few points, such as the Bluestone section [123] in southwestern Virginia, there is an absence of conglomerates and a less abrupt change in the rock-forming material. Along the eastern portion of the basin the Pennsylvanian deposits lie on the Mauch Chunk formation (regarded as of Chester age); but farther northwest they are found resting bassetwise on rocks nearly if not quite as old as the Pocono. Farther along the western margin of the bituminous coal field they come into contact with the Cuyahoga shale, Logan formation, Blackhand formation, and Maxville limestone.[39e] Yet there is a remarkable absence of local topographic relief, the Mississippian floor having been apparently a base-level coastal plain over most of the area.

Character of sediments.—The rock-forming materials are mainly terrigenous, brought down by rivers chiefly from eastward lands, which were probably the site of nearly continuous though variable epeirogenic action. Consequently the formations are in general thicker and more arenaceous toward the east side of the basin. The greatest thickening is toward the southeast, where at the edge of the Cretaceous overlap in Alabama the Pottsville, or lower division, probably exceeded 7,500 feet. Marine or brackish-water faunas, extending over wide areas, occur at numerous stages except in the later Pennsylvanian, thus showing frequent accessibility to marine life, though the conditions of sedimentation in the Appalachian trough were generally less favorable for open-water marine Mollusca than in the eastern interior arm. The subsidence kept, on the whole, relatively close pace with loading, so that, though the warping was unequal, there is slight evidence of the contemporaneous formation of new basins as the result of the orogenic changes.

General structure.—In the western portion of the basin the beds lie nearly horizontal, but toward the eastern margin—that is, the eastern escarpment—of the bituminous regions, open folds with more marked anticlines were developed, from some of which the Pennsylvanian is largely or wholly eroded, and still farther east the folding was closer, with concomitant faulting, usually overthrusting, as in the anthracite and eastern Alabama regions. The folds dating from the great post-Paleozoic movement conform in system to those in the older rocks to the east and the principal faults are similarly northwestward overthrusts. The high elevation and consequent erosion of large areas of the closer folded basins, in the northern portion of the trough, resulted in the isolation of the anthracite and Broad Top fields in Pennsylvania and the Potomac and upper Cheat basins of Maryland and West Virginia. Similar detachments are seen in the southern Appalachian region.

DIVISIONS OF THE PENNSYLVANIAN IN THE APPALACHIAN TROUGH.

Pottsville group.—The Pennsylvanian of the Appalachian trough is, as a whole, divided into subdivisions which in practical application have the value of groups, although in the northwestern areas they are mapped as formations. Of these the Pottsville, or lower group, occupies the early narrow estuary, but the later divisions extend over the greater part of the Pennsylvanian overlap. The Pottsville, like the succeeding formations, is composed of sandstones, shales, and clays (including fire clays, coals, and limestones), but it contains a larger proportion of sandstones and arenaceous shales than the later formations. This is a natural result of the conditions of encroachment and rapid filling under which it was laid down. The Pottsville is thickest in the southern exposures, where, near the eastern outcrops, it probably exceeds 7,500 feet. In the northwestern bituminous area, partly as the result of less voluminous sediment, partly by reason of the absence of all but the latest members of the group, it measures locally less than 200 feet. The older divisions of the Pottsville—that is, those within the earlier limits of the Pennsylvanian sea—occur only (1) in the southern Appalachian area, (2) along the eastern border of the coal field in the central Appalachian region, and (3) in the southern and middle anthracite fields of Pennsylvania.

Marine conditions, attested by the presence of marine Mollusca, were present at a number of stages in Pottsville time, particularly in the central and southern Appalachian regions, though limestone is extremely rare except in the upper Pottsville of the central Appalachian region, and in the Mercer shale member, in the upper part of the Pottsville in the northern bituminous areas. The Pottsville contains all the workable coals south of the Kentucky-Tennessee State line. Subdivisions of the Pottsville and their characters will be cited on a later page in connection with the discussion of the map units.

Allegheny formation.—The Allegheny, next succeeding the Pottsville, is a thin formation characterized by a larger proportion of coal, shale, limestone, and iron ore. Like those of the Pottsville, its sediments are generally grayish or whitish, though they are more apt to be somewhat ferruginous. Red beds are absent except possibly in northeastern Kentucky. Its limestones, several in number, are distinctly marine, though relatively thin, and may be traced continuously over large areas. In the bituminous districts, where it is sometimes known as the "Lower Productive Coal Measures" ("XIII"), the Allegheny ranges generally between 250 and 350 feet in thickness near the northern outcrop, though it thins southwestward to 160 feet in northeastern Kentucky. It is also greatly thinned in the bottom of the broad syncline of the main coal field. The Allegheny appears to have been completely eroded from the region south of the Kentucky-Tennessee line, but it is possible that the sandstones tipping the summits of several of the highest mountains in the coal field of northern Tennessee may represent its basal terranes.

Conemaugh formation.—The Conemaugh, which succeeds the Allegheny, is generally marked at its base by sandstone or conglomerate. It is especially characterized by sandstones, shales, and limestones, intermingled, particularly in the western area, with red and green shales, clays, and sandstones. It contains less coal than any of the other Pennsylvanian formations of the Appalachian trough, and in most of the earlier reports of the Pennsylvania and Virginia State surveys it was consequently known as the "Lower Barren Measures" ("XIV"). A thin limestone known as the Ames (or "Crinoidal") limestone member, which occurs near the middle of the Conemaugh formation, is locally present over large portions of the field, and was formerly supposed to contain the last representatives of distinctly marine Mollusca in the Appalachian trough, but recent discoveries indicate marine conditions at a level somewhat higher. Not far from the horizon of the Ames member there have been found reptilian bones allied to early representatives of the group characteristic in general of the Permian. They may be regarded as forerunners of the Permian fauna.

All sediments of Conemaugh or later age appear to have been removed from the portion of the Appalachian trough south of northeastern Kentucky, though the presence of the marine Mollusca implies continuity of these sediments down the basin to connect with the open sea.

Monongahela formation.—The Monongahela is distinguished by its relatively large proportion of coal and limestone, the latter composing over one-third of the sediments in some districts. The formation, as stratigraphically recognized in Pennsylvania, Ohio, western Maryland, and West Virginia, averages about 325 feet or less in thickness. Its coals, including the great Pittsburg coal at its base, are of notable thickness and value. As with the Conemaugh, red sediments become more prominent toward the south and its limestones, generally blue and in places containing "fresh-water" Mollusca, thin and disappear in the same direction.

The Monongahela and the Conemaugh are not fully differentiated in the anthracite regions.

Dunkard group.—The Dunkard group, which succeeds the Monongahela and which in lithologic characters and mineral content does not differ notably from that formation, is discussed in Chapter XI (pp. 492–494). The reference of its lower portion (below the Washington coal) to the Permian is not wholly beyond question.

DETAILED DISCUSSION OF FORMATIONS.

The composition and stratigraphy of the several formations of the Appalachian trough will now be considered. In order to give precedence to the series and regions more thoroughly known, the geographic order of treatment will be from north to south. Proceeding thus, we shall begin at the northwest border of the Pennsylvanian trough, encountering first the younger formations in the regions of late Pottsville overlap. Subsequently, working eastward and southward, we shall reach the thicker developments of the formations and the minor areas of the oldest formations lying along or near the earlier axis of the basin.

OHIO AND PENNSYLVANIA.

General features.—Map sections K 17 and K 18 include the north end of the great bituminous coal field in Ohio and Pennsylvania, several small isolated residual areas to the northeast, the Broad Top field, and the anthracite region. With the exception of the anthracite fields the coal measures of this strip are a unit not only in the classification applied but also as to essential continuity and parallelism of the strata.

The great bituminous coal field of these States forms a part of a plateau correlated with the Cretaceous or later base-leveling and subsequent elevation. Toward the north and west the strata, rising more rapidly than the plateau surface, outcrop diagonally and are cut by erosion into an intricate fringe of irregular lobes, tongues, and isolated patches that it is impracticable to indicate on the map scale. The eastern border of the plateau coal field is defined by the stronger anticlines to which reference has already been made.

The Broad Top coal field in Huntingdon, Fulton, and Bedford counties, in southern Pennsylvania, is a small remnant in a deep compound fold, in the region of close plication. In general the alteration of the coals increases toward the regions of greater thrust pressure; and so from ordinary domestic and gas fuels we pass through coking and steam coals to semibituminous coals at the eastern escarpment (Allegheny Front) of the great plateau field and in the Broad Top field. Small residual areas of semianthracite in Wyoming and Sullivan counties survive in other very shallow folds between the plateau and anthracite regions.

The anthracite fields, three in number, in eastern Pennsylvania, consist of a group of residual troughs lying in northeast-southwest synclines. The structure is very complex, the strata being locally overturned, especially toward the southern edge of the region, while subordinate folds connect many of the synclines in varying degrees.[795c]

It will be seen that the eastward-increasing amplitude of the folds results in erosion of the Pennsylvanian from a number of the anticlines within the plateau region. The most prominent of these are known as the Deer Park, Laurel Hill, and Chestnut Ridge anticlines. The intervening folds have been described as First, Second, and Third bituminous basins, etc., or synonymously designated by geographic terms.[a]

A radius from the border of the plateau coal field to the southwest corner of Pennsylvania spans a section extending from a point at or near the base of the upper Pottsville to the top of the Pennsylvanian as at present somewhat conventionally drawn. The middle and lower Pottsville are not encountered, as the entire upper Carboniferous area of Pennsylvania, outside of the anthracite fields, together with the whole of the Ohio Pennsylvanian, falls in the region of extension and overlap of the later Pottsville sea. The lower divisions are, however, present at the type locality, Pottsville, in the southern anthracite field.

The terranes of the several sections throughout Ohio and Pennsylvania have received careful consideration and correlation by E. V. d'Invilliers[285b] and J. J. Stevenson,[795a] who give full details or citations. The original data relating to the bituminous area will for the most part be found in the "Geology of Pennsylvania," by H. D. Rogers, 1858; in the county reports of the Second Geological Survey of Pennsylvania; in the reports of the Ohio Survey (especially volume 6 and Bulletin 9); in the following folios issued by the United States Geological Survey: Warren, Foxburg-Clarion, Beaver, Kittanning, Rural Valley, Elders Ridge, Indiana, Latrobe, Ebensburg, Johnstown, Amity, Sewickley, Brownsville-Connellsville, Rogersville, Waynesburg, Masontown-Uniontown, and Huntington; in United States Geological Survey Bulletins 65, 279, 304, 318, and 349; and in the report of the Topographic and Geological Survey Commission of Pennsylvania for 1906–1908.

Pottsville group.—The Pottsville group, earlier known as "Conglomerate series," "Pottsville conglomerate" ("XII"), and "New River series," forms the lowest division of the Pennsylvanian. As the basal and conglomeratic stage of the "Seral," the last of the ideal time divisions proposed by the brothers Rogers[674] for the Paleozoic in America, it was earlier called the "Seral conglomerate." It has sometimes been roughly correlated with the Millstone grit of Great Britain, though on the paleobotanic evidence it appears that the upper Pottsville is to be correlated with the middle Coal Measures of the United Kingdom.

The Pottsville as a whole is the most natural of the Appalachian upper Carboniferous subdivisions, for it represents the first or main epoch of sea transgression in the cycle of Pennsylvanian sedimentation. In his characterization of the Pottsville I. C. White[905f] points out the strong contrast which it presents to the red and greenish softer sediments below it, and to the softer, generally more argillaceous, terranes above it.

"The series as a whole possesses a large amount of hard white or grayish sandstone, much of which is conglomeratic. The sandstones are harder, more compact, and siliceous; than any of the lower coal series above. Bowlders of this sandstone take a smooth polish when rolled along river beds, but this is not the case with most sandrocks above this."

On account not only of the highly variable thickness of the different component terranes but also of the absence of one or more of them in different regions it is difficult to give a generalized section of much value. The following regional section in Mercer County, Pa., near the Ohio line, prepared by I. C. White,[904] is fairly typical of the upper Pottsville in Ohio, Maryland, and western Pennsylvania; and though of unusual thickness (301 feet) it is especially important on account of its location at or near the type localities for most of its members. The bracketed matter is added by the present writer.

[a] For description of structure, anticlines, and basins, see Summary Final Rept. Second Geol. Survey Pennsylvania, vol. 3; Bull. U. S. Geol. Survey No. 65; Ohio Geol. Survey, Rept. V; West Virginia Geol. Survey, vols. 2 and 2A; Maryland Geol. Survey, vol. 5, p. 260. For the anthracite regions see Second Geol. Survey Pennsylvania, mine maps in Atlas of anthracite region, and Reports of progress A and AA; also Rogers, H. D., Geology of Pennsylvania, 2 vols., 1858.

Section in Mercer County, Pa.

	Feet.
1. Homewood sandstone ["Tionesta," "Johnson Run," and "Piedmont"]	50
2. Shales	5
3. Iron ore [in western Pennsylvania and across the southern Ohio line into northeastern Kentucky]	2
4. Mercer upper limestone [marine fossils]	2½
5. Mercer upper coal [place of Mount Savage coal and fire clays in Pennsylvania and Maryland].	2½
6. Shales [locally in northern Pennsylvania inclosing a "Middle Alton" coal]	25
7. Iron ore [somewhat more persistent than No. 3, over much the same areas]	2
8. Mercer lower limestone [marine Mollusca; more persistent than the Upper Mercer limestone but disappearing eastward]	2½
9. Shales	10
10. Mercer lower coal	2½
11. Shales	10
12. Iron ore	1
13. Shales	5
14. Connoquenessing upper sandstone ["Massillon" sandstone in part; present in nearly all sections]	40
15. Shales with iron ore	10
16. Quakertown coal [generally recognized]	2
17. Shales [in places lacking]	40
18. Connoquenessing lower sandstone [lacking in portions of the Allegheny Valley, locally along the Allegheny Front, and in some of the small northeastern residual areas; "Massillon" sandstone in part]	30
19. Sharon iron shales [locally including a thin "Upper Sharon" coal]	30
20. Sharon coal	4
21. Fire clay and shales	5
22. Sharon conglomerate [usually conglomerate, at least in part, and extremely variable in thickness or absent entirely; perhaps equals the Olean conglomerate of McKean and Warren counties, Pa.; usually lacking together with Nos. 19 to 21, where No. 18 is deficient]	20
Contact with Mississippian.	
	301

The average thickness of this part of the Pottsville in the bituminous regions of K 17 and K 18 is less than 250 feet. As might be expected in a region of encroachment and overlap, the lower members are in places lacking. This lack is especially noticeable along portions of the northern border of the field in Ohio and Pennsylvania; but it is also evident locally in the interior regions, especially in the areas east of Allegheny River, in the Allegheny Front, and in the Broad Top field. It is not recognized beneath the deeper portions of the main basal syncline.

The Homewood sandstone member, like the others, is highly variable, being in some places represented only by a few feet of shales. The limestones and coals are likewise subject to disappearance, the limestones being rarely represented near the eastern escarpment. The coals are all workable at one point or another.

For the upper Pottsville in the region under consideration, as described above, I. C. White [907a] has recently revived Lesley's term Beaver River group, though excluding therefrom the Sharon conglomerate member, which was shown by Chance and D'Invilliers to be of Pennsylvanian age.

Allegheny formation.—The Allegheny, as differentiated in 1875 [a] by Franklin Platt,[637] is a formation whose limitation is largely dictated by convenience. It embraces the softer sediments of more quiescent waters intervening between the arenaceous invading Pottsville and the Mahoning and other sandstone and shale members of the overlying Conemaugh formation, or "Lower Barren Measures." It is remarkable for its good coals, on account of which it was for a time known as the "Lower Productive Measures," No. XIII of Lesley. As compared with the Pottsville the members of the Allegheny are relatively regular and continuous, and the occurrence in them of marine Mollusca is comparatively common.

The principal members of the Allegheny formation, which in the bituminous regions does not usually exceed 300 feet in thickness, are as follows:

[a] For other earlier and abandoned classifications see Stevenson, J. J., Bull. Geol. Soc. America, vol. 17, 1906, pp. 65–69.

1. Upper Freeport coal; persistent over most of the area of the formation and workable in many districts.

2. Upper Freeport limestone member; thin but widely persistent with fossils reported as "fresh-water" in some areas, "marine" in others; accompanied, especially in portions of Westmoreland and Fayette counties, in western Pennsylvania, and in Jefferson and Muskingum counties, Ohio, by the Bolivar clay member.

3. Butler ("Upper Freeport") sandstone member; highly variable in thickness, or even lacking, being replaced by shales.

4. Lower Freeport coal; widely persistent and locally very valuable.

5. Lower Freeport limestone member; usually thin and more or less earthy, with fossils regarded as indicating fresh-water conditions; here and there associated with iron deposits.

6. Freeport sandstone member ("Lower Freeport sandstone"); white and in places conglomeratic, usually 30 to 50 feet or more in thickness; locally a sandy shale.

7. Upper Kittanning coal (Cement coal); usually present, though variable, and of little importance except in the eastern portion of plateau; rarely recognized in Ohio; carries local cannel near Redbank Creek and in Beaver, Clearfield, and Indiana counties, Pa.

8. Johnstown limestone member; 1 to 8 feet, magnesian limestone lying 2 to 5 feet beneath the preceding coal, but not found in the western tier of Pennsylvania counties or in Ohio.

9. Middle Kittanning coal; important as the "Hocking Valley" coal of Ohio, where it is locally roofed by black shale with marine fossils; widespread, with rare cannel, in Pennsylvania, but unimportant except near the Ohio line.

10. Lower Kittanning coal; very persistent, nearly everywhere; valuable, especially toward the Allegheny Front, also workable in parts of Ohio.

11. Lower Kittanning clay; valuable, 5 to 15 feet thick west of Allegheny River and passing through Ohio, where it touches the Vanport limestone member; locally, especially at the east, replaced by thick shales or sandstones.

12. Kittanning sandstone member ("Lower Kittanning sandstone"); local only, chiefly in Butler County, Pa., where it is massive and conglomeratic; 50 feet or more in thickness.

13. Buhrstone iron ore; 6 inches to 20 feet thick, highly variable, usually cherty at base, underlain by Vanport limestone member; important in southern Ohio but less regular and persistent east of western counties of Pennsylvania.

14. Vanport limestone member; familiar as the "Ferriferous limestone;" marine, with rich fauna;[903] unknown in the First and Second bituminous basins (east of the Chestnut Ridge anticline) in Pennsylvania; 5 to 20 feet thick in western counties north of Kiskiminitas River; locally present in Ohio, especially toward the south, where it is fairly persistent.

15. Clarion coal; generally unimportant and less persistent; apparently lacking in considerable areas; a supposed split of this coal, the "Scrubgrass" or "Upper Clarion" coal, occurs about 10 to 15 feet higher and less than 10 feet below the limestone in portions of western Pennsylvania and over much of Ohio.

16. Clarion sandstone member; locally massive and thick, especially in southern Ohio, and fairly persistent, though usually insignificant.

17. Brookville coal; very persistent; recognized in many deep borings beneath the Monongahela formation; usually separated only by its underclay from the Homewood sandstone member of the Pottsville formation; in portions of Ohio a thin marine limestone, known in the Ohio State reports as the Putnam Hill limestone, overlies a coal correlated by Orton [621] and Stevenson [796c] with the Brookville, but it is probable that both limestone and coal are of Mercer age (Pottsville).[39d]

Considering the large territory covered, the members of the Allegheny are more regular and persistent than those of either of the contiguous formations. I. C. White,[906] confirming the conclusions of the late Edward Orton, State geologist of Ohio, remarks that "all of the main strata in the Allegheny series of western Pennsylvania can be traced bodily across that State [Ohio] from where they enter it in Columbiana County to where they leave it to enter Kentucky from Lawrence County, 250 miles from the Ohio-Pennsylvania boundary. In this intervening distance some of the coal beds may change in thickness or disappear entirely over areas of considerable size, but they ultimately come into the section again, so that the integrity of the persistent beds of the Allegheny series in Pennsylvania is maintained entirely across the State, and this is true, not only of the coal beds, but also of the limestones, sandstones, fire clays, and even the iron ores, so that a section in Lawrence County is practically a duplicate of one in Columbiana."

The Allegheny, which in northern Pennsylvania reaches a maximum thickness of a little over 300 feet and is in few places less than 250 feet, is thinner in the Broad Top field and thins to less than 250 feet in southwestern Ohio, while in the Kenova quadrangle, in northeastern Kentucky, it declines to about 170 feet. Several of its members are attenuated or lacking beneath the higher formations in the axis of the broad bituminous syncline. The local details given with great care in the Ohio and Pennsylvania county reports, cited in the general description (p. 431), are summarized in the final report of the Second Pennsylvania Geological

Survey,[285a] and the identifications of the members have been critically reviewed and revised by I. C. White[905e] and J. J. Stevenson.[796a] The variation in the sections and the introduction of local coals are discussed by Ashley.[39c] The correlations in the Broad Top field are fully considered by Stevenson.[796f]

Conemaugh formation.—The Conemaugh as defined by Franklin Platt,[637] in the Conemaugh River section of Pennsylvania, includes a series, generally less than 600 feet in thickness, lying between the Allegheny or "Lower Productive Coal Measures" ("XIII"), and the Monongahela, or "Upper Productive Coal Measures" ("XV"). On account of its relative deficiency in coals and economic limestones or iron ores it has been known as or included in the "Lower Barren Measures" also called "Elk River series"[905b] and "No. XIV."[796b]

The numerous sections given in the Ohio and Pennsylvania reports, or cited by I. C. White[905c] and G. H. Ashley,[39] show a lack of regularity far exceeding that of the members of the Pottsville. Not only do the component terranes vary greatly in thickness but in many places they are absent; yet several of the individual members are of great persistence. The principal members of the Conemaugh formation which have been described from different areas[607, 736] are, in descending order:

1. *Upper Pittsburg limestone member;* just under Pittsburg coal; one to several thin, in places brecciated limestones, containing minute univalve mollusks in a variable interval averaging about 25 feet; in Fayette County, Pa., locally replaced by iron ores.

2. *Little Pittsburg coal;* a widespread coal-bearing zone, rather than a single coal, 20 to 60 feet below the top of the formation; locally associated with two limestones, one ("Upper Pittsburg limestone") 3 to 5 feet thick, above, and the other (Lower Pittsburg limestone member) 8 to 10 feet thick, below the coal horizon.

3. *Connellsville sandstone member;* massive, conglomeratic, about 20 feet or more in thickness, largely confined to the Connellsville region of Pennsylvania and the Potomac basin of Maryland and West Virginia.

4. *Little Clarksburg coal;* 100 to 130 feet below the top of the formation; confined to southern Pennsylvania and northwestern West Virginia; directly underlain in latter region by the Clarksburg limestone member, which is impure, with ostracods and fish, and attains a local thickness of 20 to 30 feet.

5. *Morgantown sandstone member;* yellowish-gray mealy sandstone, 20 to 100 feet thick, locally conglomeratic or brecciated; 200 feet below top of Conemaugh at Morgantown, W. Va.; generally persistent in Pennsylvania, Maryland, and West Virginia.

6. *Elk Lick coal;* close under No. 5, widely persistent and usually present in Pennsylvania, Maryland, Ohio, and northern West Virginia, and locally workable to the east; surmounts the Elk Lick limestone member, 12 feet thick, in Somerset County, Pa.

7. *Ames ("Crinoidal") limestone member;* very thin bed nearly midway in Conemaugh, generally 275 to 300 feet below top in most of Pennsylvania, 200 feet below on the Ohio at Wellsburg, the interval decreasing westward to 140 feet, though swelling to 300 feet at the southern outcrop in Ohio,[905d] dark-bluish or greenish-gray tough siliceous granular limestone, usually 3 to 5 feet thick; present or represented by marine calcareous shell-bearing shales nearly everywhere except in northeastern portion of the Plateau region; a series of red clays, sandstones, and marls, the "Washington Reds," of variable thickness and color, lies above it; the limestone is rich in marine brachiopods and pelecypods; "its common fossils are *Productus nebrascensis, P. prattenianus, P. longispinus, P. semireticulatus, Hemipronites crassus, Spirifera camerata, S. plano-convexa, Athyris subtilita, Lophophyllum proliferum, Zeacrinus mucrospinus*, together with undetermined plates and stems of crinoids."

8. Harlem ("Friendsville" or "Crinoidal") coal; thin and less persistent, immediately under Ames limestone member; present in most of outcrops in Ohio and western Pennsylvania, but rare near Allegheny Front.

9. "Pittsburg Reds;" mainly soft or variegated shale and marly clays in thick variable series under No. 8; less in evidence toward the northeastern and northwestern borders of the Conemaugh area; incloses a bluish fossiliferous limestone (the Ewing limestone of Ohio State reports) over much of the Ohio area.

10. Saltsburg sandstone member; massive (20 to 60 feet); in places absent; probably same as Cow Run sand of southeastern Ohio; underlain by thin shale and local dark or gray limestone.

11. Bakerstown coal; "Tyson" coal of Maryland, correlated by Stevenson with the Barton coal; fairly persistent in southern Pennsylvania but rarely identified in Ohio; locally important in Maryland and West Virginia.

12. Upper Cambridge ("Pine Creek") limestone member; typical in Noble County and southward in Ohio; thin and local in southwestern Pennsylvania.

13. Anderson coal; unimportant; fairly persistent through Ohio and northern West Virginia but disappearing a short distance east of the Pennsylvania State line.

14. Buffalo sandstone member; correlated with the Saltsburg by Stevenson; locally a conglomerate, 60 feet thick on Kiskiminitas River; generally persistent, 30 to 50 feet thick, though thinner on northern and eastern sides of basin; less important though locally coarse on west through Ohio.

15. Lower Cambridge ("Brush Creek") limestone member; thin, black, fossiliferous, 30 to 60 feet below No. 13; generally present in Pennsylvania but disappears to west and south in Ohio.

16. Brush Creek coal; Masontown coal in part; unusually persistent though generally unimportant in Broad Top field, through Pennsylvania, and largely in outcrops through Ohio; "Gallitzin" coal of the eastern side; multiple in division, with interbedded limestones.[39b]

17. Mahoning limestone member; developed in eastern part of plateau field and locally associated with iron ore (Johnstown iron ore).

18. Mahoning sandstone member. Includes: (*a*) Upper sandstone, in places massive and conglomeratic; said to be fairly persistent through much of Conemaugh exposure on east side of basin, but generally lacking on west; separated from lower sandstone of the Mahoning member by highly variable shale interval with coal. (*b*) Mahoning coal; locally present with clays in western Pennsylvania. (*c*) Lower sandstone; generally persistent through Conemaugh area, and in places conglomeratic though locally obscure or lacking; is here and there the basal member of the formation, resting directly on the Upper Freeport coal, the topmost member of the Allegheny formation.

19. Uffington shale member; thin, local only, and crowded with marine invertebrates near Morgantown, W. Va. (Contact with Upper Freeport coal.)

The Conemaugh formation occupies, naturally, a relatively small area. It reaches a thickness of over 700 feet near Monongahela River and in Maryland. Along the northerly outcrop it averages not over 600 feet, and to the west and south in Ohio it falls off to 300 feet or less. Coals in unusual number and thickness were developed in the Castleman basin, in southern Somerset County, Pa., and in Maryland.

Broadly viewed, the Conemaugh is an arbitrarily limited and highly variable formation, largely sandstone or even conglomeratic in its lower portion, with much red and green clay material and marls in its middle, and more sandstones, locally conglomeratic, in the upper part, which was locally eroded before the deposition of the succeeding Monongahela formation.

The last, so far as at present known, of the strictly marine invertebrate faunas occurs not far above the Ames limestone member (No. 7 of preceding list), perhaps the most widely extended of the distinctly marine members.[a] According to the fossil floras, the writer is inclined to draw the Westphalian-Stephanian boundary provisionally at or close above the top of the Allegheny formation, the Mahoning sandstone member being interpreted as showing the beginning of a more pronounced orogenic movement which seems gradually to have brought about the final exclusion of the sea. On the other hand, I. C. White,[907j] citing (1) the discovery by Dr. P. E. Raymond, in the "Pittsburg Reds" (No. 9 of list) at Pitcairn, Pa., of the reptilian genera Eryops, Desmatodon, and Naosaurus, closely allied to types regarded as Permian,[130] (2) a fossil obtained near the horizon of the Ames limestone member near Salt Lick Bridge in Braxton County, W. Va., regarded as the tibia of a large reptile; (3) the Permian aspect, according to Scudder, of the insects from about the same horizon near Steubenville, Ohio; and (4) the introduction of red sediments,[b] argues for the reference of all the beds above the Buffalo sandstone member (No. 15) to the Permian. The evidence both of plants and of mollusks is distinctly contrary to this proposed correlation. The upper boundary of the Conemaugh is not yet drawn in the anthracite regions.

Monongahela formation.—The Monongahela formation, or "Upper Productive Coal Measures" (XV of Rogers), is the highest of the Pennsylvanian formations in the Appalachian trough. In K 17 and K 18 it occupies a small area in the bituminous regions, being for the most part confined to the deeper portion of the basin [285c] in southwestern Pennsylvania and eastern Ohio.[c] East of the Chestnut Ridge anticline in Westmoreland County, Pa., it appears only in very small residual areas in the Ligonier Valley and it is represented partly also in the Broad Top and Castleman basins. It is fully present in minor areas in the Potomac basin of Maryland and West Virginia.

The Monongahela as defined by I. C. White [905] begins with the great Pittsburg coal and extends to the roof of the Waynesburg coal, comprising another somewhat arbitrarily differentiated division of the Pennsylvanian. The upper part of the Waynesburg coal contains Tæniopteris, Equisetites, Baiera, and Saportæa, of Permian relations, while, as stated in the

[a] At several points local deposits of red material occur as low as the top of the lower sandstone of the Mahoning member.

[b] Red beds are stated by Dr. J. J. Stevenson [796e] to be present in the upper part of the Allegheny in northeastern Kentucky. See also Phalen, W. C., Bull. U. S. Geol. Survey No. 349, 1908.

[c] For areas of formations and individual coals see Geol. Survey Ohio, Repts. V and VI, Bull. No. 9, 4th ser.

description of the Dunkard group in Chapter XI (pp. 492–494), the beds of the Dunkard above the Washington coal carry plants undoubtedly indicative of lower Permian age. I. C. White[907i] regards the earlier Monongahela, together with the upper half of the Conemaugh, as representing the closing stage of the Permo-Carboniferous, connecting the latter with the base of the true Permian. No paleobotanic or invertebrate evidence justifying a reference of the Monongahela to the Permian has yet been found. It is regarded by the writer[4a, 899, 897] as of Stephanian age. The black shales of the Monongahela contain fish fragments, largely unstudied, while the limestones present abundant Cyprian and Estherian types, generally regarded as of fresh-water origin.

In the vicinity of Carnegie, Pa., a local unconformity occurs at the base of the formation, the topmost Conemaugh being eroded.[39a] The formation, which is variable in character, contains much limestone and coal. The section at the Lambert shaft in Fayette County, Pa., was found by I. C. White[907c] to contain 44 feet of carbonaceous shale and coals and 202 feet of limestone, out of a total thickness of 388 feet for the entire series. There is relatively little red material in areas K 17 and K 18, though the limestones turn to shale and sandstone with great increase of red and green sediments in passing southward into J 17. The Monongahela reaches its greatest thickness, over 400 feet, in central West Virginia, averages about 380 feet along Monongahela River in southwestern Pennsylvania, is 240 to 270 feet in the Maryland district, is incomplete in the Broad Top field, and thins to about 260 feet along the Ohio River boundary and to about 140 feet at its farthest northwest occurrence in Jefferson County, Ohio. Its composition in the type district is indicated by the following general section in Fayette and Westmoreland counties, Pa., compiled by J. J. Stevenson.[793, 905a] The annotations in brackets are taken chiefly from another paper by Stevenson.[797]

Section of Monongahela formation in Fayette and Westmoreland counties, Pa.

	Feet.
1. Waynesburg coal [fairly persistent in northern part of great bituminous field and on west, but locally absent in south and east; sometimes replaced by limestone breccia or iron]	6
2. Sandy shale or sandstone [Browntown sandstone]; hard, gray, massive, in Harrison County, W. Va.	20
3. Little Waynesburg coal [thin, apparently confined to southwestern Pennsylvania and northern West Virginia]	2
4. Waynesburg limestone [recognized generally in the Monongahela River valley of southwestern Pennsylvania and possibly in Broad Top field, but rarely in Ohio; usually over 8 feet thick, but fades entirely to the south in West Virginia]	20
5. Uniontown sandstone [coarse, gray, locally occupying interval in southwestern Pennsylvania, massive and conglomeratic in portions of the West Virginia area, shale in other regions]	50
6. Uniontown coal [unusually persistent as coal or black shale, in Maryland, southwestern Pennsylvania, and West Virginia, even in deeper bore holes, though apparently patchy northward in Ohio; near type locality, Fayette County, it underlies a thin limestone with pelecypods]	3
7. Uniontown limestone [generally persistent, 2 to 12 feet thick, in Pennsylvania and most of Ohio and West Virginia, though not noted in some drillings on west side of basin; 160 feet above Pittsburg coal in Salisbury basin (Somerset County, Pa.)]	12
8. Sandstone [interval appears to change to "Tyler red beds" and "Ritchie red beds" of northwestern West Virginia]	30
9. Great limestone [later designated Benwood limestone; thin along northern outcrop, lacking in portions of southwestern Pennsylvania; thickest (60 to 90 feet) in parts of Fayette and Westmoreland counties; replaced by shale and sandstone locally; patchy and broken by partings in northern part of Ohio area, fading to sandstone and shale to south in Ohio and West Virginia; includes Bulger and Dinsmore limestones]	80
10. Sewickley sandstone [local, though massive or even double]	30
11. Sewickley coal [Meigs Creek of Ohio; important and widely persistent, about 100 feet above base of series, in Maryland, Pennsylvania, Ohio, and most of West Virginia]	3
12. Fishpot limestone [same as "Sewickley" limestone of Stevenson; gray limestone, variable to 30 feet in thickness; absent east and south of area in southwestern Pennsylvania, northern Ohio, and northern West Virginia, as well as from much of deep interior of basin; fades to shale and sandstone to south; has "fresh-water" shells]	25
13. Shale or shaly sandstone	20

	Feet.
14. Redstone coal ["Pomeroy" coal of Ohio; very persistent, 50 to 70 feet below Sewickley coal; 30 to 80 feet above base of series in Maryland and nearly everywhere throughout basin except around southwestern part of outcrop area, where not always recognized]	4
15. Redstone limestone; apparently only in southern Pennsylvania and adjoining region of West Virginia and Ohio, 10 to 20 feet thick, with minute "fresh-water" fossils; thins rapidly southward in West Virginia and Ohio	10
16. Pittsburg sandstone (sandstone or shale) [variable, coarse, in places pebbly, generally present about borders of the basin, though abruptly disappearing locally in shale and sandstone, the Redstone limestone (No. 15) being apt to vanish where the sandstone is well developed; in many localities lies directly on the Pittsburg coal (No. 17)]	40
17. Pittsburgh coal [most important coal; very persistent and regular; correlated in Broad Top field, the Potomac basin of Maryland, through southern Pennsylvania, the northeastern counties in West Virginia, and the northern portion of the basin in Ohio, but becoming patchy, irregular, or absent around the southwestern part of the basin in Ohio [a] and West Virginia, and apparently absent in a portion of the south-central interior of the deep basin; yet fairly regular and workable over an area of 7,000–8,000 square miles]	12

ANTHRACITE REGION.

General features.—The position of the anthracite fields and their general relations to the Appalachian folding in eastern Pennsylvania have already been indicated (pp. 430–431). The Pennsylvanian synclines are relatively small, their combined area being about 650 square miles, of which the area of workable coal approximates but 484 square miles.[745a] The anthracite fields have been treated with great detail and thoroughness in an elaborate series of publications for each field,[b] as well as in several special reports,[c] published by the Second Geological Survey of the State. The whole has been admirably condensed by A. D. W. Smith.[745] More recently the general geologic relations and stratigraphy have been briefly discussed by J. J. Stevenson;[796h] and the stratigraphic paleobotany of the southern anthracite field has been treated in an advance publication giving correlations by the writer.[895]

In the anthracite region the greatest thickness of the Pennsylvanian, 2,500 feet, is in the southern field; the sections do not reach to horizons as high in the middle fields. In the northern field the deepest syncline contains 1,800 feet of Pennsylvanian strata.

The Pennsylvanian of the anthracite region is divided only into the Pottsville ("Seral conglomerate") and the "Coal Measures." The latter are grouped according to "white ash" or "red ash" coals, but these divisions are local and highly variable. The paleontologic correlation of the post-Pottsville beds is incomplete and without attempt to draw definite boundaries.

The strata in the anthracite region are in general much more arenaceous than those of the bituminous series in any other part of the northern Appalachian coal field, the arenaceous character being more and more predominant as the southeastern border of the region is approached. Conversely, limestone seems to be unknown except in the northern field. The series is moderately coal bearing, there being as many as 25 coals, 20 of which are of workable thickness, in the southern anthracite field, about 15 in the western middle field, and 16 in the northern anthracite field. In the eastern end of the southern anthracite field the Mammoth bed attains the remarkable thickness of 114 feet, of which 105 feet is coal.

Pottsville group.—The Pottsville as a whole is most fully developed in the southern anthracite field. It was somewhat arbitrarily defined by the Lesley Survey as extending from the Buck Mountain coal bed, the lowest stratum of the "Coal Measures," to the top of the Mauch Chunk shale (Mississippian). In the type section, the Sharp Mountain gap at Pottsville, in which the "Twin" coal is regarded as equivalent to the Buck Mountain, the thickness as published by the writer [895g] is very nearly 1,200 feet, though the Broad Mountain section to the

[a] See Bull. Geol. Survey Ohio, 4th ser., No. 9, map; also Geol. Survey West Virginia, Rept. 2A, maps.

[b] Atlas of the northern anthracite field, 6 pts.; eastern middle field, 3 pts.; western middle field, 3 pts.; southern anthracite field, 6 pts.

[c] Repts. Progress A and AA, see also Ann. Repts. 1885, 1886, and 1887.

northwest appears to be rather thicker. The group is overwhelmingly conglomeratic, the lower beds consisting of poorly assorted, locally subangular detrital material, which varies in size not only at different localities but at a single locality,[895a] and is interstratified with some mud beds and coals. The higher conglomerates are more exclusively quartzitic, the pebbles less variable and generally better rounded, and the top portion of the column consists of a plexus of most massive, fairly regular, well-assorted quartzose conglomeratic material, in which occur several thin coals. The group is underlain at Pottsville by 400 feet or more of irregular, poorly assorted puddingstone conglomerates, locally unconformable on brownish-red and olive-green muds, which by some authors are included in the Pottsville and which no doubt belong to the Pennsylvanian. This transitional series, which technically lies beneath the topmost stratum of red shale, the arbitrary lower boundary of the Pennsylvanian, quickly disappears in passing north. The lowermost Pennsylvanian in the southern portion of the anthracite regions (not deposited in the eastern middle and northern anthracite fields) bears some evidence of fluviatile deposition. The beds are, in general, unusually variable in thickness, and the stratigraphy of the coals shows a lack not only of parallelism but, to a certain extent, of synchronism. Consequently the correlation of the coals is far from complete or satisfactory. Little progress has been made in correlating the coals of the northern anthracite field with those of the basins to the south.

The fossil plants of the Pottsville in the type region exhibit a rapid development and series of modifications which are of high stratigraphic value. With the exception of the species from the topmost beds, the ferns are, in general, readily distinguished specifically from those at the base of the "Lower Coal Measures,"[a] or Allegheny formation, as recognized in the northern United States, while the floras of the lower portions of the section are found, in passing downward, to bear still less resemblance to those of the "Lower Coal Measures." On the paleobotanic basis the type section is parted into four divisions, as follows:

1. A lower division, 700 feet in thickness, called the "Lower Lykens division [895b] because it includes (paleontologically) the lower group of Lykens coals (Nos. 4-6 and "0") as mined in the western portion of the field. This, the older Pottsville, includes two zones—(*a*) the *Neuropteris pocahontas* zone, including Lykens coals Nos. 5, 6, and "0," and contemporaneous with the Pocahontas formation (basal Pottsville) of the southwestern Virginia region [123, 124, 126] (J 17), and (*b*) the *Mariopteris pottsvillea* zone, probably contemporaneous with the Quinnimont formation [b] of the central Appalachian region. Both are included in the time interval covered by the Lee formation, which to the south is represented, according to the fossil plants, by the Lookout sandstone and a part of the Walden sandstone in Tennessee and Alabama and which constitutes the lower Pottsville.

2. Above the "Lower Lykens division" is a relatively barren series, about 130 feet in thickness, which the writer [895c] for temporary convenience called the "Lower Intermediate division." It contains a mixed flora and is regarded as lying at or near the horizon of the Raleigh sandstone, the topmost division of the lower Pottsville in the Virginian region, as will be explained farther on.

3. A zone of about 200 feet, extending, roughly, from 370 to 570 feet below the top of the formation, contains the floras characteristic of Lykens coals Nos. 2 and 3, farther west, and has therefore been termed by the writer [895d] the "Upper Lykens division." It is provisionally referred to the middle Pottsville, which embraces the Sewell formation, or New River group of I. C. White,[907a] as recently proposed by him. The latter term, as restricted, is conducive to confusion, not only because of the economic development of the lower Pottsville coals along New River, but also on account of its former application to the Pocono coals (basal Mississippian), which are likewise commercially exploited along New River.

[a] "Lower Coal Measures" as sometimes applied in the anthracite fields of Pennsylvania; not the series of that name in Canada or Europe.

[b] See Raleigh, Pocahontas, Tazewell, Bristol, Estillville, and Briceville folios, Geol. Atlas U. S.

4. The upper portion of the section, extending down for about 370 feet, contains for the first 200 feet some mingling of "Coal Measures" plants with species found in the "Upper Lykens division" of the Pottsville, and was therefore provisionally termed by the writer [895e] the "Upper Intermediate division." This division, which includes Lykens coal No. 1, belongs to the upper Pottsville or Beaver River formation.[a] It will be recalled that this is the only part of the Pottsville found throughout the bituminous coal regions of K 17 and K 18, all of which falls within the region of later Pottsville overlap. In the Virginian region this upper Pottsville expands tremendously to the southeast, probably exceeding 1,500 feet in thickness and including the greater part, if not all, of the Kanawha formation in West Virginia. The paleobotanic data seem to indicate the Pottsville-Allegheny line of the bituminous fields at a coaly streak about 100 feet below the conventional top of the Pottsville in the type section, the paleobotanic boundary being inclosed in the upper part of the great plexus of conglomerates. In the more northern anthracite areas the upper conglomerate has waned and the boundary as drawn on the sheets of the Geologic Atlas generally falls on or near a coal which, so far as determined paleontologically, belongs to the Brookville-Clarion coal group.

From a thickness of over 1,400 feet in the Pottsville region of the southern anthracite field, the Pottsville, in passing to the north, thins to about 850 feet in the Mahanoy region, in the western middle field, about 400 feet in the Silver Creek basin, only a few miles to the north, in the eastern middle field; 300 feet in the vicinity of Hazleton, in the same field; and from about 250 to 163 feet, averaging about 225 feet, in the northern anthracite field.[745b, 795d] In the western part of the western middle field the lower Pottsville[b] is partly represented, though the remaining coals have thinned. It is not recognized and is probably not present in the eastern middle field, where the upper part of the middle Pottsville is thought to have a thin representative. Only the upper Pottsville ("Upper Intermediate division") appears to be present, incomplete in some sections, in the northern anthracite field, where the lowest fossiliferous stratum, at points just above the Mississippian, is not older than the Sharon shale member of the bituminous districts. Pottsville coals, such as the Dunmore coal group (Mercer age in part), are few in the northern area though workable at a number of points (Boston mine, near Pittston, etc.), where they are included in a lower "red-ash group." Only the upper Pottsville is present in the small residual areas in Wyoming and Sullivan counties. At Bernice it presents not over 125 feet, missing the lower portion of the Beaver River formation; at Mehoopany, the lowest bed, a conglomerate on the red shale, is perhaps not older than the lower sandstone of the Connoquenessing member. In other words, the basal portion of the Beaver River formation ("Upper Intermediate division" of the Pottsville type section) appears not to have been deposited in portions of the overlap area north of the anthracite fields, nor locally along the Allegheny Front or in certain other parts of the bituminous regions of K 17 and K 18. The subsidence and overlap of sediments is thus seen to have been most rapid and strongly marked in the anthracite regions.

The axis of the lower Pottsville estuary doubtless extended southwestward across the eroded region to the south of the Broad Top field, which contains no Pennsylvanian older than the Beaver River formation or upper Pottsville. The early series is not seen again until, following the eastern edge of the coal field, we begin, in the Cheat Mountain region of central West Virginia, to pick up lower beds, as the present border of the Pennsylvanian gradually passes diagonally downward into the deeper portions of the smaller basin of the early deposition. Not till we reach the Pocahontas district do we meet beds as old as the lowest of the lower Pottsville in the type section of the southern anthracite field. The Pottsville expansions have been described and illustrated elsewhere by the writer.[898b]

The "Coal Measures" or post-Pottsville in the Pennsylvanian anthracite region.—The variability of intervals and the consequent difficulties of correlation of the individual members

[a] See remarks on application of the name, pp. 433–434.

[b] I. C. White [907a] has applied the name Pocahontas group to the lower part of the lower Pottsville.

between the northern anthracite region and the regions to the south have already been mentioned. Between the southern and middle fields numerous correlations have been made by the State survey of the anthracite regions, as shown on the mine maps and in the "Summary final report." Others affecting in particular the northern field have been proposed by Stevenson,[796i] who inclines to the belief that the post-Pottsville beds also thin to the north and that the deep part of the northern anthracite field in the Wilkes-Barre and Nanticoke region may contain beds younger than the topmost in the southern anthracite field. Of this there is, however, little proof. The inclusion of the Mammoth coal bed in the Allegheny formation has been indicated by the writer,[899] who is disposed to place the Allegheny-Conemaugh line as high as the Holmes coal bed in the southern areas, or as the Baltimore or Checker coal bed in the northern anthracite field. Harmonious with this is Stevenson's conclusion [796j] that the marine fossils of the Mill Creek limestone of the Second Pennsylvania Survey reports, 688 feet above the Baltimore coal bed, are as old as Conemaugh and may be older. These fossils, as reported by Heilprin[432] and Girty,[365] comprise a distinctly marine invertebrate fauna, with Chonetes, Eumicrotis, etc. Three other thin limestones occur in the interval covering 320 feet below the limestone to which the name Mill Creek was applied by the Second Pennsylvania Survey, and a black shale with a marine fauna lies about 250 feet above that limestone. The occurrence of these marine limestones in the northern anthracite field is especially interesting, as is also the apparent absence, so far as yet reported, of typical marine faunas from any horizon in the southern field. The Oliphant coal bed, the supposed equivalent of the Hillman coal bed, would seem from the paleobotanic evidence to be older than the Monongahela formation.

In the southern anthracite field the higher coals have furnished plants regarded by the writer as of Monongahela age, but no beds of Permian age have yet been recognized in the anthracite regions.

CENTRAL APPALACHIAN REGION.

General features.—To the south, in the next section of the Appalachian trough, the Pennsylvanian strip in J 17 and the southeast corner of J 16 becomes narrow gradually in West Virginia and rapidly in eastern Kentucky. We have here only the southward continuation of the great plateau (bituminous) field, which merges into the Cumberland Plateau. Except for the Frostburg-Potomac and Cheat Mountain basins, which are isolated along the eastern margin of the coal field, the separating anticlines being eroded, the eastern margin of the Pennsylvanian is fairly parallel to the general direction of the Appalachian folding. For portions of its extent the boundary is an overthrust fault, as, for example, St. Paul, Va., where the Cambrian is thrust on the Pottsville. Other important overthrusts which have caused the exposure of older beds in the interior of the field are those along Pine Mountain, in eastern Kentucky and Tennessee, and the Sequatchie Valley, in eastern Tennessee. Aside from the folds mentioned above or in the previous section the Pennsylvanian of J 17 and J 16 is relatively horizontal.

The higher formations of the Pennsylvanian continue southward from K 17 and K 18 in greatly reduced area and markedly changed character, though the general sequence of the members is essentially the same. The principal changes pertain to composition of the beds as well as to thickness.

Monongahela formation.—The Monongahela territory practically falls within a scalene triangle whose southeast and west sides roughly conform to lines drawn from Cumberland, Md., and Cambridge, Ohio, to Big Sandy River in Lawrence County, Ky. In Maryland the formation measures 240 to 270 feet;[572] it is considerably thinner on its western outcrop in Ohio and it reaches its greatest thickness—400 feet—in north-central West Virginia. It is thin in the deeper portion of the broad syncline, farthest from the old shore lines. It is notable that the limestones, which form so large a part of the formation in southwestern Pennsylvania, disappear soon after entering West Virginia, being replaced by red and green shales and sandstones. The Sewickley coal enters farther into the basin than the Pittsburg, but the Uniontown is the only one which appears to traverse the entire deeper part of the basin.[797a]

Conemaugh formation.—The Conemaugh formation has naturally a much larger area than the Monongahela and extends closer to the anticlines near the West Virginia and Maryland line. From a thickness of 700 to 800 feet in southwestern Pennsylvania it thins to the northern and western outcrops (about 300 feet in Ohio), but on the east, in one of the sections of western Maryland, it exceeds 625 feet. In the Piedmont folio [228] the equivalent of that part of the Conemaugh above the Bakerstown coal is mapped as the Fairfax formation and the equivalent of the lower Conemaugh is included in the Bayard formation. Toward the southwest the Conemaugh thins again, so that the formation is limited to a very narrow strip, hardly more than a county in width, on entering Kentucky, where it measures about 550 feet, and, though its distribution is not fully worked out, it probably does not extend southwest of Morgan County, Ky. The fossil floras of the formations show that neither the Monongahela nor the Conemaugh is now represented in all that portion of the Appalachian trough lying to the south of this district. Like the Monongahela, the Conemaugh is notable for the diminution of the calcareous matter toward the south; the red sediments increase in passing diagonally downward through the formation, which also becomes more conglomeratic toward its eastern outcrop.

Allegheny formation.—The lower limit of the Conemaugh along its southern outcrop has recently been so radically changed as the result of a revolution in the classification of the older Pennsylvanian in the southern region that only in the latest contributions by Stevenson [796g] and I. C. White [907] is it even approximately located.

The Allegheny formation, which in K 17 and K 18 approaches so near the margin of the Pennsylvanian as to be nearly everywhere indistinguishable on small-scale maps, except in the southern and western middle anthracite fields, keeps the same relative position along the western outcrop for some distance beyond Ohio River; but on the east side it retreats westward as the thicker and successively lower Pottsville strata are developed along the Pennsylvanian outcrop; so that at the Kentucky line its connected areas are confined to a short belt lying in the western half of the field, though isolated patches cap the high ridges and tallest mountain tops far to the east.

The formation measures 260 to 350 feet in western Maryland,[572] where that portion below the Middle Kittanning coal is described by Darton and Taff[228] as the Savage formation, the upper part being included in the Bayard formation. Deep-well records show it to be much thinner beneath the Monongahela area, though it approaches 300 feet in thickness at some places on its western outcrop in Ohio. Toward the south, however, it thins remarkably, so that in the Kenova quadrangle, in northeastern Kentucky, it falls under 170 feet, though several of its limestones are there present. Remarkably enough, in consonance with the downward diagonal trend of the red material noted in the overlying formations, we find records[635a, 796d] of red shales in the upper part of the Allegheny at several points on the southeastern and southwestern borders of the basin. This feature is, however, attributed by I. C. White [907i] to weathering.

Formerly it was supposed that the Allegheny formation was very much thickened to the southeast and included what had been described [127] as the Kanawha formation, which attains a thickness of over 1,200 feet in southern West Virginia. A later review of the stratigraphy by Stevenson [795, 796a] more than confirmed the very conservative changes first proposed by the writer [896] after the study of the fossil plants. Subsequent conclusions reached as the paleobotanic studies progressed have been met by the results of the stratigraphic work of the State Survey, so that the classification given by I. C. White in a recent report of the West Virginia Geological Survey is in nearly all important points in agreement with the preliminary correlations drawn by the present writer. The Stockton coal, the topmost coal of the Kanawha formation, which was previously [906a] placed in the Upper Freeport position and regarded as the topmost bed of the Allegheny, is now put at a horizon beneath that of the Homewood sandstone member, being regarded as representing an Upper Mercer horizon. Similarly the "Roaring Creek" sandstone member, so well developed in the Tygart Valley and in the Buckhannon quadrangle, though formerly regarded as "Upper Freeport," is now placed by Stevenson and I. C. White at the level of the Homewood sandstone, the top member of the Pottsville, a correlation in which the writer concurs. It is thus seen that the entire series which in the earlier literature on the Kanawha region of West Virginia was described as constituting the Allegheny, is now recognized as belonging to the upper Pottsville,[a] together with a part, at least, of the sandstone which in that region was formerly supposed to be the Mahoning. The cautions as to the literature descriptive of the Allegheny in the southern region apply equally to that of the Pottsville, as the terranes taken from the Allegheny have been added to the Pottsville, which has accordingly been newly grouped.

The falsity of the former classification was discovered on paleobotanic evidence when the first of the quadrangles in central and southern West Virginia were mapped in detail; but the isolation of the quadrangles mapped and the very early stage of the paleobotanic studies made it impracticable at that time fully and definitely to correct the errors, hence a local nomenclature was introduced pending the time when the boundaries of the divisions composing the standard classification as used in the northern region should be definitely determined. In the Buckhannon quadrangle,[810] one of the first of these and one involving great changes in the thickness and delimitations of formations, the Pennsylvanian was mapped, largely on lithologic grounds, as follows: Braxton formation, 700+ feet [including all the strata above the conglomerate 175 feet above the base of the Allegheny]; Upshur sandstone, 350 to 500 feet [representing the Allegheny and the "Roaring Creek" sandstone (equivalent to the Homewood member of the Pottsville)]; Pugh formation, 300 to 450 feet [representing all of the upper Pottsville between the Homewood member and the lower group of conglomerates]; and Pickens sandstone, 400 to 500 feet [the lower group of conglomerates, with included coals, of the section which probably extends at the south into the top of the lower Pottsville].

Owing to the lack of paleontologic as well as of local stratigraphic data, the areal extent of the Allegheny to the southwest is not known. The Vanport limestone member, however, is stated by Stevenson [795f] to be present in the northwest corner of Breathitt County, Ky. It is probable that the formation is represented only by small isolated patches on the highest lands toward the west side of the basin, and, possibly, on some of the highest summits in the eastern synclines, for although no paleontologic data showing the presence of the Allegheny are known south of Breathitt County, the fossil plants found in the Harlan sandstone of southwestern Virginia (Estillville quadrangle), the Bryson formation of the Cumberland basin in eastern Kentucky, and the Anderson sandstone in the high mountains of Campbell and Anderson counties, northern Tennessee, are said to represent stages so high in the Pottsville as, perhaps, to justify the inference that the upper parts of these formations are of Allegheny age. This will be more fully noted in the discussion of the Pottsville.

No Paleozoic rocks of Allegheny or later age now remain in the Appalachian trough south of northern Tennessee. The evidence of fossil plants shows that all the terranes exposed south of the Briceville quadrangle are of Pottsville age.

Pottsville group.—In K 17 and K 18 the beds of the Pottsville include only the overlapping upper Pottsville, or Beaver River formation, except in the anthracite regions, where in passing from the northern anthracite field into the southern anthracite field the older and deeper Pottsville of the early Pottsville estuary are encountered. The upper Pottsville marks the later great invasion of the Pottsville sea.[898a] Other invasions occurred in both early and middle Pottsville time. The region north of a line drawn from Keyser, W. Va., to Ironton, Ohio, lies wholly within this area of upper Pottsville encroachment, which, in fact, extends somewhat irregularly for some distance to the east of that line. It is interesting to note that before the close of Pennsylvanian time the axis of the great basin seems to have shifted over into the invaded region.

[a] It is only in two publications—Stevenson, J. J., Carboniferous of the Appalachian Basin: Bull. Geol. Soc. America, vol. 17, p. 70 (note final correlations given under "Errors" in the reprint of this paper and others of the same series, 1907, p. 577), and White, I. C., Geol. Survey West Virginia, vol. 2 (A), 1908—that the new classification is applied in the stratigraphic description of the coal field.

In crossing the coal field in the region of the upper Pottsville (Beaver River formation) overlap, we find thicknesses of 325 to 380 feet in Maryland;[572] 245 feet on the Laurel Hill anticline, and about 200 feet on the Chestnut Ridge anticline, in Preston County, W. Va.; and less than 200 feet in many of the bore holes farther west in that State; while along the western margin in Ohio and south to Ironton the Pottsville generally varies between 225 and 275 feet. All this is upper Pottsville. The reduced thickness of the upper Pottsville along the Allegheny Front in Cambria and Blair counties, Pa., and along the Allegheny Valley in the Foxburg and Kittanning quadrangles, is due largely to the absence of the lower member, the Sharon conglomerate, from these areas. The study of the region of upper Pottsville overlap reveals the existence of several low northeast-southwest barriers or slightly elevated areas between which there were basins containing the Sharon conglomerate member and the Sharon shale member.

The first representative of older rocks (middle Pottsville) met in passing southward along the eastern margin of the bituminous coal fields is in the southeast corner of the Piedmont quadrangle, where, in the scarp of the Allegheny Front, the Blackwater formation, which includes all the Pottsville rocks of that area, measures 645 feet. Here we appear to have a part of the middle Pottsville, though in the northern and western portions of the same quadrangle only the upper Pottsville is present and is of the thickness noted. A considerable thickness of middle Pottsville, apparently underlain by some older or lower Pottsville, is described by I. C. White [907e] as occurring on Cheat Mountain and in the region to the southwest. In the Buckhannon quadrangle the middle Pottsville is included in the Pickens sandstone, though the section here does not extend as low as in Cheat Mountain, to the east. The representatives of the middle and lower Pottsville in this part of the eastern border of the coal field are very much thinner than they are farther south, as will be explained in the description of these divisions in the New River region of West Virginia.

A series of quadrangles studied by Campbell and his assistants, extending from the Pocahontas and New River coal region northwestward to and beyond Ohio River at Huntington, W. Va., embraces a complete section of the Pottsville from the deep early basin of the lower Pottsville out to the region of upper Pottsville overlap of the northern type. This section, which lies nearly midway of the Appalachian coal field, is taken by the writer as the typical or reference section of the central Appalachian region, though the divisions do not here attain their maximum thickness.

In the Pocahontas quadrangle,[123] the first in this section to be mapped by the Federal Survey, occur the following formations, in descending order:

Sewell formation: Shale, sandstones, and coals, 100+ feet, incomplete.

Raleigh sandstone: Conglomerate sandstone, 80 feet [invasion terrane].

Quinnimont shale: Shale, sandstones, and coals, 300 feet, overlying the Quinnimont [equivalent to the Fire Creek] coal.

Clark formation: Sandstones, some shale, and coals, 380 feet, overlying the Pocahontas, or No. 3 coal.

Pocahontas formation: Shale, sandstones, and coals, 360 feet, extending down to the red shales of the Mississippian, which are of Chester age.

These formations are generally thinner in the Raleigh quadrangle, to the north, and are correspondingly thicker in the region along the border of the field to the southwest.

The Raleigh, Charleston, and Huntington quadrangles, which present a cross section of the Pennsylvanian basin from the Allegheny Front in the region of the New River coal field to the vicinity of Ironton, Ohio, contain the following formations, the thickness of which is greatest to the southeast and least to the northwest.

Pennsylvanian formations in the Raleigh, Charleston, and Huntington quadrangles.

[From folios of the Geologic Atlas of the United States, by M. R. Campbell.]

<table>
<tr><th colspan="2">Raleigh quadrangle, West Virginia (folio 77, 1902).</th><th>Charleston quadrangle, West Virginia (folio 72, 1901).</th><th>Huntington quadrangle, West Virginia–Ohio (folio 69, 1900).</th></tr>
<tr><td colspan="2">[Eroded.]</td><td>Braxton formation, 800+ feet (chiefly red and green shales and green sandstone, with beds of coarse sandstone and conglomerate at intervals).</td><td>Braxton formation, 800+ feet (chiefly red and green shales and green sandstone, with beds of coarse sandstone and conglomerate at intervals).</td></tr>
<tr><td colspan="2">Charleston sandstone, 500+ feet (coarse sandstone with several thick seams of coal). [Partly eroded. Extends down to the "Black Flint."]</td><td>Charleston sandstone, 250–400 feet (coarse sandstone or conglomerate, with occasional bands of shale and beds of coal).</td><td>Charleston sandstone, 200–300 feet (coarse sandstone or conglomerate, with occasional bands of shale and beds of coal).</td></tr>
<tr><td colspan="2">Kanawha formation, 1,000± feet (sandy and argillaceous shales and soft sandstone with numerous beds of coal).</td><td>Kanawha formation, 650–1,000 feet (shale and sandstone with many coal beds).</td><td>Kanawha formation, 400+ feet (shale and sandstone with many coal seams).</td></tr>
<tr><td colspan="2">Sewell formation, 600–625 feet (sandy and argillaceous shale and sandstone):
Nuttall sandstone lentil, 0–200 feet (massive sandstone or couglomerate). [Equivalent to the Fayette sandstone.]
Harvey conglomerate lentil, 0–50 feet (massive conglomerate).
Guyandot sandstone lentil, 0–100 feet (coarse sandstone or conglomerate).</td><td rowspan="2">Sewell formation, 100+ feet (sandstone, conglomerate, and shale, the latter containing several beds of workable coal).
[290 feet to Mississippian at Winfield.]</td><td rowspan="4">[Older formations lacking over part of quadrangle.]</td></tr>
<tr><td colspan="2">Raleigh sandstone, 75–150 feet (coarse sandstone or massive conglomerate).</td></tr>
<tr><td colspan="2">Quinnimont shale, at north 180–200 feet; at south 200–225 feet (sandy shale; Beckley coal at top; Quinnimont coal at base).</td><td>[Probably lacking.]</td></tr>
<tr><td>At north.
Thurmond formation, 450–550 feet (sandstone and shale).</td><td>At south.
Clark formation, 350–375 feet.
Pocahontas formation, 250–325 feet.</td><td>[Lacking.]</td></tr>
</table>

The Pottsville formations up to and including the Raleigh sandstone compose the lower Pottsville as here treated and are collectively correlated by both the writer and Stevenson with the Lee formation of the quadrangles farther south, though the writer is inclined to believe that in some sections the lower beds of the Sewell formation may have been included in the Lee. In general, however, the correlation is accepted, and the term Lee is preferred as a geographic term to designate the lower Pottsville, that is, the beds extending to the top of the Raleigh sandstone. Paleobotanically these beds are correlated [895f] with the "Lower Lykens division" and the "Lower Intermediate division" of the Pottsville type section in the anthracite region (see p. 440), the "Lower Lykens division," including Lykens coal No. 5 and underlying beds, being correlated with the Pocahontas formation or possibly the whole Thurmond formation, and the higher zone, including the Lykens No. 4 coal, being referred to the Quinnimont formation.

The Sewell formation constitutes the middle Pottsville and paleobotanically corresponds approximately to the "Upper Lykens division" of the type section of the anthracite region (see p. 440), which contains the floras characteristic of Lykens coals Nos. 2 and 3. It is made by Campbell, Stevenson, and I. C. White to include at the top the Nuttall conglomerate member (equivalent to the Fayette sandstone), which is correlated with the Sharon conglomerate member by the two geologists last named. The present writer, regarding the Nuttall as the initial sea-expansion member of the upper Pottsville subcycle of deposition, would prefer to separate it from the Sewell; and, while provisionally correlating it with the Sharon conglomerate member,[898d] would restore the latter to its old place in the base of the Beaver River formation, thus conforming to the early establishment of that division by Chance [135] and D'Invilliers.[285] Chance shows that the initial omission of the Sharon conglomerate member in the definition given by Lesley in the preface to I. C. White's Report Q (p. 65) was due to the misapprehension that the sandstone was Mississippian.

The Kanawha formation is upper Pottsville and on the paleobotanic evidence corresponds roughly to the "Upper Intermediate division" of the type section of the anthracite region. (See p. 441.) Together with the underlying Nuttall sandstone member and the sandstone which is just above the overlying black flint and which corresponds to the Homewood sandstone member, it is correlated by the writer with the Beaver River formation as already described for the northern strip (p. 441).

The Charleston sandstone covers the entire Allegheny, here about 120 feet in thickness,[907h] together with a portion of the Conemaugh and the heavy sandstone ("Roaring Creek" or Homewood) at the top of the upper Pottsville. Most of the Allegheny coals are thin or lacking in the Charleston and Huntington quadrangles.

The Braxton formation represents the balance of the Conemaugh with so much (a small thickness) of the Monongahela as caps a few summits in the northwestern portion of the area.

The remarkable reduction in the thickness of the Pottsville toward the northwest is due both to thinning of the divisions and to the disappearance of the older terranes as the section passes beyond the older and smaller early basin. At the same time the absence of paleontologic material from the drill holes makes it more difficult to determine the precise limits of the several divisions. The lower Pottsville, which appears to attain a thickness of over 1,200 feet in the vicinity of Norton, Va., in the Estillville quadrangle, is said to measure 1,080 feet on Barrenshe Creek, McDowell County, W. Va., in the Tazewell quadrangle; 815 feet at Wolf Gap,[907b] Wyoming County, W. Va.; and 736 feet at Grand View, in the Raleigh quadrangle. Apparently it was not deposited in the Charleston quadrangle. It is less difficult, however, to distinguish the upper Pottsville in many of the sections in which the two lower divisions are not clearly differentiated. Thus, at Powelton, Fayette County, W. Va., the Kanawha is reported by I. C. White [907g] at 1,295 feet and the middle and lower Pottsville at 812 feet; at Hernshaw, a few miles south of Charleston, the upper is 890 feet and the middle and lower 787 feet; at Charleston the upper is 600 feet and the middle and lower 660 feet; 5 miles farther west the upper measures 490 feet and the two lower divisions 480 feet; at Winfield, in the same quadrangle, the upper is 365 feet and the middle and lower combined 275 feet; whereas in the well at Letart, to the northwest, on Ohio River, the entire Pottsville measures but 360 feet, of which the lower 60 feet is perhaps referable to the middle Pottsville. The direction of most rapid thickening is somewhat east of south. At Naugatuck, on Tug River, in Mingo County, W. Va., the upper Kanawha is said by I. C. White [907f] to measure 2,116 feet, a thickness that is possibly equaled in the Estillville quadrangle.

The determination of the northernmost outcrop of beds of middle Pottsville age along the western border of the coal field is subject to differences of opinion. Stevenson [795e] interprets the Jackson shaft coal, in Jackson County, Ohio, as just beneath the Sharon conglomerate member, and, placing the Sciotoville fire clays and coal at the same horizon, is inclined to regard the highest of the middle Pottsville terranes as a thin veneer extending as far north, at least, as Ohio River, with local developments of an underlying conglomerate (vicinity of Jackson, Ohio) which he correlates with Campbell's Rockcastle conglomerate lentil. But in the Kenova quadrangle the writer does not recognize pre-Sharon sandstones farther north than the southeast corner of the quadrangle. It is certain, however, that the middle Pottsville beds outcrop at the western border of the coal field not far south of the Kenova quadrangle and that successively lower beds are encountered in passing south through Kentucky; for in the folio on the Richmond quadrangle Campbell reports a thickness of 250 to 300 feet of Pottsville [part of which is erroneously included as Lee] below a 90-foot conglomerate (Corbin conglomerate lentil), which is correlated by Stevenson with the Sharon conglomerate member. This underlying series of beds includes the Rockcastle conglomerate member, a transgression deposit, to which reference will again be made.

In the London quadrangle, next south of the Richmond, including portions of Rockcastle, Jackson, Laurel, and Pulaski counties, Ky., Campbell finds beneath the Corbin 500 to 1,000 feet of shales and sandstones that he maps as Lee, with the Rockcastle conglomerate member (0–150 feet), which probably forms the top of the true Lee, near the middle of the thick sections.[a] It is thus shown that in these quadrangles the western border of the coal field has been eroded far enough eastward to cut into the region of the middle Pottsville encroachment of the sea. The Rockcastle appears to represent the western extension of the Raleigh sandstone of southern West Virginia. From the London region southward erosion seems to have narrowed the field so that it lies wholly within the limits of the Raleigh-Rockcastle water level—that is, within the lower Pottsville basin. In the southern part of the Standingstone quadrangle, Tennessee, which lies in the second tier of quadrangles to the south of the London quadrangle, the Bonair conglomerate member, a sandstone over 200 feet below the Rockcastle conglomerate member (top of the lower Pottsville in Tennessee), outcrops along the western border. Farther south the Sewanee conglomerate of Safford and Killebrew is found to lie above the Mississippian and at some places nearly in contact with it.[898c] This conglomerate, long supposed to be continuous with the Bonair conglomerate member, has been shown by Butts to lie about 200 feet below the Bonair in the Crossville special quadrangle, Tennessee. The "Sewanee," which forms the top of Hayes's Lookout sandstone, constitutes an important early invasion or trangression member in the old Pottsville basin.

In the northern part of the Standingstone quadrangle the Rockcastle conglomerate member, 100 to 200 feet thick, is underlain by 100 to 300 feet of sandstone and shales belonging to the Walden portion of the Lee. In the south half of the quadrangle the Bonair conglomerate member, 125 feet below the Rockcastle and 100 to 200 feet thick, locally rests on the eroded Mississippian. The Rockcastle, which in this western region originates at the north as a remarkable gravel wash filling a river valley but a few miles in width, is blended toward the south with a sandstone of wide extent, which, according to Stevenson, is recognizable in nearly all the sufficiently complete sections of Tennessee and Kentucky.

From the Standingstone quadrangle the coal field is mapped in consecutive quadrangles extending across the coal field from west to east near the southern boundary line of J 16 and also reaching southward to the Alabama line.

Before referring again to the thick eastern sections the western border will be briefly reviewed. In the southern and eastern of these border quadrangles, whose study by Hayes antedates Campbell's work, just cited, the important sandstone designated by Safford and Killebrew as the Main Sewanee conglomerate was made the top member of the Lookout sandstone. Toward the northeast the Bonair conglomerate member, which for a time was, on paleobotanic grounds, considered possibly as young as the Raleigh, was made the top of the Lookout. However, as already noted, the Bonair is, according to Butts, the second sandstone above the Sewanee conglomerate of Safford and Killebrew, and the Sewanee is more than 600 feet below the top of the Lee formation in the Briceville quadrangle and the corresponding sandstone in the Kingston quadrangle. Accordingly the Lookout sandstone, which ends in the Sewanee conglomerate, represents but about one-half (the lower) of the Lee in this district. The beds above the Look-

[a] The Corbin conglomerate member (0–150 feet) is overlain by 500 feet of the Breathitt formation, which is said by Stevenson to extend a little above the limits of the upper Pottsville.

out in the southern quadrangles are mapped as Walden sandstone, the lower portion of which, including the Rockcastle conglomerate member, is accordingly represented in the Lee of the eastern quadrangles, as has just been shown.

In the McMinnville quadrangle the Walden is reported as 250 feet thick, not thick enough to reach the middle Pottsville; while the Lookout, 200 to 300 feet thick, is here extended to cover the Bonair. Coals are present at the base and just beneath the Bonair ledge. In the Pikeville quadrangle, next eastward, 400 to 650 feet of Walden strata, but slightly surmounting the Rockcastle, remain. These beds include several coals, the most important, near the base, being the Sewanee and Soddy coals. The Lookout, which attains a thickness of 650 feet, has several coals distributed through its section.[636] Walden beds, to a thickness of 500 feet, remain in the Sewanee quadrangle, which reaches nearly to the Alabama line. In this quadrangle the Lookout expands from 120 feet on the west to 510 feet on the east. The Upper Sewanee conglomerate of Safford, about 250 feet above his Main Sewanee conglomerate, in the Sewanee quadrangle, has been referred by Stevenson to the Rockcastle horizon.

Even more than in the northern regions the terranes of the Pottsville of the southern Appalachian area are highly variable, both in character and in thickness, and are in some places lacking, so that it is difficult to follow many of the horizons, even when the work is continuous. Thin limestones or calcareous shales are present, especially in the lower Kanawha, and sediments with marine Mollusca are found here and there in each of the major divisions, but none of the marine faunas has yet been followed over a great area in the central and southern sections of the coal fields. For these reasons it was found most expedient by the United States Geological Survey in mapping the generally isolated areas of the southern Appalachian region to use for the Pennsylvanian subdivisions local formational names, which were applied to divisions differing as to lithologic characters or, in many cases, arbitrarily segregated for convenience in mapping. The detailed sections of the early publications, which unfortunately are very much scattered and which are generally either deficient in or erroneous as to broader correlations, have been well digested and thoroughly reviewed in a correlative way by Stevenson, who cites nearly all the fragmentary literature.[a] It may be noted that in most of the literature antedating the publication of the Federal folios the upper beds of the sections, though of Pottsville age, are frequently referred to horizons as high as the Mahoning sandstone member of the Conemaugh formation or even the Monongahela formation. The data now available are not sufficient to correlate with accuracy the subdivisions described in the detached areas covered by the folios, but the further study of the paleobotanic material already assembled will doubtless settle many of the points now in question.

In the Tazewell quadrangle, to the west of the Pocahontas, several of the key rocks of the Raleigh quadrangle are missing. Campbell describes the following formations:

Tellowa formation, 500 feet (incomplete), sandstones, shales, and coals.
Sequoyah formation, 450 feet, shales and sandstones with coals.
Dotson sandstone, 120 feet of sandstone overlying 60 feet of shales.
Bearwallow formation, 60 feet, conglomerate.
Dismal formation, 490 feet, shales, coals, and sandstone, including a conglomerate lentil.
Raleigh sandstone, 100 feet, conglomeratic.
Welch formation, 700 feet, shales, sandstones, and numerous coals.
Pocahontas formation, 360 feet, shales, sandstones, and coals, up to coal "No. 3."

[a] For eastern Kentucky see Crandall, A. R., Eastern Kentucky coal field: Geol. Survey Kentucky, vol. C, 1884; Moore, P. M., Geol. Survey Kentucky, new ser., vol. 1; Lesley, James, Geol. Survey Kentucky, vol. 4, 1861; Crandall, A. R., Geol. Survey Kentucky, new ser., vol. 6; Hodge, J. M., Preliminary reports on the southeast Kentucky coal field, 1887; Sullivan, G. M., Geology of parts of Jackson and Rockcastle counties, 1891; Loughridge, R. H., Geology of Clinton County, 1890; Norwood, C. J., Ninth Ann. Rept. Inspector of Mines, 1893, and Tenth Rept., 1894.

For Tennessee see Safford, J. M., Geology of Tennessee, 1869; Bradley, F. H., in Killebrew and Safford, Resources of Tennessee, 1874.

For Virginia see Rogers, W. B., Geology of the Virginias, and other State reports; Watson, T. L., Mineral resources of Virginia; Stevenson, J. J., Geological reconnaissance of parts of Lee, Wise, Scott, and Washington counties, Va.: Proc. Am. Philos. Soc., vol. 19, 1881; Hodge, J. M., The Big Stone Gap coal field: Trans. Am. Inst. Min. Eng., 1893; White, I. C., Geol. Survey West Virginia, vols. 2 and 2A; and Stone, R. W., Bull. U. S. Geol. Survey No. 316, 1907, pp. 42, 55, 68.

Of these the last three are lower Pottsville (equivalent to the Lee); and the Dotson sandstone is correlated by both I. C. White and the present writer with the Nuttall sandstone. The 60 feet of shales in the lower part of the Dotson, together with the Bearwallow and Dismal, therefore represent the Sewell, that is, the middle Pottsville. The Dotson sandstone, supposed to correspond to the Sharon conglomerate member, goes, along with the Sequoyah and Tellowa, which represent the Kanawha, into the upper Pottsville, the Sequoyah being in the lower half of that formation.

In the two contiguous quadrangles, Bristol and Estillville, lying in the Big Stone Gap field, the Pennsylvanian syncline between the Pine Mountain fault and the eastern edge of the coal field contains, according to Campbell, the following:

Harlan sandstone, 880 feet, sandstones, conglomerates and coals. [Not present in the Bristol quadrangle.]

Wise formation, 1,260 feet, shales, sandstones, and coals, with several thin marine limestones. [Only 100 feet present in Bristol quadrangle, the rest of the formation being eroded away.]

Gladeville sandstone, 100–120 feet, conglomeratic sandstones, between coals.

Norton formation, 1,200–1,270 feet, shales, sandstones, and important coals.

Lee formation, 1,240–1,530 feet, sandstones, conglomerates, shales, and few coals.

In this region, and on to the Tennessee line, the coals of the lower Pottsville are so unimportant and the sandstones so dominant that all are mapped in one formation, the Lee, which includes everything to the top of the Raleigh sandstone of the Tazewell quadrangle.[a]

Stevenson[795l] places the horizon of the Sharon conglomerate member and of its supposed southern representative, the Nuttall sandstone, in the Norton formation, at 800 or 900 feet below the Gladeville sandstone, the latter being identified by him as the sandstone just under the Upper Mercer coal on the west side of the coal field and therefore near the top of the upper Pottsville. On the other hand, the writer would place the Gladeville at or very little above the horizon of the Nuttall sandstone, making the Norton formation essentially equivalent to the Sewell—that is, the middle Pottsville—while the Gladeville itself, followed by the Wise and over 300 feet of the Harlan, which are found to contain Kanawha floras, are regarded by him as upper Pottsville. The horizon of the Homewood sandstone member, the top member of the upper Pottsville, is not yet fixed in the Harlan sandstone. The topmost beds in the "Flatwoods" of the region near Elkhorn, Ky., are put by the writer in the Harlan, the Flatwoods coal itself being of Kanawha age instead of representing the Pittsburg bed, as was formerly believed.

The greater part of the Cumberland field, to the southwest of the Big Stone Gap coal field, has been studied by Ashley and Glenn,[41] whose work unfortunately fails to join with completeness Campbell's work, just cited, or Keith's, farther south. The formations described are as follows, those above the Lee being differentiated so as most satisfactorily to map the coal groups:

Bryson formation, 300 feet, sandstones, shales, and thin coals above Red Spring coal.

Hignite formation, 440–450 feet, sandstones, shales, and coals, down to lower Hignite coal.

Catron formation, 280–450 feet, shales, sandstones, local conglomerates, and numerous coals above Poplar Lick coal.

Mingo formation, 950 feet, shales, sandstones, and good coals above the Bennett's Fork coal.

Hance formation, 600 feet, shales, sandstones, and numerous thin coals.

Lee sandstone, 1,200–1,500 feet conglomerates and sandstones, with thin shales and coals.

The lower Pottsville (Lee) appears to continue in unity from the Estillville quadrangle; the Hance and about half of the Mingo represent the Sewell, the Gladeville being provisionally placed by both Ashley and White [41b,b] in the region of the Slater and Puckett sandstone members, a little above the middle of the Mingo formation. The Catron and Hignite formations, which contain Kanawha floras, together probably with the upper part of the Mingo and certainly with the basal portion of the Bryson, are included by the writer in the upper Pottsville. The Bryson which, capping the highest knobs and ridges is present only in the deepest synclines, is there equal in part to the Harlan of the Big Stone Gap region.

[a] For information concerning the intervening area see Stone, R. W., Bull. U. S. Geol. Survey No. 316, 1907, pp. 42, 55; Bull. 348, 1908.

[b] See same paper also for correlations with other regions.

The area in Tennessee mapped by Keith begins not far beyond the region mentioned and joins, on the south, the district studied by Hayes. It includes the Briceville and Wartburg quadrangles,[a] which present a complete cross section of the coal field. The formations, distinguished on lithologic grounds, are as follows:

Pennsylvanian formations in Briceville and Wartburg quadrangles, Tennessee.

	Briceville.	Wartburg.
	Feet.	*Feet.*
Anderson sandstone: Shales, sandstones, conglomerates, and coals. [Eroded.]	1,000+	500+
Scott shale: Sandy shales, sandstones, and coals	650–500	600–500
Wartburg sandstone: Sandstones, shales, and coals	650–500	600–500
Briceville shale: Shales, sandstones, and coals	650–250	400–250
Lee formation: Sandstones, conglomerates, and thin coals	1,500–500	900–375

It is suspected that the maximum Lee here may extend one sandstone higher than in the regions to the northeast, though the Big Creek Gap outcrop of the Lee, near the eastern margin of the Briceville quadrangle, is given by the writer [41a] as about 1,250 feet thick. In general, however, the Lee is doubtless essentially equivalent to the division under the same name farther east, the variations being probably local. The inclusion of middle Pottsville terranes in the "Lee" of the Richmond and London quadrangles in Kentucky has already been mentioned. The Sewell age of the Briceville shale is agreed on, and the horizon of the Corbin (equivalent to the Nuttall sandstone) is placed by Stevenson [795h] in the bottom of the Wartburg sandstone. The Scott shale, together with the upper part of the Wartburg and the lower part of the Anderson sandstone are correlated, on the paleobotanic evidence, with the Kanawha, and therefore placed in the upper Pottsville. The lack of prospecting and exposures of the soft beds on the tops of the mountains have rendered the acquisition of fossil plants very difficult, and the Allegheny-Pottsville boundary is still undetermined. However, the Anderson of these quadrangles, the Bryson of the Cumberland basin, and the Harlan of the Big Stone Gap field are paleobotanically shown to be in part contemporaneous, each seeming to reach up into the post-Pottsville. It is probable that the highest beds of these formations, occurring only on the top of a few of the highest mountains of these regions and, in Tennessee, limited to these two quadrangles, comprise the last and only Allegheny Pennsylvanian remaining in all this southern region of the coal fields.

For comparison the section given by Campbell for the southern half of the Standingstone quadrangle, west of the Wartburg, is repeated:

Lee formation:
- Rockcastle conglomerate lentil; 100–180 feet, sandstone and conglomerate.
- Shale and sandstone, 125 feet.
- Bonair conglomerate lentil, 100–200 feet, conglomerate, sandstone, with inclosed or underlying coals, resting on the Mississippian.

The total of these divisions, about 375 feet[b] at the western outcrop in this quadrangle, agrees with the western outcrop measurements of the eastern Lee, given by Keith as 375 feet in the Wartburg quadrangle to the south. Stevenson's correlation of Campbell's Rockcastle of the western region with the top conglomerate of the true Lee as mapped along the eastern margin of the coal field appears to be well established.

The Sewanee conglomerate of Safford and Killebrew, which along the western margin of the coal field in this region, this being the region of "Sewanee" transgression, locally rests

[a] The Cumberland basin terminates on the southwest in a faulted cross anticline, along Fork Mountain, in the Briceville quadrangle.

[b] The total, including the Rockcastle and underlying Pennsylvanian beds in the northern half of the Standingstone quadrangle, is given by Campbell as 200 to 400 feet.

almost directly on the Mississippian, or is even absent, is, over most of the area, continuous as the upper member of the Lookout of Hayes.

The section of the Tennessee coal field lying south of the Briceville tier of quadrangles is included in the area mapped by Hayes at an early date in the work of the United States Geological Survey and is practically covered by the Kingston, Pikeville, McMinnville, Chattanooga, and Sewanee quadrangles. The measurements of the Pottsville formations are as follows, from east to west:

Thickness, in feet, of Pottsville formations in southeastern Tennessee.

	Kingston quadrangle.	Chattanooga quadrangle.	Pikeville quadrangle.	Sewanee quadrangle.	McMinnville quadrangle.
Walden sandstone: Shales, sandstones, conglomerates, and numerous coals, the most important being two in the first 100 feet above the base of the formation.	1,300+	600–700+ (with two or more conglomerates).	400–650+	300–500+	250+
Lookout sandstone: Sandstones, conglomerates, and workable coals; the Main Sewanee conglomerate of Safford at the top.	260–510 (with coals at various points below the top conglomerate member).	450–550	90–650 (made to include the Bonair conglomerate member in northwest corner of quadrangle).	120–510	200–350

Some uncertainty exists as to the identification of Safford and Killebrew's Sewanee conglomerate in the vicinity of Chattanooga. Stevenson,[795g] reviewing the details published by Safford [687b] and Colton,[555] concludes that the top of that terrane is 215 feet higher at the Whiteside (old Etna) mines, 235 feet higher at Daisy, and 234 feet higher at Rathbun than the position assigned it by Hayes at these points, though at Graysville and other points to the northeast in the Kingston quadrangle, there is agreement. The Upper Sewanee conglomerate of Safford, in the Walden 240 feet above his Main Sewanee conglomerate (long regarded as equivalent to the Bonair) at Tracy City, in the Sewanee quadrangle, is questionably correlated by Stevenson with the Rockcastle, the top of the Lee, and regarded as probably equivalent to the Raleigh. The flora of the Sewanee coal, about 50 feet above the Lookout at Tracy City, is somewhat like that of the Sewell coal in West Virginia and was therefore made the basis of one of the writer's earliest preliminary correlations in the southern Appalachian region, the underlying conglomerate being then correlated by him with the Raleigh. However, from his later paleobotanic and stratigraphic work it appears that if the sandstone at the top of the Lookout in the Kingston quadrangle is correctly identified with the "Main Sewanee conglomerate" as developed at Tracy City, as appears to be true, a thickness of over 600 feet intervenes between the top of the Lookout and the top of Keith's Lee in the Emory Gap region of the Briceville and Kingston quadrangles, where the upper massive Rockcastle conglomerate member, 100 feet thick, about 500 feet above the "Sewanee," is the same as Safford's and Killebrew's Emory sandstone,[690] forming the top of the Lee in Emory Gap, near the south border of the Briceville quadrangle.

The correlation as Corbin (equivalent to Nuttall) by Stevenson of a conglomerate member only 100 feet above the supposed Rockcastle conglomerate member in the Pikeville quadrangle would seem to assume a too rapid thinning of the middle Pottsville in passing from the Briceville quadrangle across to Clifty Creek.

In the Kingston and Chattanooga quadrangles the lower Pottsville seems neither to expand so rapidly eastward nor to exhibit so great a thickness as is found in the eastern basins of Virginia and Alabama.

SOUTHERN APPALACHIAN REGION.

The southern portion of the Appalachian coal field falls in the geographic unit I 16, and lies mostly in Alabama, though it cuts the northwest corner of Georgia. At the northern line, opposite Chattanooga, the residual area of the Pennsylvanian is less than 30 miles wide. From this it expands to a width of 85 miles along its southern exposure. On the east, where the longitudinal folding, locally accompanied by overthrusting, is stronger, the coal field is gashed by several anticlinal valleys, while farther east several synclinal areas are wholly detached. The three most important of the latter are the highly elevated Lookout Mountain syncline, extending south from Chattanooga; the deeply set Coosa field, a complex synclinorium south of Lookout Mountain, lying farthest east of the three; and the Cahaba syncline, ranging through nearly the same latitude, about midway between the Coosa and the main Warrior field on the west. Overthrust faulting, not uncommon along the eastern margins of the synclines, is especially notable along the eastern border of the Cahaba field and the Warrior field south of Birmingham where Cambrian strata are thrust on beds of the middle Pottsville. The Walden Plateau east of the Sequatchie Valley, extends into Alabama as Raccoon Mountain, and the Cumberland Plateau, continuing as a plateau though ruptured by several anticlines, is called Sand Mountain in northern Alabama. Subordinate folds produce oblique lobes or branches of the eastern synclines.

In passing westward the folds die out and the beds rise gradually northwestward to fringe the main field with irregular lobes and isolated patches, comparable to those along the western and northern borders of the great Appalachian basin; but to the south and west in Alabama the Pennsylvanian disappears beneath a Cretaceous mantle in the great Gulf embayment. How far the coal measures extend beneath this southward-thickening cover has not been ascertained. It is nearly certain that on the west they blend with the Pennsylvanian of the eastern interior lobe. It is probable that at the stage of Kanawha (upper Pottsville) encroachment union with that lobe occurred in Tennessee or perhaps in Kentucky.

We have seen that in southern Tennessee the lower Pottsville, perhaps slightly thinner than it is farther north, appears not to expand eastward as rapidly as the middle Pottsville, but in Alabama we find a marked southeastern expansion of the lower as well as of the middle division.

The general characters of the Pennsylvanian in the greatly elevated and much eroded northern region are shown in the Ringgold and Stevenson quadrangles, geologically mapped by Hayes, and in the Gadsden quadrangle, which, lying southwest of the Stevenson, cuts three of the eastern synclines, including the south end of Lookout Mountain.

Thickness, in feet, of Pottsville formations in northwestern Georgia and northeastern Alabama.

	Ringgold quadrangle.	Stevenson quadrangle.	Gadsden quadrangle.
Walden sandstone: Coarse sandstones, sandy shales, good coals, and clays......	930 [eroded]	500+	500+
Lookout sandstone: Sandstones, conglomerates, sandy shales, and interbedded coals; has heavy cliff, usually conglomerate, at top........................	200–550	300–400	60–570

It will be noted that the Gadsden quadrangle is nearly "in strike" with the Ringgold, which explains the similarity in the thickness of the Lookout. The highest fossils collected in the Lookout Mountain syncline, from beds reported as about 600 feet above the Lookout, suggest the basal horizon of the middle Pottsville. It is therefore very doubtful if any upper Pottsville is present in these quadrangles, which contain the highest beds in this northern section of the State.[a]

[a] For detailed sections outside of the folios cited, see McCallie, S. M., The coal deposits of Georgia: Geol. Survey Georgia, 1906; McCalley, H. B., Coal measures of the Plateau region: Alabama Geol. Survey, 1891; Spencer, J. W., Paleozoic group: Geol. Survey Georgia, 1893; Hayes, C. W., Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1902, Pl. XIV. For discussions of sections see Stevenson, J. J., Bull. Geol. Soc. America, vol. 15, p. 126.

The Blount Mountain synclinal lobe, southwest of the Gadsden quadrangle, appears to be intermediate to the Warrior field. The stratigraphy as described by A. M. Gibson presents an enlarged number of divisions which show a marked expansion, notably in the lower Pottsville. Though not paleontologically correlated, they appear to be stratigraphically referable to the divisions in the Warrior basin next beyond.

In the Warrior field the downward pitch of the synclines on passing from the Plateau (northern) district permits the retention of a great thickness, over 3,000 feet, of strata. At the same time the divisions, particularly the lower Pottsville, appear greatly thickened. In McCalley's detailed studies of this field [556] the individual coals have been traced with great success over the greater portion of the area. In the following summary of the divisions of this field the sections above the lowest important coal, the Black Creek coal, are given (in averages) for the eastern border of the field, the Warrior River section, and the edge of the Cretaceous overlap on the west. The series below the Black Creek coal is continued by McCalley's average section for Jefferson County,[554] which is placed in the middle column.

Thickness, in feet, of Pottsville strata in the Warrior basin region of Alabama.

	Eastern border.	Along Warrior River.	Western border of exposed "Coal Measures."
1. Interval of shales, conglomerates, and sandstones	50	150	25
2. Brookwood coal group; five coals	125	108	100
3. Interval of shales and sandstones	180	250	125
4. Gwinn coal group; two coals	38	32	23
5. Interval of shales, sandstones, and conglomerates	175	160	125
6. Cobb coal group; three coals	170	136	67
7. Interval of shales, sandstones, and local thin limestones	116	170	210
8. Pratt coal group; five coals	160	166	140
9. Interval of shales, sandstones, and conglomerates	340	260	210
10. Horse Creek (Mary Lee) coal group; five coals	134	148	106
11. Interval of shales, sandstones, conglomerates, and local limestones	100	68	63
12. Black Creek coal group; three coals	70	85	56
13. Interval of shales, sandstones, local limestones, and ten coals, from Black Creek coal to top of "upper conglomerate" of Tennessee	....	1,243	....
14. Interval of sandstones, conglomerates, shales, and coals, from top of "upper conglomerate" of Tennessee to top of "lower conglomerate" of Tennessee	....	100	....
15. Interval of conglomerates, shales, and coals, from top of "lower conglomerate" ("Millstone grit") to Mississippian	....	90	....

According to the preliminary correlations by the writer, based on the incomplete study of the Pottsville floras, the sandstones of the Lookout become greatly broken up and parted, with expanded intervals of varying materials, while at the same time earlier beds of lower Pottsville age are assumed to underlie those in contact with the Mississippian at the Tennessee line. He correlates the entire lower part of the section, including the conglomerate and sandstone interval (No. 11) above the Black Creek coal group (the whole averaging about 1,575 feet), with the Lookout. The Horse Creek coal group and its overlying conglomerate series, making when added to the other about 1,900 feet, is provisionally placed, on the fossil plant evidence, in the lower Pottsville, No. 9 of the section being tentatively correlated with the Raleigh sandstone of the central Appalachian sections. The Horse Creek coal group (Mary Lee) and No. 9, taken together, may be found to represent the recognized difference between the top of the Lookout on the east side of the Tennessee strip and the top of the Lee farther north.

The Pratt and Cobb coal groups are middle Pottsville, in which the Gwin also belongs, making a total of about 670 feet, and a part of No. 2 should probably also be included. It is thought, however, that the study of the Brookwood (No. 2) plants may show them to be of upper Pottsville age.

The Cahaba coal field, a few miles east of the Warrior field, occupies a deep-set and compound syncline about 40 miles long and 3 to 6 miles in width. A part of its western margin is overturned, and older Paleozoic rocks are thrust on the coals along the eastern border. This field was studied and mapped in detail by Joseph Squire [773] and the greater portion of it has recently been reexamined by Charles Butts.[107, 113]

Squire divides the section, calculated to average 5,525 feet, into four parts, which, in descending order, are as follows:

"Conglomerate group," 475 feet, four coals intercalated with conglomerates, and extending from the Montevallo coal to the top of the section.

"Productive group," 2,200 feet, sandstones, shales, and 28 coals, including the Helena coal at 240 feet, a conglomerate (called Thompson) at 310 feet, and the Little Pittsburg coal at 655 feet below the top of the "group;" the Adkins coal, 790 feet lower; and the Wadsworth coal, 500 feet lower, or about 240 feet above the base of the "group."

"Micaceous group," 1,055 feet, micaceous gray and coarse pink sandstones and grits, with seven coals intercalated; the Harkness coal, 160 feet below the top, underlain by 275 feet of sandstones and grits; the Nunnally coal 165 feet above the base.

"Millstone Grit group," 1,795 feet, conglomerates, sandstones, and six coals; the main sandstone masses at the top (360 feet), in the middle (650 feet), and just below the latter (340 feet); the Gould coals in the basal portion.

The section given by Butts agrees in most points with that abstracted above, though indicating an average total thickness of over 6,100 feet in the regions studied. It seems probable that the deeper southeastern portion of the field will ultimately be found to have a depth of 7,000 feet or more. The "Millstone Grit group" is correlated by Butts with the Lookout sandstone. On the fossil plant evidence at present available, the writer is disposed to include the Nunnally and Harkness coals (in the lower part of the "Micaceous group") also in the Lookout. At least they are of lower Pottsville age. The paleobotany of the Wadsworth coal group, which is thought to be as old as the Horse Creek coal group of the Warrior field, will probably be found to place this division also within the limits of the lower Pottsville, the Little Pittsburg-Helena coal group belonging to the middle Pottsville. Fossils of upper Pottsville age have not yet been recognized in the Cahaba field. These preliminary correlations indicate both a very great thickness and a tremendous expansion of the terranes to the southeast in Alabama.

The Coosa field, a short distance east of the Cahaba field, is about 40 miles long and 4 to 10 miles broad. The coal measures are overlain by overthrust Lower Cambrian on the east. Though this field was the scene of the first coal mining in the State, at least 12 workable coals being reported by the Alabama geologists, its deformation has been so violent and the folds are so complicated and the exposures of the soft beds so meager that little successful development has been accomplished, even in the north end of the field. Very little detailed geologic work has been done in the basin. A report on the field by A. M. Gibson [359] shows a section which exceeds 5,000 feet and which appears to be stratigraphically similar to that of the Cahaba field, though there is said to be further eastward expansion of the groups. The greater part of the reported thickness apparently belongs to the lower Pottsville. The basin lies low and, like the Cahaba, passes under the Cretaceous to the south. No paleontologic studies of the Pennsylvanian of this basin have been made.

I-K 14-15. WESTERN INTERIOR COAL REGION.

The following statement was prepared for this volume by G. H. Ashley in 1909:

GENERAL FEATURES.

The Pennsylvanian of the western interior coal region covers a large area in Iowa, Missouri, Nebraska, Kansas, Arkansas, Oklahoma, and Texas, the area exposed being a part, possibly only a small part, of that originally covered. The area of exposure has been much reduced on the southeast by folding and faulting, on most of the eastern edge by erosion, and along all of the west and southeast sides by the deposition of a mantle of later rocks. In central Arkansas the southeastern edge of the outcrop passes beneath a cover of Tertiary rocks. Farther west and south the Pennsylvanian is hidden by Cretaceous and Permian rocks. The extension to the west in Iowa and most of Kansas is concealed by Cretaceous rocks; across Kansas, Oklahoma, and Texas by Permian rocks. Deep drilling for oil and gas indicates a continuance to the west of the Pennsylvanian rocks, so far as the series is reached by such drilling, but they may be assumed as extending indefinitely beyond.

The older Pennsylvanian deposits are confined to the southeastern part of the region, in Arkansas and Oklahoma, and correspondingly in that region is found the greatest thickness of rocks. Later a series spread northwestward and westward over Kansas, Missouri, Nebraska, and Iowa. The Pennsylvanian of northeastern Missouri and southeastern Iowa would seem to have been at one time connected with the "Coal Measures" of Illinois. Whether the series in Arkansas has extended southeastward to join with the Appalachian field in Alabama is uncertain.

SUBDIVISIONS.

For purposes of study the region may readily be divided into four subareas. The Kansas-Missouri-Iowa area is characterized by rocks nearly all of which are of post-Pottsville age, that are easily divisible into the "Upper Coal Measures" and "Lower Coal Measures," by common elements in their stratigraphy, and by simple monoclinal and basin structure. The Pennsylvanian of Oklahoma and Arkansas may be divided into two subareas by a great fault or fault zone, extending from Atoka to the northeast and east, crossing Arkansas River about 40 miles above Little Rock. The area north and east of this fault, which may be called the Arkansas Valley field, differs from the Kansas-Missouri-Iowa area in structure and in stratigraphy, there being a great thickening of the series from Kansas to the southwest, where the strata are underlain by older Pennsylvanian rocks. In the main this area is gently folded and faulted. The area south of the great fault, which may be known as the Ouachita region, differs from the area last mentioned in its stratigraphy, notably in the presence of a great series of shale and sandstone not found outside of this area, and in structure, its rocks having been closely folded and markedly faulted, and possibly overthrust upon the rocks to the north. The northern Texas area is cut off from the areas to the north by the Arbuckle uplift. It is plainly a continuation of the northern Arkansas-Oklahoma area, though differing greatly in its stratigraphic details.

IOWA-MISSOURI-KANSAS AREA.

The Pennsylvanian in Iowa, Missouri, and Kansas outcrops over an area of 63,000 square miles, distributed, according to Bain,[50] as follows: Iowa, 20,000; Missouri, 23,000; Kansas, 20,000. Bain [50a] describes the "Coal Measures" in these States as follows:

"The Coal Measures of the western interior field * * * rest unconformably upon the rocks of the Lower Carboniferous or Mississippian series. They are covered in Kansas and Nebraska by the Permo-Carboniferous beds, which are conformable with them. In Iowa Cretaceous deposits rest unconformably on them, and in Iowa, Nebraska, northern Missouri, and northeastern Kansas the drift and associated deposits of the Pleistocene cover the coal-bearing strata.

"The Coal Measures of this field include limestones, sandstones, shales, fire clays, and the coal beds proper. Limestones are probably least abundant, and shales in their various phases—argillaceous, bituminous, calcareous, and arenaceous—most abundant. In the northern portion of the field limestones and calcareous shales are notably more abundant in the upper or barren portion, and less so in the lower or productive portion. In Kansas the distinction between the two divisions is not so well preserved, and in the adjacent southwestern field it quite loses value. In a general way there is a prevailing dip to the west of 10 to 20 feet per mile. In detail the dip is south to southwest in Iowa, west to northwest in Missouri, and predominantly northwest in Kansas.

"The Coal Measures of this field increase in thickness westward from their outcrop. There is also a gradual increase in maximum thickness from north to south. In Iowa the maximum thickness measured is 1,060 feet.[a] In Missouri Winslow has estimated the total thickness at 2,000 feet.[b] In Kansas Haworth gives 3,000 feet as the thickness.[c]

"On the maps accompanying this report two divisions of the Coal Measures are represented. These are the Upper and Lower Coal Measures. In Iowa and Missouri the terms

[a] Norton, W. H., Iowa Geol. Survey, vol. 6, p. 333.
[b] Missouri Geol. Survey, vol. 1, Preliminary report on coal, p. 24.
[c] Univ. Geol. Survey, vol. 3, p. 20.

Des Moines and Missourian, respectively, are used for the two divisions. In Kansas these terms have not been used, although essentially the same division is recognized. The basis of the division is largely lithologic and economic. The Coal Measures in this field belong to one series and represent a continuous sequence of deposition. The faunal change at the dividing line is slight, but the division is none the less valid and important. The Lower Coal Measures include the bulk of the productive coal beds throughout the field. From 93 to 98 per cent of the coal mined comes from them. These beds are relatively thick, are notably irregular, and show a patchy distribution. They are associated with thick sandstones, thick bodies of shale, particularly of bituminous and argillaceous types, and with thin and unimportant limestones. The Upper Coal Measures include a few very thin beds of coal of great regularity and extent. They are associated with little sandstone, and with shale usually calcareous or argillaceous in type. The measures also include a notable number of thick and persistent limestones. As already stated, these differences are not pronounced to the south, though even here the general relations are as stated above. The dividing line is drawn at the base of an important limestone, 40 to 80 feet thick, known variously as the Winterset, Bethany, or Erie. The general equivalence of these three terms is well recognized, though there is as yet some doubt as to the exact correlation of this and other minor divisions.[a] Subdivisions of both the Upper and Lower Coal Measures have been systematically recognized and mapped in Kansas by Haworth and his associates.[b] In Missouri corresponding divisions have been recognized and partially mapped by Keyes[c] and Marbut.[d] In Iowa divisions of the Lower Coal Measures have been recognized[e] but have not been mapped except in Appanoose County.[f]

"The divisions recognized in each State and their approximate correlation are shown in the following table. Keyes has suggested more exact nomenclature and correlation.[c] His suggestions have not as yet been followed in mapping.

Divisions of the Lower Coal Measures.

Kansas (Haworth).		Missouri (Keyes).	Iowa (Geol. Survey).
Pleasanton Altamont Pawnee Labette Fort Scott	Marmaton	Marais des Cygnes Henrietta	Pleasanton. Appanoose and equivalents.
Cherokee		Cherokee	Cherokee.

"It will be seen that the Lower or Productive Coal Measures are made up of three divisions. The uppermost, the Pleasanton shales, including the Altamont limestones, attain a thickness in Kansas of 200 feet. To the north they thin, until in central Iowa they are hardly to be separated from the next lower member. In Kansas they have been grouped with this middle division by Haworth under the name Marmaton formation.[g] The middle member passes under various names in different parts of the field. In Kansas it includes the Pawnee and Fort Scott limestones, with the intercalated Labette shales, and has an approximate thickness of 150 feet, a thickness which it maintains well to the north. In southwestern Missouri the shale member of the sequence is unimportant, and the limestones, the Henrietta formation of Keyes,[h] form a single escarpment, which may be seen near Hume, in Bates County. In northern Missouri and southern Iowa the formation includes a number of thin limestones separated by shales and carrying thin coal seams. This is the phase of the formation which has been called the Appa-

[a] Haworth, E., Kansas Univ. Geol. Survey, vol. 3, pp. 101-102.
[b] Kansas Univ. Geol. Survey, vols. 1 and 3.
[c] Bull. Geol. Soc. America, vol. 12, pp. 173-196.
[d] Missouri Geol. Survey, vol. 12, Clinton, Calhoun, Lexington, Richmond, and Huntsville sheets.
[e] Iowa Geol. Survey, vol. 5, pp. 374-398; vol. 6; vol. 8, p. 82.
[f] Iowa Geol. Survey, vol. 5.
[g] Haworth, E., Kansas Univ. Geol. Survey, vol. 3, pt. 6, 1898.
[h] Bull. Geol. Soc. America, vol. 12, 1901, p. 176.

noose. In central Iowa there are beds equivalent to the Henrietta, but the sequence of strata is different.

"The lowest member of the measures is the Cherokee shale, which outcrops in a crescent-shaped area following the outer lines of the outcrop of the Coal Measures from Kansas to north-central Iowa. The shales vary in thickness from 200 to 600 feet along the outcrop of the next higher formation and thin to nothing at their own outcrop. The formation is made up largely of shale and sandstone and carries numerous important coal beds. The individual strata vary in character and thickness from point to point, so that it is impossible to construct a general section of more than local value. In the southwest, especially in southeastern Kansas and the adjacent portions of Missouri, the beds are apparently more regular than elsewhere, and the irregularities found farther north serve to mark this as an exceptional portion of the field."

The persistent limestones of the "Upper Coal Measures," as well as the intervening shales, have all been named in Kansas. In many reports these have been considered as separate formations. In other reports they have been treated as members of somewhat more inclusive formations. Later work has shown that the earlier correlations of some of the limestones at different points were erroneous. Again, some of the earlier names used have later been found to be preoccupied by use for some other formation elsewhere. These facts have led to many changes in the nomenclature of the Pennsylvanian of Kansas.

In the table opposite is presented the stratigraphy of the Pennsylvanian of Kansas, as contained in several recent reports. Bulletin 211 of the United States Geological Survey gives the synonymy of the several formations listed, with the fauna of each formation or member. Bulletins 238 and 296 show the groupings and treatment of the rocks at still later dates, and the latest is that quoted from volume 9 of the State report.

ARKANSAS VALLEY AREA.

The area of Pennsylvanian strata of Kansas, Missouri, and Iowa is, in large measure, cut off from the Arkansas Valley area on the south by the Ozark uplift. The two areas are connected by a relatively narrow belt of outcropping rocks running southwestward through eastern Oklahoma. In this narrow area, which has not been studied as much as the regions to the north and south, there is a notable thickening of the formations toward the south; a running out of the limestones, so characteristic of the formations of Kansas, and the introduction of sandy beds; and a downward transgression of the red clay, which to the north is characteristic of the Permian beds but which in this region extends downward into the upper part of the Pennsylvanian. As a result of these changes the stratigraphy of the Pennsylvanian in central Arkansas and eastern Oklahoma is very different from that in Kansas. In part the increased thickness is due to the appearance of older Pennsylvanian strata at the bottom of the series.

The second table opposite shows the stratigraphic nomenclature, with the thickness of some of the strata, as given in the reports of the more important studies made in this field, in addition to a correlation with the Pennsylvanian to the east, based entirely on the work of David White.

For comparison, Purdue's section[655a] in western Arkansas (Pike, Howard, and Sevier counties) and an abbreviated section from Kansas are also given. The Mississippian formations underlying the Pennsylvanian in these sections are included in the table to show the character of the contact at different points and as bearing on the stratigraphy of the Ouachita region.

OUACHITA AREA.

As already stated, the Ouachita area is cut off from the Arkansas Valley area by a great fault or fault belt extending from Atoka northeastward and eastward. South of this fault the rocks are closely folded or overturned as well as faulted. The result of this faulting and folding has been to greatly shorten the north-south extent of the area covered by the Pennsylvanian. The writer[35] has estimated that in the southern part of this area a section along Cossatat River, now 24 miles long, was originally 35 miles long, and a section on Antoine Creek, now 20 miles long, was originally also 35 miles long. As this estimate does not make any allowance for overthrust faulting, and

Stratigraphy of the Pennsylvanian of Kansas, as interpreted by different authors.

Haworth, E., Geol. Survey Kansas, vol. 3, 1898, p. 94. (Kansas.)	Keyes, C. R., Bull. Geol. Soc. America, vol. 12, 1901, p. 175. (Mississippi Valley.)	Adams, G. I., Bull. U. S. Geol. Survey No. 211, 1903, pp. 65–66. (Kansas.)	Adams, G. I., Bull. U. S. Geol. Survey No. 238, 1904, Pl. III, opp. p. 18 and errata. (Iola quadrangle, Kansas.)	Schrader, F. C., and Haworth, E., Bull. U. S. Geol. Survey No. 296, 1906, p. 10. (Independence quadrangle, Kansas.)	Haworth, E., Kansas Univ. Geol. Survey, vol. 9, 1908, Pl. III. (Kansas.)
Cottonwood formation:	Missourian:	*Feet.*			Wabaunsee stage:
Cottonwood shales.		Garrison formation.....120			Garrison formation.
Cottonwood limestone.	Cottonwood limestone.	Cottonwood limestone. 6			Cottonwood limestone.
Wabaunsee formation, a series of alternating limestones and shales to which individual names have not yet been given.		Eskridge shales......... 40			Eskridge shales.
	Atchison shales.	Neva limestone......... 10			Neva limestone.
		Elmdale formation.....130			Elmdale formation.
		Americus limestone.... 5			Americus limestone.
		Admire shales.......... 40			Admire formation.
		Emporia limestone.... 10			Emporia limestone.
Burlingame limestone:	Forbes limestones.	Olpe shales............ 60			Willard shales.
		Barclay limestone..... 7			Burlingame limestone.
Shawnee formation:					Shawnee stage:
Osage shales.	Platte shales.	Burlingame shales.....120			Scranton shales.
		Howard limestone..... 7			Howard limestone.
		Severy shales.......... 75			Severy shales.
Topeka limestones.	Plattsmouth limestones.	Hartford limestone..... 25			Topeka limestone.
Calhoun shales.		Calhoun shales......... 60			Calhoun shales.
Deer Creek limestone.		Deer Creek limestone.. 25			Deer Creek limestone.
Tecumseh shales.		Tecumseh shales....... 75			Tecumseh shales.
Lecompton limestones.		Lecompton limestone.. 20			Lecompton limestone.
Lecompton shales.		Kanwaka shales 100		Elgin sandstone.	Kanwaka shales.
Douglas formation:					Douglas stage:
Oread limestones.		Oread limestone...... 40		Painterhood limestone.	Oread limestone.
Lawrence shales.	Lawrence shales.	Le Roy shales........ 150		Buxton formation.	Lawrence shales.
					Kickapoo limestone.
					Le Roy shales.
Pottawatomie formation:				Wilson formation:	Pottawatomie stage:
Garnett limestone.	Stanton limestone.	Stanton limestone..... 30	Piqua limestone.	Piqua limestone.	Stanton limestone.
		Lane shales........... 100	Vilas shale.	Vilas shale.	Vilas shales.
	Parkville shales.	Iola limestone......... 30	Allen limestone.	Allen limestone.	Allen limestone.
Lane shales.		Vilas shales........... 75	Concreto shale.	Concreto shale.	Lane shales.
Iola limestone.	Iola limestones.	Earlton limestone..... 15	Iola limestone.	Iola limestone.	Iola limestone.
Thayer shales.	Thayer shales.	Chanute shales 200	Chanute shale.	Chanute shale.	Chanute shales.
Erie limestones.		Drum limestone...... 30		Drum limestone.	Drum limestone.
				Coffeyville formation:	
		Cherryvale shales 120		Cherryvale shale.	Cherryvale shales.
		Dennis limestone..... 15	Bronson limestone: Dennis limestone.	Dennis limestone.	Dennis limestone.
		Galesburg shales...... 100	Galesburg shale.	Galesburg shale.	Galesburg shales.
		Hertha limestones 20	Mound Valley limestone.	Mound Valley limestone.	Mound Valley limestone.
			Ladore shale.	Ladore-Dudley shale.	Ladore shales.
	Bethany limestones.		Hertha limestone.		Bethany limestone.
Marmaton formation:	Des Moines:				Marmaton stage:
Upper Pleasanton shales.	Marais des Cygnes shales.				Pleasanton shales.
Altamont limestone.					Coffeyville limestone.
Lower Pleasanton shales.		Dudley shales........ 150	Dudley shale.		Walnut shales.
	Henrietta limestones.	Parsons limestone..... 25	Parsons limestone.	Parsons formation.	Altamont limestone.
		Bandera shales 100	Bandera shale.	Bandera shale.	Bandera shales.
Pawnee limestone.		Pawnee limestone..... 25	Pawnee limestone.	Pawnee limestone.	Pawnee limestone.
Labette shales.		Labette shales........ 60	Labette shale.	Labette shale.	Labette shales.
Oswego limestones.		Fort Scott limestone.. 25	Fort Scott limestone.	Fort Scott limestone.	Fort Scott limestone.
Cherokee shales.	Cherokee shales.	Cherokee shales....... 450	Cherokee shale.	Cherokee shale.	Cherokee shales.
Boone limestone (Mississippian.)	Kaskaskia, etc.	Boone limestone...........	Boone limestone.	Boone formation.	

ifferent parts of the western interior coal field.

[...hickness given in feet.]

...rkansas coal field.		"Indian Territory coal field" (Drake, N. F., Proc. Am. Philos. Soc., vol. 36, 1897, pp. 388–407).	Southern Oklahoma.			Arbuckle Mountains, Oklahoma (Taff, J. A., Prof. Paper U. S. Geol. Survey, No. 31, 1904, pp. 34–35).	Western Arkansas (Purdue, A. H., The slates of Arkansas; Bull. Geol. Survey Arkansas, 1909, p. 48).	Abbreviated Kansas section (Haworth, E., and others, Kansas University, Geol. Survey, vol. 3, 1898, p. 94).
...teven-... York ... p. 51.	Collier, A. J., and others, Bull. U. S. Geol. Survey No. 326, 1907, p. 12.		Taff, J. A., Coalgate folio (No. 74), Geol. Atlas U. S., 1901.	Taff, J. A., Atoka folio (No. 79), Geol. Atlas U. S., 1902.	Taff, J. A., Tishomingo folio (No. 98), Geol. Atlas U. S., 1903.			
			Feet. Seminole conglomerate .... 50+ Holdenville shale .... 260 Wewoka formation .... 700 Wetumka shale .... 120 Calvin sandstone .... 145–240 Senora formation .... 140–485 Stuart shale .... 90–280 Thurman sandstone 80–260					Cottonwood formation. Wabaunsee formation. Shawnee formation. Douglas formation. Pottawatomie formation. Marmaton formation.
Feet. 0–3,900		*Feet.* Poteau group 2,000	Boggy shale 2,000–2,600	*Feet.* Boggy shale .... 800+				Cherokee shales.
... 100	*Feet.* Savanna formation.		Savanna sandstone 1,000	Savanna sandstone 750–1,100				
500–600	Paris shale 700							
. 0–100		Cavaniol group 5,500				*Feet.* Sandstone, shale, and coal. 10,000–11,000		
. 0–500			McAlester shale .... 1,800, 2,000 Atoka coal, probably Hartshorne coal.	McAlester shale ..... 1,150–1,500 Atoka coal, at same horizon as Hartshorne coal.				
. 0–500	Fort Smith formation 400							
. 0–500	Spadra shale 350–500							
100–400	Hartshorne coal.	Grady coal.						
)0–2,500	Hartshorne sandstone 100–300		Hartshorne sandstone 150	Hartshorne sandstone 150–200				
50–150							Atoka sandstone 6,000	
500–600	Atoka formation 1,500–5,000	Lower Coal Measures 17,000	Atoka formation 3,100	Atoka formation 3,200				
500–600								
						Wapanucka limestone.	Jackfork sandstone 6,600	
			Wapanucka limestone 100	Wapanucka limestone ... 100–150				
					Franks conglomerate ... 300–500+	Franks conglomerate.	Stanley shale.	
					Unconformity			
					Glenn formation 1,000–3,000			
						Unconformity	Unconformity	
			Caney shale (Carboniferous and probably Devonian) .... 800+	Caney shale 1,500	Caney shale 1,500	Caney shale.		
					Sycamore limestone 0–160			Boone chert.
				Woodford chert (Devonian and Carboniferous).	Woodford chert (Devonian and Carboniferous).	Woodford chert.		

...y between Pennsylvanian and Mississippian as given in the reports cited.

as the Ouachita area as a whole has a width of about 70 miles, it is evident that the total shortening has been very considerable. The rocks appear to have been pushed from south to north.

Stratigraphically the upper part of the series of rocks is similar to the series in the Arkansas River valley, from the Caney shale upward. The lower part of the series differs from the adjoining rocks in the Arkansas area in the presence of a great thickness of sandstone and shale resting on the Ordovician rocks and belonging beneath the Caney shale and apparently above the Woodford chert. These have been estimated by Ulrich to have a thickness of 14,000 feet on Little Missouri River. This series was named by Taff [806] the Standley (now spelled Stanley) shale and Jackfork sandstone. At the west is the Caney shale, supposed to be later than the Jackfork. To the east the Caney shale has not been recognized, and the Atoka formation overlies the Jackfork. In the Atoka folio Taff gives the Jackfork sandstone and the Stanley shale a thickness of 5,000 feet each. Branner [96] gave these beds, including the Atoka, a thickness of 18,480 feet in the area west of Little Rock. Purdue,[655a] in a paper on the Arkansas slate area, gives the thickness of the Atoka, Jackfork, and Stanley as 6,000, 6,600, and 6,000 feet, respectively, or a total of 18,600 feet, in substantial agreement with the earlier estimate of Branner.

The age of the Jackfork sandstone and Stanley shale is still a matter of some doubt. They are either late Mississippian or early Pennsylvanian, possibly passing from the one over into the other.

The proper correlation of the Caney shale is also a matter of some doubt. In folios 74, 79, and 98 of the Geologic Atlas of the United States the Caney was assigned first to the "Carboniferous and probably Devonian" and later, on the evidence of fossils which were thought by Girty to indicate a late Mississippian age, to the Mississippian. Two years later (1905) Girty [363c] placed the Caney in the Pennsylvanian because, inasmuch as it was underlain by 10,000 feet of Carboniferous strata, there was reasonable doubt of its Mississippian age. In 1909 the same author [366] published a description of the Caney fauna in which, after citing the inconclusive paleobotanic evidence, he summed up the faunal evidence as follows:

"The faunal evidence furnished by the Caney is much more extensive than that of the fossil plants referred to above. The Caney fauna has a facies widely different from that of the typical upper Mississippian faunas, and it would be difficult to determine its position in the time scale were it not that it is closely related to certain faunas in Arkansas which contain more of the typical upper Mississippian species and which have long been regarded as belonging to that period. When I originally determined the Caney as neo-Mississippian, I did so because its fauna was so closely allied with that of the Moorefield shale of Arkansas. If, upon returning to the subject with a presentation of one side of the evidence upon which this conclusion was based, it were possible to say that the preliminary opinion had been erroneous, it would afford me real satisfaction as opening a way out of the present difficulties. But a more detailed study of the one fauna and a hasty review of the other have only added to the weight of the evidence. A large number, and those in many cases the most striking and typical of the Caney species, occur also in the Moorefield shale. * * *

"The ordinary inference from these facts, one which I should draw without hesitation were it not for the bearing of the plant evidence found in the Standley, is that the Caney and the Moorefield-Fayetteville beds were contemporaneous in a geologic sense.[a] But this, it may be urged, does not necessarily entail the Mississippian age of the Caney without carrying the inquiry one stage further. Careful consideration has been given the hypothesis that the Moorefield-Fayetteville beds may be not Mississippian but Pottsville in age. While some circumstances lend a color of probability to such an hypothesis, the negative evidence seems at present to warrant its rejection.

"If, then, the Caney correlates with the Moorefield, if the Moorefield is of Mississippian age, if the Caney rests on the Jackfork sandstone, and if the evidence furnished by the Standley flora halts between upper Mississippian and Pottsville, the conclusion that the Standley is upper Mississippian and that the sedimentation of that period was peculiar and excessive in the

[a] The White Pine shale of Nevada, which is also a black shale formation, likewise contains a fauna similar in many respects to that of the Caney.

Ouachita region seems to involve the fewest inconsistencies. This conclusion is tentative and unsatisfactory but seems to accord best with the evidence known to me. Future discoveries may prove it wrong."

The Pennsylvanian shales, limestones, and sandstones of Oklahoma have been studied by Gould and his associates,[375] who have classified them as follows:

The rocks in the area under discussion consist of a thickness of from 10,000 to 12,000 feet of sediments of Pennsylvanian age extending from the Mississippian to the Permian. In general these rocks consist of alternating layers of shale and sandstone. The shales greatly predominate, making up approximately three-fourths or possibly nine-tenths of the entire thickness of the strata. In the northern part of the State there is a number of ledges of limestone, but even in this region shales constitute more than three-fourths of the strata, the remainder being about equally divided between sandstone and limestone. Farther north, in east-central Kansas, the limestone ledges are not only more numerous (no fewer than twenty distinct ledges having been recognized) but they are thicker, while sandstones make up a relatively small per cent of the entire series.

In Kansas it has been noted that on passing from the center of the State to the Oklahoma line the various limestone ledges frequently thin out and some of them disappear before the line is reached. Others pass for several miles into Oklahoma before disappearing, but, except in eastern Kay County, comparatively few limestones reach the Arkansas River. Of the half dozen or more which persist south of that stream only one ledge, so far as known, exceeds 10 feet in thickness.

It has also been found that as the limestones thin out to the south and finally disappear, sandstones often come in, usually either just above or just below the limestone. In other cases the ledges become more arenaceous to the south, until finally the ledge which was a limestone has become a sandstone. It frequently happens, also, that additional sandstone ledges come in, first as mere arenaceous bands in the shales, then as thin lenses which thicken to the south and finally become ledges of hard sandstone 20 to 50 feet thick, which resist erosion and give rise to pronounced escarpments. In a number of instances, however, the thinning out of the limestone ledges is to the north. This fact is particularly well exemplified in the case of several limestone ledges in the region about Bartlesville, and between that city and Arkansas River above Tulsa. Here at least two heavy ledges of limestone disappear to the north. Many of the ledges, both limestone and sandstone, when traced for any considerable distance are found to be local lenses. The general rule throughout the area is, however, that limestones "finger out" to the south and sandstones to the north, while the intervening shales coalesce.

Another factor which complicates the difficulty of the situation is the gradual thickening of the entire series to the south, particularly near their base. For instance, the basal group, to be hereinafter described as the Muskogee group, is about 450 feet thick at the Kansas-Oklahoma line, but in the region north of the Choctaw fault, in the eastern part of the State, the same group has an approximate thickness of 9,000 feet. Part of the apparent thickening in this instance is probably caused by unconformity by overlap on the Mississippian, but much of it is doubtless caused by normal thickening of strata southward. The thickening of other groups from north to south, while not so conspicuous as in the case mentioned, is nevertheless often obvious.

From what has preceded, it will be evident that the problem cf the proper division and correlation of the various beds is, in the absence of paleontological data, at best difficult. In rare cases only may any single ledge of either limestone or sandstone be traced from Kansas line southward for any considerable distance. As has been stated, many of the sandstones and a few of the limestones are lenticular and have but a comparatively limited areal extent. These conditions have already given rise to considerable confusion in folio and economic mapping, and it is feared that, as this work progresses, the complications may be augmented. It is with the hope of lessening the possibility of confusion in the application of stratigraphic terms and the needless multiplication of names in the future that this article has been prepared.

PROPOSED SOLUTION.

The authors are convinced that the problem of the future division and correlation of the various beds may be greatly simplified by dividing all the rocks in the region into a few general groups, the limits of which may be demarked by certain conspicuous ledges of limestone and sandstone which extend southward from the Kansas line. After studying the region in considerable detail, it has been found that there are at least four of these ledges of sufficient importance and linear extent along the line of outcrop to serve as adequate group markers, which groups must, of course, be confirmed by paleontological evidence. Beginning on the east, these ledges are as follows:

1. The Claremore formation, the approximate equivalent of the Fort Scott limestone of Kansas, which is correlated with the Calvin sandstone in the Coalgate folio.
2. The Lenapah limestone, which lies at the approximate horizon of the Upper Parsons or Coffeyville limestone of Kansas.
3. The Pawhuska formation, which is believed to be the equivalent of the Deer Creek and Hartford limestones of Kansas.
4. The Wreford limestone, which, south of the Cimarron River, gives way to the Payne sandstone.

From the study of the map it will be seen that these four formations trend approximately parallel northeast and southwest, from the Kansas line toward the region of the Arbuckle Mountains. The southern extension of none of them has been definitely located, but it is believed that accurate field studies will fix the position of each formation.

PROPOSED GROUPS.

It is therefore proposed to demark the limits of four general groups of the Pennsylvanian rocks of eastern Oklahoma as follows:

1. The Muskogee group, including all the rocks from the base of the Pennsylvanian series to the base of the Claremore formation. The name proposed is that of Muskogee County, which lies near the center of the area occupied by the group.
2. The Tulsa group, including everything from the base of the Claremore formation to the base of the Lenapah limestone. The name is from Tulsa County, in the eastern part of which the rocks of the group are well exposed.
3. The Sapulpa group, including the rocks between the base of the Lenapah limestone and the base of the Pawhuska formation. The name is from Sapulpa, the county seat of Creek County.
4. The Ralston group, including everything from the base of the Pawhuska to the base of the Wreford, which has usually been considered the base of the Permian. The name here proposed is from the town of Ralston, in northern Pawnee County.

In proposing these groups the authors do not wish to be understood as attempting to fix definitely the nomenclature of the region. The purpose is merely to provide a comprehensive yet simple scheme of classification which may be followed in future mapping. The classification is made entirely upon stratigraphic and lithologic data.

DESCRIPTION OF GROUPS.

MUSKOGEE GROUP.

Area.—The Muskogee group includes a series of rocks, chiefly sandstones and shales, extending from an unconformity at the top of the Mississippian series on the east to the base of the Claremore formation[a] and its approximate southern equivalent, the Calvin sandstone, on the west. In the northern part of the State it includes the approximate area occupied by the southern continuation of the Cherokee shales of Kansas; in the southern extension it includes the great coal region of Oklahoma. The area included in this group in Oklahoma is bounded on

[a] This formation includes the Fort Scott limestone of Kansas and some of the upper part of the Cherokee shale. At the south boundary of the Claremore quadrangle as much as 100 feet of the Cherokee is included.—C. D. Smith, comment on manuscript.

the north by the Kansas line, and on the northeast by the areas occupied by Mississippian rocks. On the east the Arkansas line is the boundary. The Choctaw fault, the Cretaceous overlap in Atoka County, and the Arbuckle Mountains demark the southern limit. It includes all or part of the following counties in Oklahoma: Ottawa, Craig, Mayes, Rogers, Wagoner, Cherokee, Okmulgee, Muskogee, Sequoyah, Le Flore, Haskell, McIntosh, Okfuskee, Hughes, Latimer, Pittsburg, Coal, Pontotoc, and Atoka.

Stratigraphy.—Near the Kansas line, in which State the name Cherokee shales has been applied to the rocks of the group, the approximate thickness of the strata is 450 feet and consists largely of shales, with local beds of sandstone and limestone and several thin beds of coal. The following section from Pryor Creek to Claremore made by Messrs. Ohern and Wolf will give a fairly comprehensive idea of the stratigraphy at that place.

Section from Pryor Creek to Claremore.

	Feet.
14. Shale with a few interbedded sandstones	135
13. Massive medium-grained sandstone	17
12. Shaly sandstone	3
11. Argillaceous, heavily bedded fossiliferous limestone	$2\frac{1}{2}$
10. Bluish shale	35
9. Carbonaceous shale capped by 6 inches of ferruginous siliceous limestone	3
8. Gray fine-grained sandstone	7
7. Arenaceous shale	70
6. Alternating shales and sandstones	70
5. Argillaceous fossiliferous limestone	8
4. Massive medium-grained sandstone	37
3. Shaly sandstone	8
2. Massive medium-grained sandstone	14
1. Bluish shale, weathering to light yellow, and a few interstratified sandstones	550
	960

In the Muskogee folio Mr. Taff describes two formations, the Boggy and the Winslow, the latter being the equivalent of the Hartshorne, McAlester, and Savanna formations as exposed in the coal fields farther south. The formations above the Boggy have not been described in Muskogee, Okmulgee, and McIntosh counties.

The stratigraphy of the southern part of the Muskogee group is better understood than that of any other part of the Pennsylvanian series in Oklahoma. Numerous reports and folios bearing upon the subject, chiefly from the pen of Mr. Taff, whose work in the region continued almost without interruption from 1895 to 1908, have given us a very comprehensive idea of the stratigraphy, structure, and economic resources of the coal fields of the State. The general sequence of the formations with their approximate thickness as shown in Coal and Hughes counties is here given, the oldest below:

	Feet.
Calvin sandstones	200
Senora formation	500
Stuart shale	250
Thurman sandstone	200
Boggy shale	2,000
Savanna sandstone	1,200
McAlester shales	2,000
Hartshorne sandstone	200
Atoka formation	3,000
	9,550

This entire series of strata is coal bearing. In Arkansas beds of considerable thickness occur in the Atoka formation, but in Oklahoma these beds are usually thin and inconspicuous. The McAlester formation contains four beds of workable coal and a number which may eventually be developed. The Savanna contains at least three and the Boggy formation two workable beds. Several occur in the higher formations of the series, particularly one in the upper part of the Senora which is mined at Henryetta, Schulter, and Morris. In the southeastern part of the area occupied by rocks of the Muskogee group the strata have been extensively folded and in certain places faulted. A series of anticlines and synclines have their axes extending northeast-southwest.

It is not the purpose in this connection to discuss the problem of the cause of the thickening of the various beds of the Muskogee group to the south, or what amounts to the same thing, the thinning of the beds to the north. It has usually been assumed that the change in the thickness is due largely to unconformity by overlap. While in the present state of our knowledge, particularly in the absence of complete paleontological evidence, it would be extremely unwise to say that this cause did not obtain, at least in part, still in the light of accumulating evidence it seems very probable that we must look elsewhere for reasons to account for a considerable part of the southern thickening of the beds.

TULSA GROUP.

Area.—This group includes all the rocks lying between the base of the Calvin-Claremore formation and the base of the ledge which in Kansas has been known as the Upper Parsons or Coffeyville limestone, but which in a paper by Ohern, now in press, is designated as the Lenapah limestone. The rocks of the group outcrop on the surface as a band, averaging 20 miles in width, and extending from the Kansas line south to the region of the Arbuckle Mountains. The Lenapah limestone[a] has not been certainly located south of the North Canadian River, although there is reason for believing that it will eventually be correlated with a limestone in the upper part of the Holdenville formation, which outcrops not far from the town of Holdenville, in Hughes County, and which probably extends nearly to Ada. The rocks of the Tulsa group occupy all or part of the following counties: Craig, Nowata, Rogers, Tulsa, Wagoner, Okmulgee, Okfuskee, Coal, Hughes, and Pontotoc.

Stratigraphy.—The rocks of the Tulsa group, as exposed in the northern part of the State, include formations which in Kansas have been described under the names Fort Scott limestone, Labette shales, Pawnee limestone, Bandera shales, Altamont limestone, and Walnut shales. The combined thickness of these rocks at the Kansas line is about 250 feet; farther south this thickness is much greater.

The Fort Scott limestone, known to the oil drillers of Kansas and Oklahoma as the Oswego lime, was first described in Kansas, where it consists typically of two limestone members and an intervening shale member. Ohern, however, finds that in northern Oklahoma a third limestone member comes in below the Fort Scott of Kansas and persists at least as far south as the Arkansas River. For this formation, consisting of three limestones with two intervening shale beds, each containing coal, in a paper now in press, he is proposing to use the name Claremore.

The Labette shales, named and described in Kansas, extend from the Kansas line southward across Oklahoma, finally, on the disappearance of the higher limestones, coalescing with other shales. The Pawnee and Altamont (Lower Parsons) limestone, which at the Kansas line are separated by the Bandera shales, come together in southern Nowata County and form a single ledge, the Oologah, the "Big lime" of the drillers. The ledge extends southward, crosses the Arkansas River near Broken Arrow, and disappears in the vicinity of the Concharty Mountains.

From the Arkansas River south the rocks of the Tulsa group consist of sandstones and shales with an occasional lentil of limestone. In the Coalgate folio Mr. Taff has described the following formations beginning with the Calvin:

	Feet.
Seminole conglomerate	150
Holdenville shale	250
Wewoka formation	700
Wetumpka shale	120
Calvin sandstone	200

If, in the above section, the Tulsa group includes the Calvin, Wetumpka, and Wewoka formations, and probably 200 feet or more of the Holdenville formation, this would indicate that

[a] This formation is not recognizable south of Watora, in Nowata County, Okla. The Dawson coal, however, which occupies practically the same horizon, extends southward beyond Kansas River.—C. D. Smith, comment on manuscript.

the rocks of the group as exposed in the region south of the Canadian River reach a thickness of approximately 1,200 feet.

SAPULPA GROUP.

Area.—The rocks which constitute the Sapulpa group include everything from the base of the Lenapah limestone to the base of the Pawhuska formation (as that term was used by J. P. Smith) as these formations are exposed in the northern part of the State. Neither the Lenapah nor the Pawhuska has been definitely located south of the North Canadian River and for that reason the southern limits of the group can not now be accurately demarked.

The area included in the group averages 35 miles in width, extending from the Kansas line south to the vicinity of the Arbuckle Mountains. It includes all or part of Nowata, Washington, Osage, Pawnee, Creek, Tulsa, Okmulgee, Payne, Lincoln, Okfuskee, Pottawatomie, Seminole, Pontotoc, and probably McClain, Garvin, and Murray counties.

Stratigraphy.—Included in the Sapulpa group in Oklahoma are rocks which in Kansas have been described under the following formation names: Coffeyville limestone, Pleasanton shales, Bethany Falls limestone, Ladore shales, Mound Valley limestone, Galesburg shales, Dennis limestone, Cherryvale shales, Drum limestone, Chanute shales, Iola limestone, Lane shales, Stanton limestone, LeRoy shales, Kickapoo limestone, Lawrence shales, Oread limestone, Kanwaka shales.

The approximate combined thickness of these rocks as exposed in southern Kansas is 1,000 feet. In Oklahoma the thickness of the group gradually increases until at the Arkansas River it is probably 1,200 feet or more.

So far as known, with the exception of the Lenapah, none of the limestone ledges exposed in Kansas persist as far south as the Arkansas River. The Drum limestone splits near the Kansas line, and the lower member, which Ohern calls the Hogshooter, disappears some 20 miles north of Tulsa. The upper member of the Drum disappears soon after crossing the State line. Two limestone lentils, the Dewey and Avant, come in not far from Bartlesville and persist beyond the Arkansas River, where they also disappear. As the limestones disappear near the Kansas line, sandstones become prominent and farther south increase in thickness until they make up a considerable part of the rocks of the group, although, as in other parts of the general region occupied by Pennsylvanian deposits, shales are the predominating rock.

No accurate section has ever been made across the southern part of the region occupied by rocks of the Sapulpa group, and for that reason it is impossible to do more than to approximate the thickness of the group along the Canadian River, but it is probable that in this region it is somewhere between 1,500 and 2,000 feet.

In its southwestern extension the Sapulpa group passes into and includes the eastern part of the Oklahoma Red beds, being part of the so-called Chandler beds. * * *

RALSTON GROUP.

Area.—The Ralston group includes the rocks in the upper part of the Pennsylvanian series, beginning at the base of the Pawhuska formation and extending to the base of the Wreford limestone and its southern continuation, the Payne sandstone, which has usually been considered the base of the Permian.[a] The group is exposed as a band averaging 30 miles in width extending parallel to the other groups described in this paper, from the Kansas line south toward the Arbuckle Mountains.

Neither the Pawhuska formation nor the Payne sandstone has been definitely located as far south as the North Canadian River and consequently the limits of the southern part of the Ralston group, which is exposed in Lincoln, Oklahoma, Pottawatomie, Cleveland, McClain, and Garvin counties, can not be accurately demarked. In the northern part of the State this group is exposed in Osage, Kay, Pawnee, Payne, and Lincoln counties.

Stratigraphy.—The equivalents of the following formations in Kansas, the combined thickness of which is approximately 800 feet, are included in the Ralston group as the latter is exposed in northern Oklahoma: Lecompton limestone, Tecumseh shales, Deer Creek lime-

[a] Beede now considers the Elmdale as the provisional base of the Permian.

stone, Calhoun shales, Topeka limestone, Severy shales, Howard limestone, Scranton shales, Burlingame limestone, Willard shales, Emporia limestone, Admire shales, Americus limestone, Elmdale formation, Neva limestone, Eskridge shales, Cottonwood limestone, Florena shales, Neosho formation.

These formations are exposed along the Flint Hills in southern Kansas, but near the Oklahoma line most of the limestone members thin out and disappear, while sandstones come in and thicken to the south. No accurate section across the group has been made in Oklahoma, but it is probable that the group does not thicken to the south as rapidly as do the groups heretofore described. In fact, there is some evidence which indicates that in Lincoln, Pottawatomie, and Cleveland counties the rocks representing the southern extension of the Ralston group are not so thick as they are farther north.

In southern Pawnee and northern Payne counties the color of the rocks in the Ralston group changes and becomes a deep brick-red and so continues to the southern limits. This area includes the greater part of the so-called Chandler beds mentioned above.

HIGHER ROCKS.

Above the Ralston group the sequence of limestones and shales with occasional sandstones continues uninterruptedly for several hundred feet. The Kansas geologists have described these rocks under the following names, the oldest below:

Wellington shales.
Marion formation.
Winfield limestone.
Doyle shales.
Fort Riley limestone.
Florence flint.
Matfield shales.
Wreford limestone.

The limestones contain much flint, which, being resistant, withstands erosion, giving rise to a series of pronounced escarpments, which, in southern Kansas, constitute the Flint Hills. The rocks of the Marion are less resistant and form few pronounced escarpments. The Wellington shales are all soft rocks and weather into a flat plain.

In Oklahoma, all these formations pass into the Red beds along the line indicated on the map. Several of the limestones, particularly the Wreford, the Florence, and the Fort Riley, extend several miles into the Red beds before finally losing their color and merging with red sandstones and shales.

This peculiarity of relations is represented on the map in Kay and adjoining counties, where there is exposed an area of non-red Permian rocks, triangular in shape, bounded by the Kansas line, the Wreford limestone, and the eastern margin of the Red beds.

The Pennsylvanian terranes of Iowa are described as the Missouri and Des Moines groups. Smith[753] has the following note on the Missouri:

The Missouri of southwestern Iowa is composed of shales, limestones, and limited amounts of sandstone. The shales, which comprise much the greater part of the strata, are generally calcareous—so much so that even those in immediate contact with the coals effervesce readily with acid. The limestones occur in layers from an inch or two in thickness to ledges 20 feet thick. Usually the limestones are highly fossiliferous. In all the Coal Measures exposures of Adams, Montgomery, Page, and Taylor counties not a single sandstone is to be found. Deep drillings also show a total absence of sandstone in the Missouri in these counties.

The Des Moines is described by Lees[531] as follows:

The beds of the Des Moines stage are usually divided in a broad way into three general divisions. These, as indicated in the section, are, from above downward, the Pleasanton, the Appanoose, with its equivalent beds farther northwest, and the Cherokee. Of these three the lower division, the Cherokee, is the most important, in Iowa as well as in Missouri and Kansas. * * * It will be seen from the section that shales are the preponderating element in this division, while sandstones are also quite important. Coal beds and fire clays play a minor part, although economically the former are exceedingly important. All these beds are wonderfully irregular in distribution. They thicken and thin with amazing rapidity and grade from one to another horizontally as well as vertically. * * * The beds of coal vary in thickness up to 7 feet, with an average of about 4 feet. Their areal extent is usually not above a few hundred acres and many of them are much below this maximum. Many of them lie in depressions in the St. Louis limestone, and their limits are determined by this formation. The Cherokee beds form the eastern line of outcrop of the Lower Coal Measures from Van Buren to Webster counties. Their maximum thickness will probably average 500 feet, although over most of their area they are considerably thinner. * * *

The Appanoose formation is typically developed in Appanoose and neighboring counties, as well as across the State line in Missouri. The beds composing this division are much more regular in structure than those underlying them, and the coals, while thinner, are more continuous and dependable. The most important of these coals is the Mystic seam, which underlies an area of about 1,500 square miles in the two States. * * *

Accompanying this coal seam are several relatively thin limestone beds marked, like the coal, by great continuity and uniformity of character. Some shales and a conglomerate are also present. * * *

The upper division of the Des Moines, the Pleasanton, is not of great importance in Iowa. While in Kansas these beds attain a thickness of about 200 feet and carry some important coal seams, they thin to the north and in Iowa are characteristically barren of coal and scarcely distinguishable from the next lower division. They thin rapidly in Guthrie County and probably do not extend beyond the northern limit of this county.

It is not to be understood that these three divisions are sharply set off one from the other, for they are for the most part conformable each to each, and hence there are no clear dividing lines. The divisions are made because each phase exhibits certain well-marked features which set it off in a general way from the others.

J-K 15-16. EASTERN INTERIOR COAL REGION.

The following statement on the eastern interior coal region was prepared for this volume by G. H. Ashley:

The Pennsylvanian of the eastern interior coal region consists of about 2,000 feet of rocks, occupying a simple structural basin that includes most of Illinois, southwestern Indiana, and part of western Kentucky, an area of about 50,000 square miles. The rocks consist of shales, sandstones, coals, clays, and limestones, usually in members of small thickness, many times repeated. Soft shales and sandstones predominate. Coals up to 13 feet thick, usually underlain by stigmarial clays, occur at about forty horizons, and limestones up to 20 feet thick are fully as numerous.

The basin, while mainly structural, was enlarged and extended by pre-Pennsylvanian erosion in the underlying Carboniferous rocks. To the north especially erosion removed successively the several Mississippian formations, and in part of northern Illinois the Pennsylvanian rests on Ordovician rocks.[346]

The oldest Pennsylvanian rocks of the region correspond in age with the Pottsville of the Appalachian region and are confined to the central and southeastern parts of the basin in southern Illinois [900] and probably southern Indiana and the eastern part of this region in Kentucky, this basin probably having been for a time connected with the northern Appalachian field. These rocks are predominatingly sandy, with shale, clay, thin coals, and in many places conglomerate. The sandstone is massive and resistant and now forms a belt of rugged hills along the whole eastern and southern margin. The oldest of these rocks are probably of lower Pottsville age, and the top not older than Sharon, the basal member of the upper Pottsville. Unconformably above these in southern Indiana are 100 feet or less of rocks of later Pottsville age, more shaly in character and containing workable coals in small basins, as well as valuable clays. These rocks may have had an original extent equal to or greater than the underlying sandstones.

Above the rocks just described are about 300 feet of rocks approximately corresponding in age with the Allegheny formation of Pennsylvania. These rocks are predominantly shaly. They contain at least sixteen coal beds, several of which are widely workable, forming the productive part of the Pennsylvanian. The coals are usually underlain by clays and overlain by shales. Most of the shales are either light colored and contain fragments of land plants or a marine or brackish-water fauna, or they are black and highly bituminous and contain an open-sea fauna. As a rule marine limestones closely overlie the roof shales, and at several horizons such limestones underlie the underclays. The beds of this part of the section are very persistent, many coal beds, clays, and limestones having been traced more or less continuously over large parts of the field. The geology of the basin has been described in several State and Federal reports.[a]

The coals have been variously designated by numbers and letters. In Illinois the coals of this part of the series have been called Nos. 2 to 7. In Indiana they are known as coals II to VII, some of which correspond to coals of similar number in Illinois, and for the smaller intermediate coals small letters have been added. Numerals also have been used in Kentucky, where 9, 11, and 12 correspond to V, VI, and VII of Indiana and Illinois.[40, 268, 952]

The upper 1,000 feet of the series is characterized by more limestones, some of them widely persistent, by thinner and fewer coals, and by more sandstone.

In the early reports the Pennsylvanian of this basin was divided into (1) Basal sandstone or Millstone grit, (2) Lower or Productive Coal Measures, and (3) Upper or Barren Coal Measures,[951] the line between the "Upper Coal Measures" and the "Lower Coal Measures" being drawn at a limestone variously known in the reports of different regions as the Shoal Creek, Curlew, Carthage (?), Carlinville, New Haven. and Somerville limestone, local names being also given to some of the other more persistent limestones and sandstones of the coal measures. In 1898 the present writer[36] divided the coal measures of Indiana into "divisions" on the basis of the principal coals, an arrangement continued in his supplemental revised report published in 1909.[40] The sandstone of Pottsville age in Indiana had previously been designated the Mansfield sandstone by Hopkins.[462] In 1900 the series was divided by the writer[37] into the Mansfield, Wabash, and Merom groups, corresponding respectively to (1) the Mansfield sandstone and associated rocks; (2) the rocks between the nonconformities above the Mansfield sandstone and below the Merom sandstone; and (3) the Merom sandstone and overlying rocks. In 1902 and 1903, for cartographic purposes, Fuller and Ashley[347, 348] divided the series above coal VII into the Wabash, Inglefield, Ditney, Somerville, and Millersburg formations, and the upper part of the series, below coal VII, into the Petersburg and Brazil formations.

In view of the probable difficulty of carrying the bounding lines of these formations over all the basin, the names have not been retained in recent work. Since 1906 White and Weller have done considerable paleontologic work in all parts of the basin, in addition to the stratigraphic work in Illinois by DeWolf and in Indiana by the writer. (See references above.) As a result, the Pennsylvanian of the eastern interior basin has been divided into three formations, the first, or Pottsville, extending from the bottom of the series up to the top of the underclay of coal II in Indiana and coal No. 2 in Illinois; the second, or Carbondale formation, extending from that horizon up to and including coal No. 6; and the third, or McLeansboro formation, from the top of coal No. 6 to the top of the series. It is possible that future work may show that the limestone which in the Illinois State reports has been called Shoal Creek limestone can be traced over all of the basin, and that it may again be used as a line of division between the upper and lower parts of the McLeansboro formation. Coal V of Indiana, which appears to be the same as coal No. 5 of Illinois and coal 9 of Kentucky, may be developed throughout most of the coal field. If future tracing shows that it is, it may possibly be used

[a] Illinois State Geol. Survey, vols. 1-7, 1866-1890; Bulls. 3, 4, 6, 8, 1906. Indiana Dept. Geol. and Nat. Hist., vols. 1-14; vol. 23, pp. 1-1573, containing a detailed report; vol. 33, containing a revised supplement to the report in vol. 23. Kentucky Geol. Survey, vols. 1-4; vols. 1-5, new series; reprints A, C, D; Bulls. 3, 4. U. S. Geol. Survey, folios 67, 84, 105, Geol. Atlas U. S.; Twenty-second Ann. Rept., pt. 3, 1902, pp. 272-303.

as the dividing line between two formations in the middle member. Again, future work may show it possible to divide the beds of Pottsville age into at least two formations, the upper one including the more shaly portion unconformably overlying the Mansfield sandstone.

The table opposite shows the subdivisions of the Pennsylvanian that have been made in the several fields of this region, with their known or probable correlations.

K 16. MICHIGAN.

The Michigan section of the Pennsylvanian is discussed by Lane[519] in a paper recently published. It comprises the Parma sandstone and Saginaw formation and is wholly of Pottsville age.

The Parma is a sandstone with small white pebbles of the size of split peas. According to Lane it may be regarded as the basal shore phase which was deposited earlier in the deeper and later in the marginal portions of the basin. It is thus synchronous in part with the Saginaw. The thickness assigned to the Parma in a well at Saginaw is 60 feet.

The Saginaw formation is described by Lane[519h] as a succession of white shales or sandstones, black shales and coal, and blue shales, with a few thin bands of blackband iron ore and nodules of siderite containing zinc blende and iron pyrites. Limestones with marine fossils occur but are rare. *Lingula carbonaria* or *mytiloides* is found in the black shales. It appears to mark the horizon of the Upper Verne coal, which in places lies close above the Lower Verne coal, separated from it by a limestone.

The flora of the Verne coals, which Lane lists, is assigned by David White to the horizon of the Mercer coal, or upper Pottsville. Nothing younger than Pottsville is known, and it is probable that the earliest Pottsville is not represented in Michigan, even in the center of the basin.

To the account of the coal measures for this volume G. H. Ashley has contributed the following notes regarding Michigan:

The Pennsylvanian of Michigan is nearly everywhere deeply buried beneath glacial drift, so that our knowledge of its thickness, distribution, and stratigraphy depends almost altogether on drillings. Including the Parma sandstone at the base, it covers an area of about 11,000 square miles, of which the coal-bearing part of the series covers possibly 6,500 square miles.[516a] This area is situated in about the center of the Southern Peninsula. The structure is that of a "very flat, gentle synclinorium, whose longest axis is perhaps from northeast to southwest. This is modified by minor undulations."[515a] The Pennsylvanian has a thickness of 700 feet or more, including the Parma sandstone at the base. This sandstone is about 100 feet thick, though measurements up to 145 feet are reported and measurements below 100 feet are common. In places the sandstone is absent.[171]

For the rocks above the Parma sandstone the name Saginaw formation has been used.[514] This formation consists of sandstone and shale, with coal, clay, limestone, and iron carbonate in nodules or thin beds. Coal occurs at twelve or more horizons.[171a] The coals appear to lie on floors of irregular surface, varying in thickness to correspond—that is, the coal is thicker in the low places or "swamps" and thinner in the higher places. Many of the low places have the shape of a trough. The coals may range in thickness up to 5 feet; most of the merchantable coal is less than 4 feet, and some less than 2 feet. Under the coal is usually clay, and over it black shale, with blue shale and limestone above. Cannel coal or cannel-like coal is associated with many of the Michigan coal beds, usually at the top of the bed. Sandstones are abundant in the Saginaw formation, many of them as thick beds of white sandstone, in places grading into red at the top.[515] They do not occur at any constant horizon in the formation.

A comparison of the dip of the higher members of the Saginaw with that of the underlying strata and the stratigraphic sections in various parts of the basin indicates that at least part of

Correlations in eastern interior coal region.

[By G. H. Ashley.]

White, David, correlations with Appalachian field. See paper quoted in next column.	Ashley, G. H., Supplementary report on the coal deposits of Indiana: Thirty-third Ann. Rept. Dept. Geology and Nat. Res. Indiana, 1909.	*Feet.*	Ashley, G. H., The coal deposits of Indiana: Twenty-third Ann. Rept. Dept. Geology and Nat. Res. Indiana, 1899.	Fuller, M. L., and Ashley, G. H., Ditney folio (No. 84), Geol. Atlas U. S., U. S. Geol. Survey, 1902. Fuller, M. L., and Clapp, F. G., Patoka folio (No. 105), idem, 1904.	Cox, Collett, and others, earlier usage of Indiana Geol. Survey.	Kentucky Geol. Survey reports.	Illinois Geol. Survey reports.	Ashley, G. H., The eastern interior coal field: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1902, p. 273.	Bull. Illinois Geol. Survey No. 16, 1910, p. 181; No. 17, 1912, p. 74.
	Rocks, with Aldrich and Friendville coals Parker coal	200 1		Wabash formation.					
	Interval Merom sandstone	120 40	Merom sandstone.	Inglefield formation.	Merom sandstone.		*Feet.* Sandstone, shale, and thin coals. 450 Upper Coal Measures.	Merom group.	
Post-Allegheny.	Interval with coals VIII *a* and *b*	90	Division VIII.	Ditney formation.		Coal 18.	Shoal Creek or Carlinville limestone.		McLeansboro formation.
				Somerville formation.		Carthage limestone.			
	Coal VIII (0–4)	1	Coal VIII.		Coal N.				
				Millersburg formation.		Coals 17–13.	Lower Coal Measures.		
	Interval Coal VII (0–6)	70 4	Division VII. Coal VII.	Millersburg coal.	Coal M (N, L, K, etc.).	Anvil Rock sandstone. Coal 12 or A.	Interval.. 180–270 Coal 7.		
	Interval (6 inches to 60 feet) Coal VI (0–9)	40 6	Division VI. Coal VI.	Millersburg coal (lower bench).	Coal L (N, M, K, etc.).	Coal 11 or B.	Coal 6.		
	Interval, coals V *a* and *b* Coal V (4–11)	70 7	Division V. Coal V.	Petersburg formation. Petersburg coal.	Coal K (L, M, Y, etc.).	Coal 9 or D.	Coal 5.	Wabash group.	
Allegheny.	Interval, coal IV *a* Coal IV (2–7)	130 5	Division IV. Coal IV (VII).	Brazil formation. Survant coal ?	(Coal N, etc.).	? Coal 7 or F ?	Coal 4 ?		Carbondale formation (includes coal No. 6 or Herrin coal at top and coal No. 2 or Murphysboro coal at base).
	Interval, coals III *a* and *b* Coal III (0–11)	70 6	Division III. Coal III (VI).	Rock Creek coal ?	(Coal L, etc.).	? Coal 6 or Fa ?	Coal 3 ?		
	Interval, coals II *a* to II *e* Coal II (0–4)	100 2	Coal VI.	Holland coal ?	Coal L.	? Coal 5 or Fb ?	Coal 2 ?		
	Interval (6 inches to 40 feet) Minshall coal (0–6)	20 4	Coal V.		Coal K.				
	Interval Upper Block coal	30 3	Coal IV.		Coal I.	? Coal 4 or G ?			
Pottsville.	Interval Lower Block coal	30 3	Coal III.		Coal F.	? Curlew limestone ?			Pottsville formation.
	Mansfield sandstone, etc. Cannelton coal (0–5) Sandstones, shales, and coals	100 3 50	(Division I). Coal II (I). Coal I.		Conglomerate series or Millstone grit. Coal A.	Conglomerate measures. Coal 1 B or L or Main Nolan.	Battery Rock coals. Caseyville conglomerate.	Mansfield group.	

the earlier Pennsylvanian was confined to the center of the basin, the strata of later age extending outward by overlap to the present limits of the coal field and beyond.[515]

The Pennsylvanian of Michigan appears to be all of Pottsville age.[516] From a study of the plants David White has suggested that the Verne coals, near the top of the series, may come at about the horizon of the Mercer coals of Pennsylvania. The basal sandstone, or Parma sandstone, may be of the age of the Sharon conglomerate member of the Pottsville of Ohio and Pennsylvania.

K 19. RHODE ISLAND AND EASTERN MASSACHUSETTS.

The Carboniferous strata in Rhode Island occupy the Narragansett Basin, which has been described by Shaler, Woodworth, and Foerste. From fossil plants obtained in these beds Lesquereux considered them equivalent to beds of the upper Carboniferous (Pennsylvanian) in Pennsylvania. Woodworth[732] tabulates the strata as follows:

Tabular view of the strata in the Narragansett Basin.

Group.	Northern field.		Southern field.		Remarks.
	Local areas.	Characters.	Local areas.	Characters.	
Dighton (1,000–1,500 feet).	Rocky Woods conglomerate. Seekonk conglomerate.	Coarse quartzite and granitic pebble conglomerates, with finer conglomerates and sandstone.	Purgatory conglomerate.	Coarse quartzite pebbles, usually much elongated and indented.	Probably though not certainly identical in all parts of the field, lying in synclines above the Coal Measures.
Rhode Island Coal Measures (10,000 feet).	Westville shales and Seekonk sandstones. Tenmile River beds. Mansfield beds. Cranston beds. Sockanasset sandstones. Pawtucket shales.	Alternations of fine and medium quartz, quartzite and granitic pebble conglomerates, with pebbly sandstones, sandstones (graywacke), shales, and coal beds, becoming metamorphic southward. Colors, black, blue, green, gray, locally red. Odontopteris flora and insect beds.	Aquidneck shales of Dr. Foerste. Kingstown series of Dr. Foerste.	Mainly shales with coal beds. Mainly sandstones and conglomerates with coal shales; usually metamorphic.	Both the Aquidneck and Kingstown series of Dr. Foerste, when traced northward, appear to form equivalent sections beneath the Dighton group, one on the eastern, the other on the western side of Narragansett Bay, and both extend downward to the basal beds in this typical area.
Wamsutta (1,000 feet).	Wamsutta {Slates and shales. Attleboro sandstone. Wamsutta conglomerates.	Beds of quartz, quartzite, felsites, felsite breccias, and felsite conglomerates, sandstones, arkose, and shales. Colors, red, locally brown, and green. Calamites.			The Wamsutta beds are not traceable south of Providence; probably represented by lower strata of Dr. Foerste's Kingstown series. In the vicinity of Pawtucket the Coal Measures underlie the Wamsutta.
Pondville (100 feet).	Millers River conglomerates, arkose beds.	Quartz conglomerates. Coarse, white, granitic waste or arkose.	Basal beds.	Quartzose conglomerates and arkose.	Essentially similar products of decayed granitic land surface in all parts of basin.
Unconformity.	Widespread erosion interval, representing all of Silurian and Devonian time and probably upper Cambrian.				
Pre-Carboniferous.	Broad exposures of granitite intruded into lower and middle Cambrian and pre-Cambrian sediments.		Same as in northern field.		Pre-Carboniferous strata not definitely determined; Cambrian or pre-Cambrian.

Sayles and La Forge[705] have published a note on faceted and striated pebbles from the Roxbury conglomerate, from which they conclude that the conglomerate is in part at least of glacial origin. They say:

The tillite occupies the upper portion of what has been known as the Roxbury conglomerate and at Squantum is from 500 to 600 feet thick and is overlain by about 60 feet of stratified conglomerate, sandstone, and interbedded slate, which make the top of the Roxbury and form a transition to the overlying Cambridge slate. The possible glacial origin of the Roxbury conglomerate has been suggested by the late N. S. Shaler and others, but these are the first known discoveries in that formation of definite evidence of glacial action or of the existence of glacially deposited beds.

They conclude that the Roxbury conglomerate and Cambridge slate are probably of Permian age.

The Boston Basin of eastern Massachusetts contains terranes which have been assigned to the Carboniferous, in part on physical and in part on paleontologic evidence, and which consist of arkose, conglomerate, sandstone, and slate. The rocks were described by Crosby[182] and have been made the subject of a very detailed study by Mansfield,[570] who has given special attention to the origin and distinguishing characteristics of the conglomerates. He describes them under the headings "Roxbury series," "Norfolk Basin series," "Narragansett Basin series," and "Harvard conglomerate." These distinctions are areal rather than stratigraphic and are made because in the absence of fossils and under the conditions of occurrence exact stratigraphic correlation among the small areas of outcrop was not practicable. Mansfield[570a] concludes that—

The evidence adduced in the preceding paragraphs as to origin is largely negative and unsatisfactory. The bedding and texture of the sediments, though attaining a fair degree of regularity, do not display these features in so high a degree of development as might be expected in true marine strata. The apparent gradation upward from coarse to fine texture in the Boston Basin, suggestive of marine transgression, is offset by the occurrence in the Narragansett Basin of a gradation in the opposite direction, suggestive of nonmarine deposition. The fossils thus far found in the Narragansett and Norfolk basins are indicative of nonmarine rather than of marine origin. Similar evidence is borne by the irregularities of bedding and of texture. The lithological similarity of the Roxbury conglomerate to the rocks of the Norfolk and Narragansett basins makes it probable that all are of like origin and that the entire Carboniferous series of this region is nonmarine. More than one process, however, was concerned in the formation of the series. The more regular and even-bedded portions are suggestive of quiet fluviatile or lacustrine origin, while the more irregular and tumultuous portions of the deposit indicate torrent action. The great quantity of large pebbles of relatively fresh granite and the abundance of feldspathic material in the sandstones and in the matrices of the conglomerates suggest that much material was furnished to the streams of that time by glaciers of which no direct evidence now exists.

In describing the geology of Worcester and vicinity, Perry and Emerson,[634] after giving an account of local occurrences, summarize the facts relating to the Carboniferous as follows:

Starting at Worcester, as a center, we find first and uppermost the Worcester phyllite. This rock underlies the central part of the city and may be traced southwesterly and northeasterly across the State. It presents varying stages of metamorphism, from a true argillite to a well-defined mica schist, and contains in different places minerals resulting from metamorphism, as garnets, chiastolite, graphite, staurolite, and anthracite. The laminæ of the phyllite are frequently highly crumpled, producing folds almost infinitesimal in size and infinite in number. In some places these fine folds have been so compressed and flattened that they constitute the beginning of folia of a new structure across the old. In one place, also, this rock exhibits the development of a new structure by the rotation in sections of the laminæ between fault planes.

That the phyllite is really uppermost in position with reference to the other rocks of sedimentary origin found in Worcester is shown by its superposition in anticlines. In deciding as to its position in the geologic series—that is, its age—we rely on the specimens of *Lepidodendron acuminatum* found at the so-called coal mine here in Worcester, and we assign it to the Carboniferous. It probably belongs to an early part of that period.

On the east this phyllite blends into a rusty, fibrolitic, graphitic mica schist which is found in small, detached patches within the Bolton gneiss area. These are probably remnants, indicating the former greater extension of this schist formation.

The second and lower formation in Worcester is a micaceous quartzite of a brownish-gray color. This is associated with the phyllite in the latter's extent across the State and occurs in bands east and west, sometimes also in the midst, of the phyllite.

Because of the close relationship which these two formations bear to each other, the micaceous quartzite is also assigned to the Carboniferous period. They have been folded together on a large scale in the Oakdale-Millstone Hill anticline, the phyllite above and the quartzite beneath, and they have been crumpled together on a small scale in many places, as may be seen in the rocks of the deep cuts of the Boston & Albany and Boston & Maine railroads here in Worcester. These two formations appear, as far as can be seen in the midst of such severe folding, to be conformable.

Like the phyllite, the quartzite also shows the development of a new or secondary structure across the old or original structure; and in the case of the rock of Wigwam Hill the new structure was formed by the compression of small folds in the micaceous part of the quartzite, so that these compressed folds have become the folia of the schist as it is at the present time. This quartzite is in a few places conglomeratic, and the pebbles show deformation by pressure, being more or less flattened in the plane of the laminæ.

Penetrating the Carboniferous phyllite and quartzite are granite bosses, of which Millstone Hill is typical. These granites are later than the Carboniferous. That of Millstone Hill contains inclusions of both the phyllite and quartzite. The structure of the adjoining Carboniferous quartzite wraps around this granite, sometimes with the original bedding and sometimes across it. The rocks in the immediate vicinity of the granite have been greatly shattered and now frequently appear as breccias or made up of small angular blocks cemented together by fine quartz veins. Even the phyllite included in the granite is brecciated, indicating that the pressure was not excessive when this was included in the molten granite, hence that this granite did not solidify at a very great depth beneath the surface of the earth. * * *

The Carboniferous quartzite, traced to the east, blends into a coarser-grained, more highly metamorphosed quartzose mica schist, frequently containing alternating hornblendic bands. Between the laminæ of this schist there has been forced, by parallel injection, much coarse granite. This schist and granite afford many minerals, both original and secondary, as enumerated in the study of the quarry near Quinsigamond. The alternation of schist and granite is very gneissoid in appearance and often presents a close resemblance to a metamorphic conglomerate. From this appearance, and from the fact that it extends through the town of Bolton and there contains the well-known limestone mineral locality, this phase of the Carboniferous quartzite is called the Bolton gneiss.

It is upon this Bolton gneiss that are spread the patches of the rusty, fibrolitic, graphitic mica schist phase of the Carboniferous phyllite already referred to as indicating the former greater extension of that formation.

Within this Bolton gneiss are also small areas of crystalline limestone in the towns of Boxboro, Bolton, Northboro, Millbury, and Webster. These crystalline limestones abound in minerals formed during the metamorphism, and the Bolton and Boxboro limestones have long been noted for the scapolite and other minerals they afford. * * *

The Bolton gneiss may be traced northeasterly, easterly and southeasterly from Worcester and is found underlying Oxford, Millbury, Grafton, Shrewsbury, Northboro, Berlin, Bolton, Boxboro, and other towns to the northeast. It is seen from this that the Bolton gneiss makes up a large portion of the eastern part of the plateau of central Massachusetts. * * *

It is well for us, therefore, in tracing the Bolton gneiss, to follow a southeasterly direction through the town of Millbury into the town of Sutton. * * * In this direction we find that the Bolton gneiss extends from Worcester through Millbury and the northwestern part of Sutton; then as we go still farther to the southwest, in the vicinity of West Sutton, we become aware that the rock beneath is quite different. This change from one formation to another may be nicely seen about three-fourths of a mile southwest of West Sutton.

This more ancient formation consists, generally, of a light-colored, nearly white, finely grained, sugary quartzite, which is at times actinolitic. It constitutes a comparatively narrow band extending through the towns of Webster, Oxford, Sutton, Grafton, and Westboro and is called the Westboro quartzite. As it dips beneath the Bolton gneiss on the western side of a large anticline, the quartzite is considered older than the gneiss. In appearance this quartzite reminds one of the Cambrian quartzite of western Massachusetts, though there is nothing in this eastern rock to definitely fix its geological age. * * *

We have now briefly considered the rocks from Worcester to the eastern and southeastern border of the plateau of central Massachusetts, bringing out the relation of each to the succeeding one, as far as we can. Let us next start from Worcester, and, in like manner, trace the rocks westerly. Passing over the phyllite, which is found underlying the central part of Worcester and which has already been considered, we find in the western part of the city the Carboniferous micaceous quartzite, identical with that found east and in the midst of the Carboniferous phyllite. This arrangement of these two formations is due to folding and subsequent erosion, by which the lower one is revealed alongside of the upper.

On following this micaceous quartzite in the extreme western part of Worcester the rock becomes coarser in grain and abounds in parallelly injected granite, giving an appearance that frequently simulates a metamorphic conglomerate. This western and more highly metamorphosed phase of the Carboniferous quartzite has been called the Paxton schist, from its occurrence in that town, just as the similar gneissoid extension of the same quartzite on the east is called the Bolton gneiss. The Paxton schist is less gneissoid than the Bolton gneiss because of a smaller proportion of injected granite.

Lying above the Paxton schist, as is shown by its upper position in an anticline in the northwestern part of Worcester, is a rusty, graphitic, fibrolitic mica schist identical with the rusty, graphitic, fibrolitic mica schist found in patches within the area of the Bolton gneiss. This rusty schist has been crumpled into almost innumerable folds, both large and small, and contains much injected granite. Lying as it does above the Paxton schist, which is a more highly metamorphosed phase of the Carboniferous quartzite, this rusty schist bears the same relation to the Paxton schist that the Worcester phyllite bears to the Carboniferous quartzite; also on the east side of Worcester there is, in a small area, a transition from the phyllite into a like rusty, graphitic, fibrolitic schist; this rusty schist in the western part of Worcester, called the Brimfield schist, is then, a more highly metamorphosed or more coarsely crystallized phase of the Worcester phyllite and belongs to the Carboniferous period. This Brimfield schist, in addition to making up large areas, also occurs in limited patches within broad areas of the Paxton schist. These patches probably indicate the former extension of this upper Brimfield schist and are remnants that have escaped in the profound erosion by which the rock surface of this plateau has been formed. These two rocks, the Paxton and Brimfield schists, together with their included eruptives, make up the plateau of central Massachusetts westerly from Worcester to the boundary as already defined.

But these Carboniferous rocks have even a greater extension to the south and north and may be traced far into Connecticut on the one hand and beyond the Massachusetts boundary into New Hampshire on the other.

L 19-20. NEW BRUNSWICK.

The Carboniferous of New Brunswick comprises Mississippian, Pennsylvanian, and Permian strata. Bailey has summed up the general facts in an article, quoted at some length in Chapter VIII, from which the following [45b] regarding the "Coal Measures" is taken:

The contrast between the above-described rocks [lower Carboniferous] and those of the coal formation is, in the central counties, usually very marked, the bright-red color so characteristic of the one being replaced by an equally characteristic gray color in the other, while at the same time the strata cease to be calcareous. The basal beds of the coal formation are especially noticeable as being very light colored and almost entirely made up of well-rounded pebbles of white quartz. Conglomerates which are somewhat less coarse occur also higher in the series, but with them are beds of coarse sandstone and thinner beds of shale, with, in places, thin seams of coal. Upon the shore of the Baie des Chaleurs about 50 feet of fine shales, gray, green, or red in color, with limestone nodules, extend for several miles in the coastal cliffs about New Brandon, resting upon gray sandstones, but over the larger part of the central coal field the absence of fine sediments is a noticeable and unpromising feature.

Though gray is the prevailing color in the rocks of the coal formation, it is necessary to add that it is not unfrequently replaced by a dark purple tint. Occasionally also the beds are reddish, but where this is the case it is always a question whether the rocks so colored are not of the next division, viz, the newer coal formation or Permo-Carboniferous.

The only data available with regard to the thickness of the coal formation in the Central Basin is that to be derived from borings, particulars of which will be given later. The greatest attained at Grand Lake was 400 feet. At Dunsinane, in Kings County, a depth of 1,200 feet was reached, apparently all in the Carboniferous. In Westmoreland County north of Moncton a depth of 700 feet has been reached in apparently Carboniferous strata. In Albert, where the strata are more highly tilted, the Carboniferous rocks alternate, by displacement, with lower Carboniferous beds, but never attain any considerable thickness.

CHAPTER XI.

PERMIAN.

Color, light gray.
Symbol, 11.
Distribution: Southwestern United States; West Virginia, Ohio, and Pennsylvania; New Brunswick and Nova Scotia. Elsewhere mapped with "Carboniferous undivided." (See fig. 13.)
Content: Permian limestone and red beds, Kansas to Texas; Permian red beds, New Mexico; Opeche and Minnekahta formations, Black Hills; Dunkard group of the northern Appalachians; red and gray sandstones and subjacent New Glasgow conglomerate of New Brunswick, Nova Scotia, and Prince Edward Island. Includes some Triassic red beds in mapping.

Permian areas.

H–I 13–14. TEXAS AND NEW MEXICO.

The strata assigned to the Permian in trans-Pecos Texas and adjacent parts of New Mexico comprise the Delaware Mountain formation, the Capitan limestone, the overlying unnamed sandstones and limestones on the eastern flanks of the Guadalupe Mountains, and the red beds of Pecos Valley, which include the Castile gypsum and the Rustler dolomite. These formations outcrop in the areas colored as Carboniferous undivided, and Richardson's descriptions of them are given in Chapter VIII (p. 360).

The Delaware Mountain formation and the Capitan limestone contain a unique fauna, named the Guadalupian, which has been described in detail by Girty,[364, 367] who tentatively assigned it to the Permian. (See p. 359, Chapter VIII.)

The Capitan limestone, the uppermost formation known to contain the Guadalupian fauna, on the eastern flanks of the Guadalupe Mountains, southwest of Carlsbad, N. Mex., is overlain by a few thousand feet of sandstone and limestone to which formation names have not yet been given. These in turn are overlain by the red beds of Pecos Valley, which, according to Richardson[670a]—

consist of a group of varicolored sandstone and shale, red predominating, interstratified with beds of magnesian limestone and gypsum. In detailed study it is desirable to divide these rocks

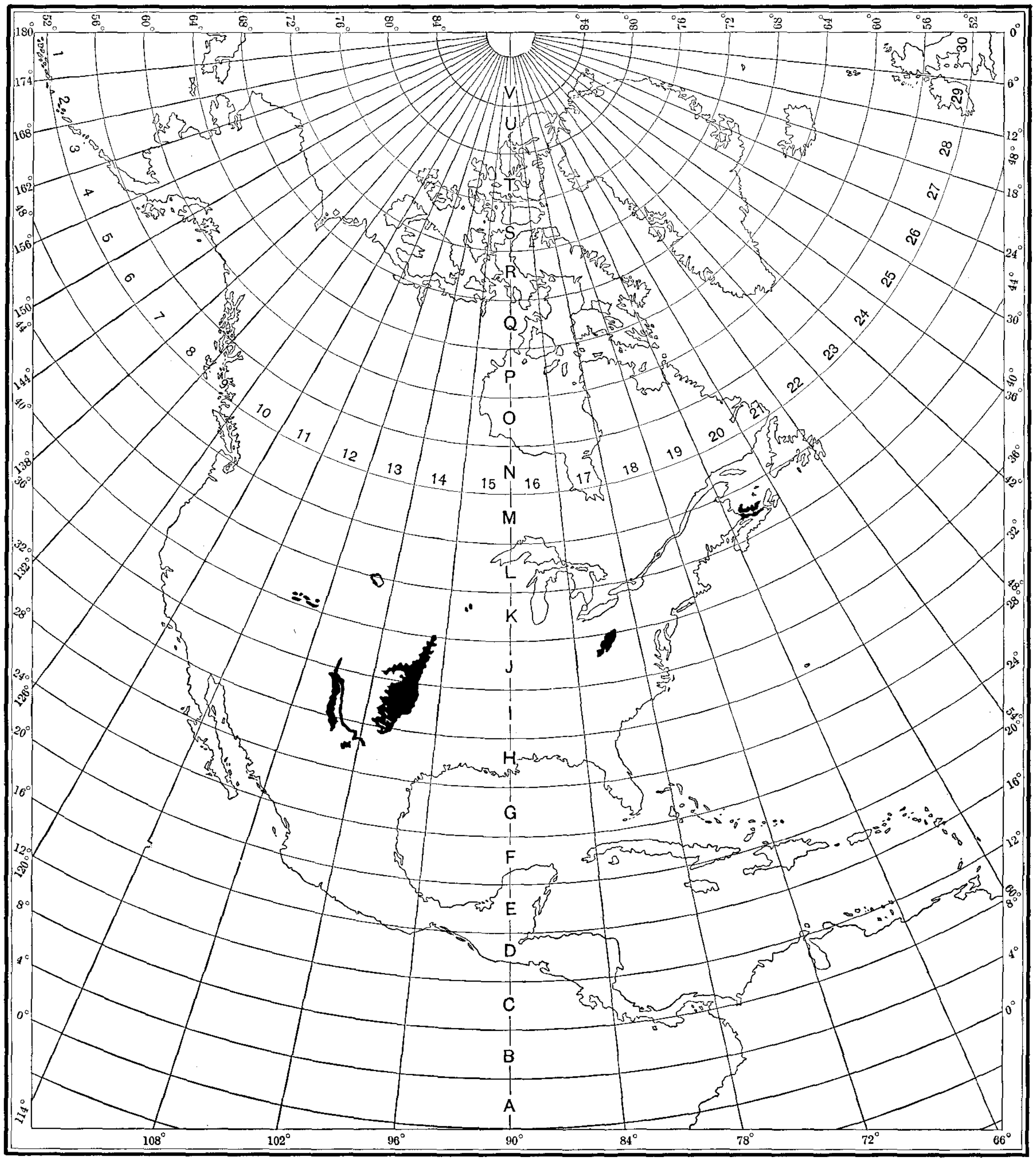

FIGURE 13.—Sketch map showing the distribution of Permian rocks that are separately represented on the geologic map of North America and the key to references in the text.

into a number of formations of comparatively limited extent similar to the Castile gypsum and the Rustler formation, which when traced for a number of miles beyond the area in which they were named lose their individual character and become difficult to recognize as such. The formations of the red-bed group are characteristically lenticular. * * *

The red beds of Pecos Valley are delimited above, as Cummins and Drake determined a number of years ago, by an erosional unconformity, which separates them from the overlying Dockum formation, of Triassic age. The lower limit of the red beds of Pecos Valley, defined as the lowest occurrence of either red strata or of gypsum, is variable and is not a definite horizon but rather forms a zigzag line extending diagonally across the strike of the rocks. * * * [In central New Mexico] almost the entire Carboniferous section is composed of red beds.

Fossils are of rare occurrence in these red rocks, although at a few localities shells have been obtained from the interbedded limestones, and fragments of fossil wood also have been found. Dr. Girty does not feel justified in saying anything definite as to the age of the fossils collected from the red beds either by Mr. Fisher or by myself. These include *Schizodus ovatus* and *Pleurophorus* aff. *subcostatus* from 7 miles northwest of Roswell, N. Mex., and a Schizodus having the general shape of *S. harei,* and a form suggesting by its shape a small Myalina from the Rustler Hills, El Paso County, Tex. Nevertheless the stratigraphy indicates that the red beds of the Pecos Valley are to be correlated with part of the Permian red beds of Oklahoma and northwest Texas, for they were connected by tracing around the northern border of the Staked Plains, by W. F. Cummins in 1891. * * * Cummins's work has been confirmed by C. N. Gould, who has mapped the Greer and Quartermaster formations, which are part of the Permian red beds of Texas and Oklahoma, across several counties in the panhandle of Texas, and along the Canadian River as far as the Texas-New Mexico boundary.

This stratigraphic correlation is in agreement with paleontologic data recently obtained by Dr. J. W. Beede, * * * who found fossils in a limestone in the red beds south of Lakewood, N. Mex., which he correlates with the Whitehorse-Quartermaster fauna.

The Permian of northern Texas is continuous with that of Oklahoma in area and stratigraphy. It comprises red beds, which grade southward into blue clays and limestones, just as the red beds of Oklahoma change northeastward into similar rocks. Cummins[198] says:

In previous discussions of the Permian formation in Texas [a] I have separated the strata into three divisions, naming them Wichita, Clear Folk, and Double Mountain, the Wichita being the lowest in the series. In my description of the Coal Measures in Texas I separated the strata into five divisions, giving to the upper division the name of Albany and the one immediately below that the name of Cisco. * * *

The Wichita division was described as extending southward as far as the Salt Fork of the Brazos River. It is represented as resting on the top of the Cisco division of the Coal Measures, along its entire eastern border, and as being overlain by the Clear Fork division along its entire western border.

The Albany division of the Coal Measures was described as beginning on the north at the Salt Fork of the Brazos River and extending southward to the southern limits of the Coal Measures in the State, resting directly upon the Cisco division and overlain on the west by the Clear Fork division of the Permian. It will therefore be seen that the Wichita and Albany divisions were made to occupy the same stratigraphic position.

At the time these divisions were first described the relationship between them could not be determined from the facts then in my possession. The area of the Wichita division was known to be Permian and had been somewhat described prior to my giving it the present designation. It was embraced in the area known as the "Red Beds" of Texas. In it the invertebrate fossils were partly those known to occur in the Upper Coal Measures, and partly those that were char-

[a] See Ann. Repts. Geol. Survey Texas, 1889 to 1892.

acteristic of the Permian in Europe. The vertebrate fossils, which had been found quite abundantly in the area, were forms peculiar to the Permian. The area was therefore assigned to the Permian without any hesitancy.

The fossils that had been taken from the area assigned to the Albany division were only such invertebrate fossils as had been found in the Upper Coal Measures, and no vertebrate fossils had been found.

Instead of the strata being composed of red clay beds and sandstones, as was the case in the Wichita division, they were principally limestones and yellowish and bluish clays. In view of these dissimilarities it was thought best to describe the two areas under different names, although it was thought at the time that it was more than probable that the Wichita and Albany divisions were but different facies of the same beds. * * *

During my recent examinations the true stratigraphic relation between the two divisions has been brought out, and I can now say with absolute certainty that they are the same in time and belong to the Permian.

The Wichita division is now admitted by everyone to be Permian. This conclusion is based chiefly on the fossils that have been taken from the area and which have been described and determined by different specialists.

Prof. E. D. Cope described the vertebrate fossils collected from this division, a list of which was published in the second annual report of the Geological Survey of Texas. These fossils show the Permian age of the beds as plainly as any one kind of life can show the age of any formation.

The invertebrate fossils were partly described by Dr. C. A. White, and a list of his determinations was published in the second annual report of the Texas Geological Survey. The evidence from this source strongly corroborates the conclusion reached by a study of the vertebrates, showing the Permian age of the division.

Part of the flora collected from the division was described by Dr. I. C. White, and the evidence thus obtained also corroborated the conclusion of the Permian age of the strata.

Williston[a] dissents from this statement and cites Case,[131] who summed up the evidence as follows:

The evidence for the Permian character of the beds rests, then, on the presence of a single genus, Naosaurus, common to the Permian of North America and Europe, and on the community of many very primitive characters and numerous more specialized ones, which, however, reach either down into the Carboniferous below or up into the Triassic above.

Cummins continues:

The Permian age of this division being admitted, it follows that if the Albany division is but a different facies of the same bed it also must be Permian. This fact has been abundantly shown by the stratigraphic work done during the past season by myself and party.

In previous years I made and published complete sections, by instrumental measurement, across the area of the Albany and Wichita divisions at right angles with the strike, and gave descriptions of the different beds composing the divisions, with a partial list of the fossils collected from them. The lines of these sections were about 70 miles apart. The section across the Albany division began at Albany and ran thence in a northwestern direction, crossing the Clear Fork of the Brazos River at the mouth of Fish Creek. The section across the Wichita division began at a point 8 miles north of the town of Seymour and ran thence to Wichita Falls.

During the past year (1894) I have traced prominent beds found in each of these divisions across the country between these two sections, and have found them to be continuous from one to the other. By this means I was enabled to see the gradual change in the beds and to understand that they were the same in time of deposition.

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[a] Personal communication.

The panhandle of Texas has been surveyed by Gould,[374] who gives the following section and description of the gypsiferous red beds and sandstones below the Cretaceous:

Geologic formations of the Texas panhandle.

System.	Formation.		Characteristics.
Triassic.	Dockum group.	Trujillo.	Red shales. Red to gray sandstone and conglomerate (upper sandstone). Red shales. Red to gray cross-bedded sandstone and conglomerate (middle sandstone). Red shales. Massive to cross-bedded sandstone (lower sandstone).
		Tecovas.	Dark-red or magenta shales and soft sandstones. Variegated shales and soft sandstones.
Carboniferous (Permian).	Quartermaster.		Red clay. Massive white dolomite (Alibates lentil). Red clays. Massive white gypsum (Saddlehorse lentil). Red shales.
	Greer.		Massive white gypsum in ledges interstratified with red shales.

By far the greater part of these rocks are of Permian, Triassic, or Tertiary age. The Permian and Triassic rocks are generally spoken of as red beds, owing to the predominating color of the clay which forms a large proportion of these deposits.

Farther east in Texas and particularly in Oklahoma the Permian red beds are well exposed and have been divided into five formations—the Enid, Blaine, Woodward, Greer, and Quartermaster. In the region here described only the two upper formations of the Permian red beds occur, and these are found in the deep canyons, where erosion has cut through the overlying Triassic and Tertiary formations. The Triassic red beds are exposed along the edge of the Llano Estacado in Texas and New Mexico, as well as in the canyons cut by the various streams that rise in the southern part of the High Plains.

The formations are described and correlated in detail in the report by Gould, and references to earlier work are given.

In a recent article on the Wichita formation of northern Texas, Gordon [371] submits results of investigations made in connection with a study of the underground-water conditions of that area. The invertebrate fossils are discussed by Girty and the plant material by David White. In regard to the correlation and classification, Gordon has the following to say:

That the limestone series of Baylor County is the equivalent of the "Albany" formation of the southern area is fully established by both the stratigraphic and the faunal evidence. The beds in the northern area, which include the limestones, shales, and sandstones of Baylor County and the sandstones and shales of Archer and Wichita counties, constitute the Wichita formation. Our investigations therefore fully support the conclusions of Cummins and Adams as to the equivalency of the "Albany" and Wichita formations. * * *

The Permian age of the beds to which the name Wichita was originally applied has been accepted quite generally, though there are not wanting those who regard the evidence as unsatisfactory. It was based chiefly upon the vertebrate and plant remains. In the southward or

"Albany" area the beds are wholly marine and destitute of both plants and vertebrates, though abounding in the remains of invertebrates. The Pennsylvanian aspect of this fauna has strongly impressed some investigators, including the author of this paper, and doubt was entertained as to whether the plane of separation between the Pennsylvanian and the Permian should be drawn at the base or at the top of the formation. The studies of David White, Beede, and others have contributed much in recent years to a knowledge of the Permian in America and in the main support the view of the Permian age of the Wichita formation. In a recent paper Beede has ably discussed the Permian of Kansas, with which he correlates the "Red Beds" of Texas. Cummins correlates the beds of eastern Baylor County which he regards as the top of the Wichita formation with the Fort Riley limestone of the Chase group of Kansas. * * * The top boundary of the Wichita formation was drawn by Cummins at the top of a stratum of red clay overlain by thin beds of limestone and blue shales at a point on the Big Wichita 4 miles west of the east boundary of Baylor County. However, as we have shown, beds which are undoubtedly the same as those which appear at Seymour and southward in Throckmorton County appear in the banks of the Big Wichita River some 8 to 10 miles west of this point. The thickness of the strata included here, which overlies Cummins's topmost beds and are here included with them in the Wichita formation, is estimated to be 250 to 300 feet. The whole limestone and shale series of Baylor County thus included as the upper division of the Wichita formation is provisionally placed at 450 to 500 feet and consists, as shown elsewhere, of limestone beds of varying thicknesses separated by varying but usually great thicknesses of shale.

How much of this is to be correlated with the Fort Riley limestones can be determined only by more detailed stratigraphic and paleontologic studies. Cummins evidently intended to include the lower beds only in his correlation. It may be that further studies will show that the overlying beds of the Winfield limestones of Kansas are represented here.

In regard to the fauna Girty says:

Not until recently, it seems to me, has adequate evidence been adduced either for distinguishing the Permian of Kansas and that of Texas sharply from the underlying Pennsylvanian or for correlating them with the Permian of Europe. C. A. White found the Wichita fauna to have essentially a Pennsylvanian ("Coal Measures") facies, in which, however, certain characteristic Permian ammonites occur. A similar conclusion seems to be demanded by the evidence of the present collections. * * *

Mr. White finds that about 50 per cent of the Wichita flora consists of species characteristic of the Permian, while most of the remainder are known to occur in rocks regarded as of Permian age. If we omit the fauna of the Kansas Permian, to include which would be a sort of circulus vitiosus, no condition comparable to this has been demonstrated by the invertebrate fossils and, in so far as I have seen the evidence, no such condition exists. I am, therefore, accepting the Permian age of the Kansas and Texas beds, but at present strictly on the paleobotanic evidence.

David White states:

In accordance with the paleobotanical standards of western Europe, I refer the plants of the Little Wichita in Texas to the lower Permian, the terranes being probably referable to the Chase group in Kansas. In this connection it should be observed, however, that the Artinskian flora of the Urals is essentially Permian, and that paleobotanists universally agree with the general usage of the geologists of western Europe in referring the Artinsk to the Permian.

I–J 12–13. UTAH, COLORADO, ARIZONA, AND NEW MEXICO.

The Permian of the Southwestern States is involved in the "Red Beds," which comprise Pennsylvanian, Permian, and Triassic strata variously associated in different districts. As the surveys yet made suffice to distinguish the formations of either age from the others in a few localities only, it is necessary in general to map them as a whole, and they are all included, so far as they may be present, in the "Red Beds," in the dark greenish-blue areas of the map (9).

Cross has recently divided the "Red Beds" of the plateau province in southwestern Colorado into the Cutler formation (Permian?) and Dolores formation (Triassic). Below the Cutler occur the Rico and Hermosa formations (Pennsylvanian), whose approximate equivalents farther south, in the Rio Grande region, are "red beds" as described by Lee.[528a]

The Cutler formation is thus characterized by Cross and Howe:[193]

The Cutler formation embraces somewhat more than the lower half of the Red Beds section of southwestern Colorado. Its strata are invariably red in color and include sandstone, arkose grit, conglomerate, shale, and limestone. The maximum observed thickness is about 1,600 feet.

The formation seems conformable with the underlying Pennsylvanian beds, but above it occurs a stratigraphic break with at least local unconformity. The base of the formation is indicated by the Pennsylvanian fossils of the Hermosa or Rico formations and in a broad way by the color line. No fossils have been found in the Cutler beds.

Great variability in lithologic constitution, both vertical and lateral, is one of the most striking features of the Cutler formation. The sandstones are sometimes fine grained and massive, but bedding is ordinarily distinct and few homogeneous beds exceed 10 or 15 feet in thickness. All strata are calcareous, and the finer-grained sandstones grade into calcareous shales and impure marls or into sandy limestones. These rocks are naturally more or less friable and crumbling.

The finer-grained strata are of the strongest red color, which is due to a ferritic pigment, and they are also commonly characterized by abundant bronze or rusty mica, which renders them fissile. Clay beds are rare, as is massive limestone. Commonly the more calcareous strata are nodular or gnarly and grade into calcareous sandstones. Greenish and grayish tints are locally found in the nodular limestones and a mottling with red is common. Some of the nodular limestones appear to be intraformational conglomerates.

The sandstones frequently grade into arkose grits and these into conglomerate. With increasing coarseness of grain the red changes to pink, and locally beds of coarse grit are gray or almost white. In other cases the finer matrix of grits and conglomerates is dark red. The cement of the strata is calcite, and most of the conglomerate and arkose beds are comparatively resistant to weathering and form prominent ledge outcrops on all steep slopes.

The grit beds often reach 35 feet in thickness. They are variably massive, being in some places almost homogeneous from top to bottom, while more frequently divided by several thin shale or sandstone layers. Cross-bedding is almost universal. Sporadic pebbles are present in all grits, and with their increase the stratum becomes conglomerate.

The sandstones are mainly quartzose, the grits contain much feldspar, mica, and small pebbles like the larger ones of the conglomerates. The latter contain pebbles of granite, gneiss, and various schists, of quartzite and limestone, of greenstone and porphyry, and many of red, pink, smoky, or white quartz, part of which may come from veins.

The pebbles are in general larger near the San Juan Mountains. Bowlders a foot in diameter are occasionally present, but most pebbles are only a few inches in diameter. The relative abundance of different rocks among the pebbles varies according to locality. The greenstone schists, metadiorite, and green porphyry are most abundant in the Uncompahgre Valley exposures; granites and quartzites are always prominent.

Taking the formation as a whole, the grits and conglomerates comprise about one-third or less of its total thickness in the quadrangles surveyed, and they are distributed throughout the section. It may be assumed that as distance from the source of the pebbles increases, the formation becomes more and more a series of fine-grained sandstones and shales, with subordinate grits and conglomerates.

The assignment of Permian age to the Cutler formation rests on its apparent conformity to distinct upper Pennsylvanian strata and on its unconformity with the overlying Triassic. No fossils have yet been found in it. Its recognition outside of the San Juan district is difficult. Cross [193b] presents the known facts and suggests the probable correlation of the Cutler with appropriate divisions of the sections observed by his predecessors.

The Red Beds of the Rocky Mountain province have proved to be perhaps the most difficult portion of the Paleozoic and Mesozoic section to analyze and reduce to definite groups and formations. In the first place, the red color has been found unreliable as a guide in correlation. It extends at some places into the fossiliferous Pennsylvanian rocks and may penetrate upward into Jurassic beds. Fossils have been discovered in Red Bed strata in many different localities—here of Permian, there of Triassic affinities. Unfortunately the two kinds of fossil evidence have seldom been found in one section, affording a means of division. Triassic fossils occur in some places very near the top of the Red Beds and in others near their base, in proximity to known Pennsylvanian strata. This apparent range of Triassic fossils has been a prominent factor in forming what seems to be the general opinion that the larger part of the Red Beds is to be assigned to the Trias.

As far as I know, no one has presented evidence of a stratigraphic break within the Red Beds or suggested that the conflicting evidence as to age might be explained by such a break. The Ouray unconformity, however, establishes for southwestern Colorado a definite line between Triassic and pre-Triassic portions of the Red Beds, which can be traced on a lithologic basis where no visible unconformity exists. From evidence which will be presented in following pages it seems certain that the Dolores formation may be positively recognized through its fossils and lithologic character in Utah and Arizona and very possibly in New Mexico. As a step toward a better understanding of the Red Beds I desire to make certain suggestions as to the correlation of the Cutler and Dolores formations with strata in other parts of Colorado, in Wyoming, and particularly in the plateau province of Utah, Arizona, and New Mexico. The discussion is based on a study of the literature, on recent published discoveries, and on unpublished information. Naturally much of the correlation suggested is tentative.

Four principal factors have had influence in this tentative correlation:

(*a*) *The lithologic character of formations compared.*—This is the most important on the whole, since it is the only one applicable in all places.

(*b*) *Fossil evidence.*—This guide is becoming more and more important as new discoveries are made. Unfortunately, collectors of fossils and even paleontologists are not always alive to the importance of careful stratigraphic studies and accurate measurement and description of sections in the localities where fossils are obtained. Their work is therefore often shorn of much of the value that should attach to it.

(*c*) *The influence of post-Triassic elevation and erosion.*—The stratigraphic break at the base of the La Plata sandstone [Jurassic] is one of great magnitude throughout the western portion of Colorado. In several places the La Plata is seen in angular unconformity with the entire Paleozoic and older Mesozoic section. It is possible that synchronous elevations, in gentle folds or low domes, occurred in the plateau district, but have not been recognized.

(*d*) *The influence of the pre-Triassic elevation and erosion.*—While it appears probable that the pre-Dolores uplift was by no means so extensive as the post-Dolores disturbance, it is plain that its influence must be looked for in the plateau country as well as in the Rocky Mountains.

The type locality of the Cutler formation (Cutler Creek, Ouray quadrangle, Colo.) is in longitude 107° 45′, latitude 38°. The plateau province stretches thence westward, cut by the tributaries of Grand River known as Dolores and San Juan rivers and their branches. Regarding the general geologic conditions bearing on correlation in this region Cross says:

The general conditions under which correlation of the San Juan formations with those of the plateau section must be made are as follows: Adjacent to the mountains there is a broad zone of gentle westward slope in which Cretaceous beds occur. The main streams flowing west and south cut valleys into and in some places through the Cretaceous into underlying formations. Nearer the canyon of the Colorado the valleys widen and broad platforms and terraces of Jurassic and Triassic beds appear, the Cretaceous being restricted to the divides and isolated mesas. The Paleozoic formations appear at first only in isolated exposures in the deeper canyons, but far to the southwest rise to form the broad plain called the Colorado Plateau, on the south side of the Grand Canyon. Thus the older the formation the greater are the gaps between districts of good exposures, and the greater the likelihood that in the covered tracts unsuspected complications have entered into the problem.

Cross also describes the occurrence of Triassic and Jurassic strata and says:

The heart of the plateau is about 80 miles northwest of Ouray, and Cretaceous formations occupy the greater part of the intervening country. The San Miguel River, however, affords a section extending somewhat below the Dakota sandstone for the entire distance from the Telluride quadrangle to its union with the Dolores River, and the Dolores itself penetrates locally through Jurassic and Triassic into Carboniferous formations.

* * * * * * * * *

Below the Dolores beds Spencer found coarser Red Beds, often conglomeratic, with pebbles 3 inches or more in diameter, and several hundred feet of such strata were noted. No opportunity was found to measure a section showing the full thickness of these coarser Red Beds, but, as observed by Peale, they are underlain by fossiliferous Pennsylvanian Carboniferous in Sinbad Valley, where there is also much structural complexity obscuring the relations.

Spencer's observations seem to show that the section of the lower Dolores Valley embraces strata to be correlated with the Cutler [Permian ?], Dolores [Triassic], La Plata [Jurassic], and McElmo [Jurassic ?] formations of the San Juan region.

Peale reconnoitered southwestern Colorado in connection with the Hayden Survey (1875) and mapped as "upper Carboniferous" certain beds which he classed as "probably Permian." These presumably represent the Cutler. Cross[189b] restudied the section in 1905 and describes the remarkable Permian (?) conglomerates in contact with and near granite outcrops on West Creek.

Where the sediment was seen resting on granite, the lower layers consisted of coarse, angular gravel, scarcely bedded at all. At a distance of a few feet above the granite bedding planes become more distinct, through alternation of finer and coarser material aided by color differences, the finer-grained material being reddish. At 25 feet above the granite the characteristic alternation of grit and conglomerate began. But the distribution of pebbles and bowlders is very irregular, the latter are often subangular, and the whole is so little consolidated that the disintegrated beds seem like surface gravels.

Cross gives a detailed section of conglomerate and grit 879 feet thick and continues the discussion of correlation as follows:

The pebbles of the conglomerate strata of this section are principally of granite and the most abundant variety is the very coarse textured one with large orthoclase crystals occurring in the nearest exposures of the Uncompahgre Plateau. Among the pebbles are some of greenstone schist which indicate that the pre-Cambrian complex furnishing this material is similar to that from which the Cutler conglomerate of the San Juan was derived. Similar greenstones were observed in the conglomerates of Grand River valley.

Below the measured section there may be several hundred feet of similar strata, for the somewhat deeper cutting of Dolores River does not reveal the base of the succession of grits and conglomerates. The next lower formation is probably a series of gypsiferous shales and sandstones and the nearest locality at which such strata are known to occur is in Sinbad Valley, 12 miles south from West Creek. A fault running near the base of the northeastern scarp prevents a clear determination of the relations, but the gypsiferous beds are manifestly older than the strata below the Dolores. These belong no doubt in the series measured on West Creek. Owing to complex folding and faulting * * * the extent and relation of the gypsum-bearing beds can not be ascertained, but they are apparently some hundreds of feet in thickness.

* * * * * * * * *

Comparing the strata known on Grand River between the Dolores base and the Pennsylvanian limestones with the Cutler formation (Permian?) of the San Juan Mountains, it is clear that the gypsiferous part of the series has no similar representative in the mountain district. If such beds ever existed in the San Juan region, they were removed prior to the deposition of the saurian conglomerate, and this does not seem at all unlikely, for gypsiferous beds are known in the Paleozoic red beds of northwestern Colorado, as reported by Peale.

The grits and conglomerates of West Creek are so near their source that they differ from the Cutler beds in being much coarser and more strongly arkose, but the section seen on Grand River and Fisher Creek certainly resembles in lithologic character the Cutler beds of the Uncompahgre Valley below Ouray and appears to occupy the same stratigraphic position.

The Cutler formation and the pre-Dolores red-bed strata of Grand River clearly correspond to the lower part of Powell's Shinarump group—that is, to the "Permo-Carboniferous" of the Wasatch and Uinta mountains, according to the nomenclature of the Fortieth Parallel Survey, or to the Permian of Dutton, in the Grand Canyon monograph. Fossils indicating a Permian or Permo-Pennsylvanian age were found by the Fortieth Parallel geologists in the Wasatch Mountains and by Walcott in the Kanab Valley of northern Arizona. The apparent absence of fossils in most localities where these beds have been examined is no doubt due to the fact that they are mainly continental deposits, an origin indicated by their texture.

Concerning the section on Grand River, Cross[189a] says:

Near Moab, on the northeast side of Spanish Valley, a poorly exposed section reveals about 250 feet of strata, mainly reddish sandy shales, between the "saurian conglomerate" [Triassic] and the uppermost Pennsylvanian limestone. On Grand River about 1 mile above the Moab ferry the "saurian conglomerate" reappears above the level of the river, and, as it rises gradually to the northeast for several miles, a larger and larger section of the pre-Dolores strata is exposed, but nowhere, so far as our observations go, do the Pennsylvanian beds appear, all the sub-Dolores section belonging to the upper (Permian?) series of the Carboniferous. This is itself evidence of a great break immediately below the "saurian conglomerate." That the break represents uplift and erosion producing angular unconformity is well illustrated on both sides of Grand River about 10 or 12 miles northeast of the ferry and just below the mouth of Castle Creek, a stream heading on the west side of the La Sal Mountains. * * * This unconformity * * * may be traced for about half a mile, and it was estimated that at least 600 or 800 feet of beds are visibly truncated by the conglomerate in one continuous exposure. The occurrence of an extensive section of gypsiferous sandstones and shales beneath the Dolores conglomerate in Fisher Valley, on the northwest side of the La Sal Mountain, adds so much to the beds transgressed; and a still higher series of sandstones and conglomerates is known, so that, altogether, it is estimated that not less than 1,500 and possibly 2,000 feet of Permian (?) or upper unfossiliferous Pennsylvanian beds have been eroded in the locality of the section first mentioned, opposite Moab.

Returning to Cross's earlier paper,[193f] we learn that Gane, in a trip down the San Juan Valley, traced the Triassic (Dolores formation) but had "no opportunity to study the underlying formation."

With reference to the supposedly Permian equivalents of the Cutler formation in the Zuni Plateau, New Mexico (I 12), Cross derives his information from Dutton[301] and, after describing Newberry's section of the same region, says:

The "Saliferous sandstones" of Newberry's report Dutton divides into three formations. At the base is a formation 450 feet thick, mainly "sandy shales, containing gypsum and selenite in abundance, with here and there thin bands of limestone." At some unspecified horizon in this formation Dutton found "several specimens of Bakewellia and an attenuated form of Myalina." On this ground he correlates these beds with the Permian of the Kanab Canyon district, where Walcott had discovered a more extesinve fauna. "The Permian beds are distinguished for their dense and highly variegated colors—chocolate, maroon, dark brownish reds alternating with pale, ashy gray, or lavender colors."

The Permian strata thus described are overlain by "a very coarse, almost conglomeratic sandstone," some 50 feet in thickness, which Dutton correlates unhesitatingly with the "Shinarump conglomerate" (a particular conglomerate within the Shinarump group), referring to the fact that it is persistent and uniform in aspect wherever it appears throughout the plateau country of Utah and Arizona. He does not further describe it in this report.

Following Walcott, the conglomerate thus identified as the Shinarump in the Zuni Plateau is considered by Dutton as the basal stratum of the Trias.

After discussing the Triassic of Dutton's section, Cross[193g] continues:

Beneath the Trias in the Zuni district is Dutton's Permian, lithologically a typical Red bed formation. That would correspond to the Cutler formation in stratigraphic position; but other factors enter into the problem at this point and render any definite suggestion of such a correlation premature. Below the Zuni Permian comes the Aubrey group, and beneath the Cutler occurs the Hermosa formation (ignoring the uncertain Rico beds), both Aubrey and Hermosa carrying Pennsylvanian invertebrate faunas. Dr. G. H. Girty informs me, however, that these faunas are not known to have a single species in common, and the equivalence of the two fossiliferous formations is therefore by no means to be assumed, though their stratigraphic position seems to be the same.

In northeastern Arizona, according to Ward,[865] the Moencopie formation rests in marked unconformity on the underlying Paleozoic strata (Aubrey group) and is therefore not to be classed as upper Paleozoic (Permian). Ward therefore placed the Moencopie in the Triassic, but later work by Darton[246b] tends to place it in the Permian.

In the northwestern part of Arizona is the Kanab Plateau, traversed by Kanab Canyon, which leads from the north to the Grand Canyon of the Colorado. Here Walcott[844] determined the presence of Permian strata. He says:

The Permian group terminates above with ripple-marked, banded reddish-brown and chocolate-colored arenaceous shales and sandstone. A plane of unconformity by erosion separates it from the overlying Shinarump conglomerate, which is considered as the base of the lowest Mesozoic group. It is undoubtedly of Triassic age, but, as yet, this has not been determined by paleontological evidence in the Colorado Valley.

The chocolate arenaceous shales give way below to drab or lavender-colored arenaceous and gypsiferous marls and shales, that pass, midway of the group, into reddish-brown shales of the same general character. A thin stratum of impure limestone is intercalated in this bed 44 feet above the summit of the lower division and 15 feet above a band of impure shaly limestone. This band of limestone is of variable thickness and character and forms the base of the upper division. Numerous fossils occur in it and the associated arenaceous layers.

The summit of the lower division was slightly eroded antecedent to the deposition of the limestone. The upper bed is a reddish-brown gypsiferous marl that becomes more arenaceous below, finally passing into a sandstone that rests on the chocolate and cream-colored limestone beneath. This has suffered extensive denudation by erosion and is now found only in patches from 10 to 20 feet in thickness over limited areas, the sandstone filling the spaces between. Recent erosion has cut channels down through each to the formation beneath, which is a member of the Upper Aubrey group. A slight plane of erosion with an entire change in the character of the rock separates the two groups.

The Permo-Carboniferous of Mr. G. K. Gilbert[a] is the same as my lower division of the Permian. It is placed as a subdivision of the group, now that the beds above are known to be of Permian age.

The stratigraphy of the section shows a group separable into two divisions, defined above and below by planes of unconformity by erosion and a decided change in the character of the beds from those of the subjacent and superjacent formations. There is no physical break in the beds above the Permian limestone of the upper division before the conglomerate is reached. This stratigraphical arrangement is sustained by the evidence of the fauna found in the limestones and associated arenaceous layers in the upper division.

The genera Myalina, Schizodus, Nucula, Aviculopecten, Murchisonia, Naticopsis and Goniatites are represented in the lower chocolate-colored limestone. The fauna is distinct in specific character from that of the Carboniferous groups beneath, and more intimately related to that of the fossiliferous beds of the Upper Permian division. Mr. G. K. Gilbert obtained from this same horizon Pleurophorus, Schizodus, and Bakevellia, a group of shells, as he states, suggesting the Permo-Carboniferous of the Mississippi Valley.[b]

Twenty-three genera represented by thirty-four species comprise the fauna of the upper division. Of these, the following have strong Paleozoic relations: Scolithus ——?, *Lingula mytiloides*, *Discina nitida*, Orthis ——?, *Rhynchonella uta*, Terebratula ——?, Nucula, two species, Aviculopecten, three species, Myalina, four species, Naticopsis, two species, Pleurotomaria ——?, Macrocheilus ——?, Cyrtoceras ——?, Goniatites ——?, and Nautilus ——?.

The Permian character of the fauna is more marked by the presence of Pleurophorus, three species, Schizodus ——?, three species of Bakevellia including *B. parva*, Pteria ——?, Mytilus ——?, Rissoa ——?, and the still more typical Mesozoic genera Pentacrinus and Pileolus ——?.

The Pentacrinus plates were discovered by Mr. Edwin E. Howell below the Shinarump conglomerate in southwestern Utah. They belong to a species distinct from *P. asteriscus* of the Jurassic. Three species are now known to pass from the lower division to the limestone of the upper division.

The Permian character of the fauna, taken with the evidence afforded by the stratigraphy, clearly establishes the Permian as a well-defined and distinct group in the Colorado Valley. It occurs at the same horizon as the Permian determined by Mr. Clarence King in northern Utah, western Colorado, and southern Wyoming, fully corroborating the views advanced by him of the age of the beds resting on the "Bellerophon bed" of the Upper Carboniferous.[c]

Walcott's section is as follows:

Permian (855 feet):
- Plane of unconformity by erosion.
  - Upper Permian (710 feet): Gypsiferous and arenaceous shales and marls, with impure shaly limestones at the base.
- Plane of unconformity by erosion.
  - Lower Permian (145 feet): Same as upper division with more massive limestone at the base.
- Plane of unconformity by erosion.

Upper Aubrey (835 feet): Massive cherty limestone with arenaceous gypsiferous bed passing down into calciferous sandrock.

G. H. Girty[d] comments on the above section as follows:

There is hardly room for doubt that Walcott's Permian is equivalent to the "Permo-Carboniferous" of the Wasatch Mountains and to the Permian(?) of the section studied by

[a] U. S. Geog. Surveys W. 100th Mer., vol. 3, 1875, p. 177. See also Arch. R. Marvine's report in same, p. 213.
[b] Idem, p. 177.
[c] U. S. Geol. Expl. 40th Par., vol. 1, pp. 245-246 and atlas.
[d] Comment on manuscript.

Weeks in southeastern Idaho, the upper half of which contains the Lower Triassic faunas of J. P. Smith. Personally I expect to find that the lower part of the Permian(?) strata in Weeks's section is not separable paleontologically, as it is scarcely lithologically, from the upper part, all being Permian or Triassic, as the case may be. Walcott's Permian I believe to correlate rather with the upper than the lower part of these strata.

I-J 14. KANSAS AND OKLAHOMA.

The strata assigned to the Permian of Kansas are thinly interbedded limestone and shale of marine origin. They have been minutely distinguished and their study is embarrassed by the number of names attached to thin beds, some of which are but local members. Prosser [648] gives the following tabulation and discusses the nomenclature and correlation.

Classification of the upper Paleozoic formations of Kansas.

	Feet.[a]
Permian system (?):	
Cimarron series [red beds]:	
Kiger stage:	
Taloga formation.	
Day Creek dolomite	1–5
Red Bluff formation	175–200
Salt Fork stage:	
Dog Creek formation:	
Chapman dolomite	
Amphitheatre dolomite	
Cave Creek formation:	
Shimer gypsum	
Jenkins clay	
Medicine Lodge gypsum	1,000
Glass Mountain formation:	
Flower-pot shales	
Cedar Hills sandstone	
Kingfisher formation:	
Salt Plain member	
Harper sandstone	
Big Blue series:	
Sumner stage:	
Wellington shales	200
Marion formation	100
Chase stage:	
Winfield formation	25
Doyle shales	60
Fort Riley limestone	40
Florence flint	20
Matfield shales	70
Wreford limestone [b]	40
Base of the Permian.	

Adams adopts the formation names used by Prosser in the foregoing classification, from Wreford limestone to Wellington shale, both inclusive.

The sequence of strata throughout the Pennsylvanian and Permian is an alternation of limestones and shales without any marked interruption of stratigraphic

[a] The thicknesses given up to and including the Wellington shale are from Adams; [4] those of the higher formations from Cragin.[175,176]

[b] Beede has recently traced the Wreford limestone into the McCann sandstone of Gould, yielding typical Texas Permian vertebrates.—Note by S. W. Williston, June, 1909.

or faunal succession. The distinction of Pennsylvanian and Permian has been difficult and is apparently artificial.

Prosser [648a] discusses the correlation of the Wreford and higher formations as Permian—that is, the equivalent of the Russian Permian—cites the opinions of many geologists on both sides of the question, and considers favorably the distinction of the Permian as a system equal in rank to Carboniferous or Triassic. Beede [63] and David White [901] regard the series as Permian. Girty [371a] accepts the Permian age of the Kansas and Texas beds but largely on the paleobotanic evidence adduced by White.

The Cimarron "series" is not discussed by Prosser, as it is a typical red-bed formation and does not contain marine fossils. Cragin [175a] gave the following concise description in defining it:

> With the Wellington formation ends the Big Blue, lower, or limestone-bearing series of the Permian. Succeeding it without break, but possibly with a gradually introduced angular unconformity, are the Harper sandstones and higher prevailingly red formations that comprise the remainder of the Kansas Permian and constitute the Cimarron series, which, for Kansas, is nearly the same as the "red beds."
>
> So far as known, the series is destitute of any trace of organic remains.

In Oklahoma the shale and limestone strata of the Kansas Permian give place to red beds, the shales becoming red and sandy and the limestones red shales or sandstones. The division into many small formations is lost and a different sequence is recognized. Gould [373] has made the following comparison of the divisions of the Oklahoma Permian with those proposed by Cragin for Kansas:

Relations of classifications of Permian rocks.

<table>
<tr><th>Cragin's classification.</th><th colspan="2">Classification used in this [Gould's] report.</th></tr>
<tr><td rowspan="2">Taloga.</td><td colspan="2">Quartermaster formation.</td></tr>
<tr><td>Greer formation.</td><td>Mangum dolomite member.
Collingsworth gypsum member.
Cedartop gypsum member.
Haystack gypsum member.
Kiser gypsum member.
Chaney gypsum member.</td></tr>
<tr><td>Day Creek.
Red Bluff.
Dog Creek (Stony Hills).</td><td>Woodward formation.</td><td>Day Creek dolomite member.
Whitehorse sandstone member.
Dog Creek shales member.</td></tr>
<tr><td>Cave Creek.</td><td>Blaine formation.</td><td>Shimer gypsum member.
Medicine Lodge gypsum member.
Ferguson gypsum member.</td></tr>
<tr><td>Glass Mountain.
Kingfisher.</td><td colspan="2">Enid formation.</td></tr>
</table>

The several formations are described by Gould [373a] as follows:

> The Enid formation consists chiefly of brick-red clay shales with some interbedded ledges of red and whitish sandstone. It occurs in two general areas, which may be distinguished on lithological grounds as follows: An eastern area, in which there are a few inconspicuous ledges

of sandstone, and a western area in which the sandstones are mostly wanting. In the present state of knowledge it is impossible to draw an accurate line of separation between these two areas, and for this reason the strata in them are not defined as separate members.

The eastern area of the Enid formation is triangular and occupies several counties in the central part of the Territory, in which there is little hard rock of any kind.

* * * * * * * * *

Throughout this area the soil is red, except where later deposits cover the uplands or among the sand hills north of some of the streams. Red clays and occasional ledges of thin sandstone outcrop along the bluffs of a few streams.

* * * * * * * * *

The rocks of the western area of the Enid consist chiefly of red clay shale, some inconspicuous ledges of soft sandstone, and occasional bands of whitish or greenish shales, which vary from 1 inch to several feet in thickness. The upper strata are in some places highly gypsiferous, and at some localities brine springs issue from them.

* * * * * * * * *

The Blaine formation consists of red shales with interbedded strata of gypsum and thin ledges of dolomite. It includes the portion of Prof. Cragin's Flowerpot formation above the base of the Ferguson gypsum and all of his Cave Creek formation. It is named from Blaine County, Okla., where it is typically developed.

The characteristic which justifies its recognition as a formation is the abundance of gypsum contained in it, and its extent and limits are defined accordingly. The bottom of the lowest massive gypsum bed—the Ferguson gypsum member—is the base of the formation throughout its occurrence northwest from Darlington, Canadian County. Where it disappears the shales of the Enid continue up to the base of the Medicine Lodge gypsum member, which necessarily becomes the basal member of the formation. The top is the Shimer gypsum member. Where the gypsum members run out, as they all do north of Darlington, the Blaine can not be distinguished readily from the Enid below and the Woodward above, and this local division of the red beds can not well be traced.

* * * * * * * * *

The thickness of the Blaine formation varies considerably with the locality, but it averages about 75 feet.

Above the Blaine are approximately 300 feet of rocks consisting chiefly of shales, sandstones, and dolomites and distinguished from the formations above and below by the prominence of dolomites and the absence of gypsum. The formation includes all the rocks between the two conspicuous gypsum horizons, the Blaine and the Greer, and in general it may be divided into three members—the Dog Creek, the Whitehorse, and the Day Creek—which were all recognized and named by Prof. Cragin from localities in Kansas, except that his term Red Bluff was preoccupied, and for it the name Whitehorse has been substituted. For the formation as a whole, from the top of the Shimer gypsum to the base of the Chaney gypsum, the name Woodward is proposed, from the county in Oklahoma where the strata are well represented.

* * * * * * * * *

Above the Woodward formation are red clays, shales, and sandstones, and intercalated beds of gypsum and magnesium limestone or dolomite 150 to 300 feet thick. Gypsum is the characteristic deposit of this formation, as it is of the Blaine. The formation for which the name Greer is proposed, from the county in southwestern Oklahoma where it is well exhibited, is exposed over a very irregular area. For purposes of discussion it may be grouped according to two general areas, an eastern and a western.

* * * * * * * * *

The rocks of the eastern area of the Greer formation strike northwest and southeast just west of the outcrops of the Woodward formation. They are chiefly red clay shale, interstratified at several horizons with red sandstone and gypsum, which are, however, very irregularly bedded and can rarely be traced as continuous or definite ledges. Nevertheless, the thickest ledges of gypsum known in the red beds are found in this area. Thus 5 miles northwest of Weatherford a ledge 60 feet thick was measured; in the vicinity of Cloud Chief, beds 50 feet thick are not uncommon; and in a well near Seger, Washita County, a ledge 115 feet thick is reported. But these beds are not constant, thickening rapidly or disappearing without apparent regularity. Along a single bluff one may see the beds change from gypsum to sandstone within a distance of a few rods, and a quarter of a mile farther the sandstone again merges into gypsum. So variable is the stratification of all the rocks of the Greer formation in this region that no attempt is made to divide it into members. A section would usually not answer for a point half a mile away.

* * * * * * * * *

Above the Greer are 300 feet or more of soft red sandstones and arenaceous clays and shales, to which the name Quartermaster has been applied. So far as known this is the highest formation of the red beds in Oklahoma.

In the lower part of the formation the rocks are chiefly shales, typically red but sometimes containing greenish bands and layers. The shales become more arenaceous above and in places form a strong consolidated sandstone, which is rather thin bedded and prone to break into small rectangular blocks and weather queerly into long and narrow buttresses or rounded, conical, or nipple-shaped mounds from 10 to 50 feet or more high. These mounds may be solitary, but in some areas hundreds of them occur in a single quarter section. The sandstone is further characterized by the marked and very peculiar dip of the rocks in certain directions. The strata often dip at angles of from 20° to 40° to all points of the compass, even in a small area. These dips often produce escarpments that have the appearance of those formed by regularly bedded dipping strata. The most plausible explanation of this phenomenon is that the erratic dipping is caused by the undermining of deep-seated rocks, probably some of the various gypsum members of the Greer.

Regarding the age of the red beds of Kansas and Oklahoma, Gould [373b] makes the following statement:

The scarcity of fossils in the Kansas-Oklahoma red beds has been a matter of comment ever since these rocks have been studied. In Kansas, particularly, Hay, Cragin, Prosser, Beede, Williston, and others have at various times searched carefully over the counties in which these rocks are exposed, but without avail. So far as known not a single fossil has ever been found in the Kansas red beds.

In Oklahoma, fortunately, the results have been more satisfactory. Not that the fossils are abundant, for they are in fact very rare, yet enough forms have been found at various horizons to assist the geologist in the classification of the rocks. Four years ago the geologic age of the red beds was not certainly known, for at that time fossils had been found in but one locality, and these for the purpose of correlation were far from satisfactory. Of the five localities west of the provisional base of the Permian from which fossils have been obtained in Oklahoma, two only have yielded invertebrates, in two other localities vertebrates alone have been found, and from the fifth locality vertebrates, invertebrates, and plants have been secured. A brief description of these localities and the fossils obtained from each will be given.

On the farm of W. T. McCann, 5 miles southeast of Nardin, Kay County, a number of fossils were found in a ledge of sandstone which lies just at the base of the red beds. A vertebrate, identified as *Eryops megacephalus* by Dr. S. W. Williston, a small crustacean, *Estheria minuta,* and some fossil leaves comprise the collection. [The McCann sandstone of Gould is traced stratigraphically by Beede to the Wreford limestone of Kansas. See note *b*, p. 486.]

Dr. E. C. Case has identified the following forms obtained near Orlando, Logan County:[a]

Pisces:

Diacranodus (Pleuracanthus) ampressus (?) Cope.

Sagenodus (?) sp.

[a] Case, E. C., On some vertebrate fossils from the Permian of Oklahoma: Second Biennial Rept. Oklahoma Geol. Survey, 1902, pp. 62, 68.

Batrachia:
- Diplocaulus magnicornis (?) Cope.
- limbatus (?) Cope.
- salamandroides Cope.
- Trimerorhachis sp. Cope.
- leptorhynchus sp. nov.
- Cricotus sp. Cope.
- Cricotillus brachydens g. et sp. nov.
- Eryops megacephalus Cope.
- Crossotelos annulatus g. et sp. nov.

Reptilia:
- Naosaurus sp. Cope.
- Embolophorus (?) sp. Cope.
- Pariotichus ordinatus Cope.
- sp. Cope.
- Pleuristion brachycoelous g. et sp. nov.

A number of vertebrates have recently been discovered 5 miles east of Pond Creek, Grant County. These bones have not been identified, but from superficial examination they appear very similar to the specimens from Nardin or Orlando.

In a ledge of soft, sandy dolomite which underlies the Medicine Lodge gypsum near Ferguson, Okla., a number of invertebrates have been found, among which Dr. J. W. Beede finds the following forms: *Pleurophorus subcuneatus* Meek, Schizodus (?) like *S. wheeleri*.

Near Whitehorse Spring, 16 miles west of Alva, a considerable number of invertebrates were obtained. Dr. Beede identified the following genera:[a] Naticopsis, Pleurotomaria, Pleurophorus, Lima, Sedgwickia, Aviculopecten, Bakewellia, Conocardium, and Dielasma. The last four genera are represented by new species.

Regarding the age of the red beds, Dr. Williston identifies *Eryops megacephalus*, from Nardin, as a Permian amphibian, described by Cope, from Texas. Of the Orlando fossils, he says: "Altogether these fossils unmistakably point to the Permian." Dr. Case points out the close resemblance of these fossils to similar forms from the Permian of northern Texas, Ireland, and Bohemia.[b]

Dr. Beede, in the paper referred to, in speaking of the Whitehorse invertebrates, says:[c]

"On the whole, these fossils show an advance over the fossils of the Permian below. Some of the species still persist, as we should expect from the fact that there is no unconformity between these various formations. On the other hand, there is a new species of Dielasma belonging to a group new to the American Permian. * * * Taking all this into consideration, there can be little doubt that the age of these beds is Permian."

Of these localities, Orlando, Nardin, and Pond Creek are in the Enid formation, Gypsum Hills locality in the Blaine, and the Whitehorse locality in the Whitehorse sandstone, the middle member of the Woodward formation. So fas as known no fossils have been found in the Greer and Quartermaster formations of Oklahoma, but there is no reason for supposing that these beds differ greatly in age from those immediately subjacent.[d]

J-K 13. SOUTHERN WYOMING AND NORTHERN COLORADO.

The so-called "Red Beds" of this region, long supposed to be chiefly or wholly Triassic, are now known to be in part at least Permian. The Triassic age of the remaining upper portion has been questioned but is established by Williston. Prior to Williston's publication, Cross [193m] reviewed the evidence as follows in part:

The Red Bed section of the mountainous portion of Colorado and Wyoming is clearly not divisible into the units traceable throughout the plateau province. * * * The changes in

[a] Beede, J. W., Advance Bull. Second Ann. Rept. Oklahoma Geol. Survey, April, 1902.

[b] Letter of November 24, 1900.

[c] Op. cit., p. 62.

[d] Since the above was written fossils found in the Quartermaster sandstone in Collingworth County, Tex., have been identified by Dr. Beede, who finds that they are very similar to those from Whitehorse and of Permian age.

lithologic character in the mountain province are much more notable and render correlations less certain. * * * Until many districts have been reexamined with care, it will be premature to attempt direct correlation of the Dolores and Cutler formations as such with the elements of sections in central and northern Colorado; but there are various facts bearing on the distribution of Triassic and Carboniferous Red Beds which may be briefly presented:

* * * * * * * * *

Turning to the lower part of the Red Beds, evidence has recently been presented by the late W. C. Knight showing that in the Laramie Basin of southern Wyoming the Triassic strata of Hayden and King should be referred in part at least to the Carboniferous system and probably to the Permian series. Knight gives a section of 1,578 feet of Red Beds which rest on granite. A little below the middle of this section a fossiliferous sandstone was found, the fauna resembling "to a marked degree the fossils of the Kansas and Nebraska Permian." Only one thin limestone was noted in the section, but Knight made the significant observation "that the strata of the lower portion of the Red Beds are identical with the strata of limestones to the northward, the difference in the lithological characteristics being due to the varied physical conditions during sedimentation."

These limestones also contain in their upper portion a fauna resembling that of the Kansas "Permian," but Knight remarks that Coal Measure fossils have not as yet been collected from the lower beds.

Since Knight could find no stratigraphic or fossil evidence for subdividing the Red Bed section of the Laramie Plains, he refers it as a whole to the Permian and compares it particularly with the Permian of Kansas and Oklahoma. * * *

Accepting the views expressed by Knight concerning the fauna of Red Beds of the Laramie Plains, it is clear that the section above his lowest fossil-bearing horizon is younger than the Rico formation [Pennsylvanian] but may correspond as a whole or in part to the Cutler formation. * * * The unfossiliferous portion whose reference to the Permian is still open to possible doubt is 850 feet in thickness, and it does not appear that the section was complete, up to the Jurassic beds. There is, therefore, ample room for a Triassic formation in the Red Beds of the Laramie Plains.[a] * * *

In the vicinity of the Triassic horizon observed by Hills [on Grand and Eagle Rivers, Colorado] the upper Paleozoic section is of very different character from that near Laramie, but its upper portion was assigned to the Permian by Peale on the basis of a few plants considered by Lesquereux as of that age. The strata so referred are gypsiferous shales of various colors, yellow, pink, and creamy, with some limestone, and are not to be correlated either with the Laramie Permian or the Cutler beds on present evidence. These gypsiferous beds are overlain by the Red Beds of Peale, assigned to the Triassic, and seemingly this division must include the bone beds of Hills, since the succeeding formation is apparently the normal fresh water Jura. * * * The well-known Red Bed section of the Front Range foothills in Colorado was assigned to the Trias upon no definite evidence, by geologists of the Hayden Survey. * * *

In the Denver monograph Emmons and Eldridge named the entire Red Bed section of that district the Wyoming formation, distinguishing within it the lower and upper divisions, on purely lithologic grounds. The Lower Wyoming embraces beds like the Fountain in lithologic character and, in addition, the quartzose Creamy sandstone. Both Emmons and Darton have recognized the resemblance of the red arkose strata of the Lower Wyoming to the Fountain beds; but the suggestion of the latter that the Fountain and Lower Wyoming are quite equivalent is to my mind less natural than to consider the Lower Wyoming a group embracing the Fountain beds and the lithologically distinct "Creamy sandstone," which Darton thinks is equivalent with the Tensleep sandstone of the Bighorn Mountains, Wyoming, and which in any case deserves a special name.

The Upper Wyoming of the Denver region embraces the remainder of the Red Bed section, and it is referred to the Trias by Emmons and Eldridge. Darton, however, in his valu-

[a] At Red Mountain, south of Laramie City, characteristic Upper Triassic vertebrates occur in the uppermost "Red Beds." See Williston, S. W., Jour. Geology, vol. 13, 1905, p. 339.—B. W.

able discussion as to the correlation of formations of the Black Hills, Bighorn Mountains, and the Front Range presents reasons for supposing that the Upper Wyoming, as developed near Denver, may be wholly referable to the Permian series. This is based on stratigraphic relations and the belief that a limestone occurring shortly above the "Creamy sandstone" is the equivalent of the Minnekahta limestone of the Black Hills, where it contains Bakewellia and Edmundia, forms apparently identical with those characteristic of the so-called Permian of the Mississippi Valley.

Poorly preserved shells of similar appearance were found in the limestone at Morrison. Darton believes that the Opeche and Minnekahta (Permian) and the Spearfish (Triassic?) formations, distinguished by him in the Black Hills, extend southward through Wyoming into northern Colorado, but as their exposures are not continuous, and as lithologic details vary in the different areas of outcrop, he proposed Chugwater as a group term, which is thus practically equivalent to Upper Wyoming. Darton states that the upper or Triassic (?) portion of the Chugwater group thins out and disappears before the Denver area of Red Beds is reached, leaving only the supposed Permian as present in the Morrison and Golden sections especially described by Eldridge.

From the brief review just given it appears that the Red Bed section of the Front Range foothills contains no member to be correlated with the fossiliferous Triassic (Dolores) of the western portion of Colorado. The views of Darton and the writer harmonize in referring the entire Red Bed section of the Denver region and southward, at least to the Canyon City embayment, to the Paleozoic. The Fountain beds seem to me to be synchronous in origin with the Pennsylvanian formations of the San Juan region. An unconformity separates each from the Mississippian Carboniferous (Millsap or Ouray) and above each in apparent conformable relation is a nonfossiliferous complex of Red Beds. On the west slope these are embraced in the Cutler formation, while at the base of the Front Range is the more variable section of the Wyoming group, succeeding the Fountain. That the beds of the Wyoming group (excluding a possible Triassic portion) are coextensive with the group consisting of the Molas, Hermosa, Rico, and Cutler formations of the San Juan is of course not to be assumed.

J-K 17. PENNSYLVANIA, WEST VIRGINIA, AND OHIO.

The Dunkard group is the highest Carboniferous of the Appalachian basin and is classed as Permian on the evidence of fossil plants. Stevenson[797b] thus states its occurrence and character:

The Dunkard area is much smaller than that of the Monongahela, embracing little more than 7,000 square miles. It is confined to Washington and Greene counties of Pennsylvania, the western-central counties of West Virginia, and Belmont, Noble, Monroe, Washington, and Meigs of Ohio. Small outlying areas occur in other counties, but they are insignificant. At one time the beds of this formation were continuous eastward to beyond the Alleghenies, as fragments remain in Maryland and west-central Pennsylvania. The extreme thickness, as found in the southwest corner of Pennsylvania at the West Virginia line and determined by oil-well records, is a little less than 1,200 feet. The thickness decreases greatly toward the north, the bottom 475 feet becoming about 165 feet at the most northerly exposure and the succeeding 240 feet is reduced to 150 feet at its northernmost exposure, nearly 30 miles south from that of the lower interval. There is a similar decrease in a northwestward direction, and toward the southwest one finds the bottom 700 feet of the thickest area reduced to barely 500 feet in Tyler of West Virginia, 35 miles away. Nothing can be determined respecting conditions toward the east, as erosion due to great anticlines prevents comparison with the fragments east from the Alleghenies in the deep basins of Broad Top and Maryland.

In the original description of this formation as it is in Pennsylvania, Stevenson divided it into the Washington County and the Greene County group, placing the plane on top of the Upper Washington limestone. Aside from the convenience of a division in a column of such length and complexity, one must recognize in the physical conditions good reasons for this separation. These, as will be seen, appear only in part along Dunkard Creek, where Dr. White's studies led him afterward to group the whole succession into one formation, the Dunkard. They are best shown farther north, in central Greene County, where they justify a return to the original grouping and to the recognition of the Washington and Greene formations as of equal rank with the Monongahela and others below.

In the Washington and Greene formations, which compose the Dunkard group, Stevenson distinguishes sixteen and eighteen members respectively, alternations of coal, limestone, and sandstone.

The comprehensive study of the Dunkard flora by Fontaine and I. C. White [344] was revised by David White.[897] Stevenson [797] reviews the evidence as follows:

The results of this revision were published in 1903. The collections, made at the typical as well as at other localities and horizons, led Mr. [David] White to place the forms in five categories—(*a*) those characteristic of the Rothliegende or higher formations of the Old World; (*b*) those closely allied to Permian types; (*c*) those whose habit and facies suggest a late date; (*d*) those of Mesozoic aspect; (*e*) Coal Measures type.

In the first category Mr. White places three species of Callipteris, one each of Goniopteris, Pecopteris, Alethopteris, Odontopteris, Caulopteris, Equisetites, and Sigillaria, with two species of Sphenophyllum; in all, 12 species. In the second are also 12, but the author states that the number might be extended according to the personal equation of the observer or to the amount of material available for comparison, while, at best, evidence of this class is of subordinate value, some of the forms placed here belonging with equal propriety also in succeeding categories. He places in the third category 14 forms, all of them new and unknown elsewhere; these in their general facies suggest a later date than Coal Measures. He places 9 forms in the fourth category and regards their presence as an interesting and important argument for Permian age, for they are types whose nearest relatives are Mesozoic or whose facies strongly suggest types characteristic of Mesozoic. Here are species of Equisetites, Saportæa, Jeanpaulia, and Tæniopteris, as well as other genera. On the other hand are forms belonging to the fifth category, a considerable element of Coal Measure species, whose presence is invincibly against reference of the beds to a level above the basal Permian. The number of species common to the Dunkard and lower formations, only 22 at the time when Profs. Fontaine and I. C. White published their work, is now known to be much greater, as the Monongahela flora has been studied in part. Mr. White enumerates 29 common forms which are of ordinary occurrence in the Coal Measures, these being only the more widespread forms, more than one-half of them appearing frequently in the Allegheny or Conemaugh.

Mr. White finds in the Dunkard plants a transitional flora, such as would be expected in a region where conditions remained practically the same. The boundary between Coal Measures and Dyas is to be determined by the appearance of characteristic Rothliegende species rather than by the presence of persistent Coal Measure types. In western Europe the presence of Callipteris, simple fronded Tæniopteris, Callipteridium of the *gigas* or *regina* type, and the genus Walchia in a flora consisting largely of forms common to the Coal Measures is regarded as sufficient evidence of Rothliegende age, though *Callipteris conferta* and even Walchia may appear lower down. In the Appalachian region a small form of *Callipteris conferta* appears at the horizon of the Lower Washington limestone, while the typical larger form, with *Callipteridium gigas* and others, is unknown below the Dunkard coal bed. The evidence of Rothliegende age for beds below the Lower Washington limestone consists in the presence of *Equisetites rugosus* and several less important forms and of some others which have Mesozoic or Permian aspect; but these latter are extremely rare, having been found only in a single coal drift, though careful search has been made for them elsewhere.

Mr. White regards the beds below the Lower Washington limestone as containing a transitional flora and not distinctly Rothliegende, but above that limestone the flora becomes increasingly characteristic. As in that limestone is the first appearance of *Callipteris conferta*, he thinks the lower limit may be drawn safely at that horizon. The flora of the upper Dunkard is to be compared with the Stockheim and Cusel beds in Germany and the series in the basin of Brives, in France. None of the characteristic coniferous genera Ullmannia, Tylodendron, Walchia occurs in Dunkard beds, though all are in Prince Edward Island and Walchia is reported from Texas; and similarly many genera of ferns characterizing the Rothliegende of Europe seem to be wholly unrepresented.

In connection with Mr. White's conclusions, it is well to recall some relations noted in preceding pages. The general physical conditions during Allegheny and Conemaugh were practically the same, for while the basin was contracting there was no material variation in character of the movements, but with the beginning of the Monongahela the area of greatest subsidence was shifted a hundred miles and a new condition remained unaltered throughout the Monongahela and Washington, which in this respect are one as the Allegheny and Conemaugh are one. A notable change occurred at the Washington, and Mr. White has shown that the strongly marked lower Rothliegende flora makes its appearance near the bottom of the Greene formation.

K 10. KLAMATH MOUNTAINS, CALIFORNIA.

Certain limestones of the Klamath Mountain region are faunally more closely related to the Guadalupe group of the Permian of trans-Pecos Texas than to any other terrane in the United States.[a] (See pp. 359–360, Chapter VIII.)

K 12–13. WYOMING, NORTHERN COLORADO, AND UTAH.

In the Park City mining district, northeastern Utah, Boutwell distinguished the Woodside shale, Thaynes formation, and Ankareh shale. (See section given on p. 380, Chapter VIII.) The Woodside is a fine-grained unfossiliferous red shale 700 to 1,180 feet thick, which conformably overlies the Park City formation (Pennsylvanian). The Thaynes is characteristically calcareous and rich in fossils. It is 1,190 feet thick. In 1907 Girty reported that "the fauna and horizon are those which in the Fortieth Parallel Survey reports are called Permo-Carboniferous" and said: "It seems probable that the fauna will be correlated with the Permian of the Grand Canyon section." Revising this statement in 1910, he states: "Latest information makes it doubtful whether these are not Triassic, in part almost certainly equivalent to the Triassic of Idaho."

The Ankareh shale is a siliceous red shale and sandstone, 1,300 feet thick, which on rather meager paleontologic evidence is classed as Permian.[93a]

The Woodside and Thaynes formations of northeastern Utah were recognized by Veatch[839] in southwestern Wyoming, where they have a development similar to that at Park City. Above the Thaynes limestone and below the fossiliferous marine Jurassic, Veatch distinguished the Nugget formation, which he classed as Triassic(?). His Nugget comprised two members, a bright-red sandy shale, reaching a maximum thickness of 600 feet (now correlated by Gale with the Ankareh shale), and an upper sequence of light-colored sandstones (to which the name Nugget is now restricted).

The divisions of the red beds recognized by Veatch were in 1906 traced northward by Schultz[b] into central Uinta County, Wyo.

The region examined by Boutwell, Veatch, and Schultz is the western part of the province in which the red beds of Permian and Triassic age are developed.

[a] Girty, G. H., personal communication.

[b] Schultz, A. R., personal communication.

Formations similar to those described occur about the Bighorn Basin and Mountains, but the divisions have been called by local names, as equivalent formations in the two areas are not identified.

In the Bighorn Mountains Darton[237, 239b] distinguished the Amsden formation, the upper part of which contains a distinct Pennsylvanian fauna and the lower part of which in some areas is of Mississippian age. Succeeding the Amsden, he recognized the Tensleep sandstone (Pennsylvanian), the Embar formation (Pennsylvanian and Permian?), and the Chugwater formation (Triassic or Permian). The Tensleep is a massive white sandstone, in part calcareous, and the Embar consists of limestones with associated shaly and cherty beds. The characteristic fossil of the Embar is *Spiriferina pulchra,* which occurs just below the "Permo-Carboniferous" of the Wasatch Mountains and the Permian of the Grand Canyon. The Embar thins out northward and in the northern part of the Bighorn Range the Chugwater formation rests on the Tensleep sandstone.

The Chugwater formation thus occupies part or all of the stratigraphic interval between the Pennsylvanian and the marine Jurassic (Sundance formation), in northern Wyoming. It is a typical red-bed formation from 600 to 1,200 feet thick. Darton[239d] describes it as follows, in part:

> The rocks are mainly soft, massive, red, fine grained sandstones, merging into red shale, but extensive gypsum deposits and a few thin limestone beds are also included. * * *
>
> The general character of the Chugwater deposits does not vary greatly in different portions of the region. Toward the top and bottom red shales predominate, while in the middle soft sandstones and alternations of sandstones and shales are the principal features. Near the base there is invariably a thin bed of purplish-gray limestone, generally varying in thickness from 5 to 15 feet. Fifty feet or more higher there is another bed of limestone, mostly massive, of dirty-gray or buff color, in which weathering develops a characteristic porous structure. This bed has a thickness of 10 to 15 feet along the east side of the uplift and to the south, but along the west-central and northwestern slopes of the mountain its thickness increases considerably and it forms a conspicuous ledge. Toward the top of the formation there is always a succession of thin-bedded, light-colored limestones separated by red shales. These limestone bodies vary from two to four in number, and they are usually separated by from 10 to 50 feet of shales. Gypsum deposits occur in the Chugwater formation in irregular bodies in the lower and upper portions, the most persistent bed or series of beds being not far from the base. The formation attains its greatest thickness in the region northwest and southwest of Buffalo, where it measures 1,230 feet. In the region west of Sheridan the amount is 1,100 feet but it gradually diminishes to the north, being only about 600 feet at Bighorn River. On the west side and southern portion of the range the average is about 800 feet, but it diminishes somewhat to the north, the amount being not over 700 feet near Horse Creek.

Darton cites occurrences of fossils from the lower part of the Chugwater formation which are, however, poorly preserved or for other reasons indeterminate as to age. In the opinion of Girty and Schuchert they are probably Permian. The upper part at least of the Chugwater is regarded as probably of Triassic age, and both Darton[239e] and Fisher[331a] doubtfully assign the whole formation to the Triassic.

K 13. BLACK HILLS, SOUTH DAKOTA.

The Permian of the Black Hills comprises some indeterminate part of the red beds, which Darton has separated into the Opeche, Minnekahta, and Spearfish formations. The Opeche and Minnekahta are now regarded as Permian, but the Spearfish is believed to be probably of Triassic age. Below the red sandstones of the Opeche occur other sandstones which have yielded "indistinct casts of *Productus semireticulatus* and *Seminula dawsonii* (*Athyris subtilita*)" and which are provisionally assigned to the Pennsylvanian. Concerning the formations Darton[237c] says:

Opeche formation.—In this formation the first of the red beds makes its appearance in the Black Hills region. The materials are soft red sandstones, mainly thin bedded and containing variable amounts of clay admixture, having a thickness varying from 120 feet in the southeastern part of the hills to about half that amount to the northwestward. The basal beds of the formation are usually red sandstones, the beds varying in thickness from 4 to 13 inches. Gypsum occurs at a few points in beds which are neither thick nor extensive.

The age of the formation has not been definitely determined, for so far it has yielded no fossils. From the fact that the overlying Minnekahta limestone is of Permian age, and the deposition of gypsiferous red beds in other regions began in Permian time, the formation is provisionally assigned to that division.

Minnekahta limestone.—Overlying the Opeche red beds there is a limestone persistent over a wide area in the Northwest, which I have designated the Minnekahta limestone. Though thin, averaging less than 50 feet in thickness, it is hard, flexible, and, by the easy erosion of the red beds in which it is inclosed, outcrops in long slopes and prominent ridges.

The rock is uniform in character throughout, being a thin-bedded light-colored limestone, containing magnesia and more or less clay. Its thin bedding is a characteristic feature, although the thin layers are so cemented together that the outcropping ledges present a massive appearance. * * * On weathering, it breaks into slabs usually 2 to 3 inches in thickness. On the western side of the hills its coloring is slightly darker, varying from a dove color to lead-gray, and some of the beds present a seminodular structure. An increased admixture of clay is also observed in some layers. The general appearance of the formation is always slightly pinkish, with a tinge of purple, from which fact the old term "purple limestone" originated.

The limestone contains fossils at a number of localities, but the forms are not well preserved and not altogether decisive as to the age of the deposits. At a locality 15 miles west-northwest of Hot Springs there were observed Bakewellia and Edmundia similar to those observed in the Kansas Permian, and from this evidence the limestone is assigned to the Permian. Near Sturgis similar fossils occur.

Spearfish formation.—The designation Spearfish formation has been applied to the main body of gypsiferous red beds which outcrop in a broad zone encircling the Black Hills uplift. This formation consists of from 350 to 700 feet of red sandy clays, with intercalated beds of gypsum which sometimes are 30 feet thick. The bright-red color of the shales and the snowy white of the gypsum are striking features of the formation. Were it not for the gypsum the formation would present no noticeable features of stratigraphy, as the sedimentary material is almost entirely a red shale containing varying amounts of fine sand admixture. It is generally thin bedded. The gypsum occurs in beds at various horizons, some of the larger beds extending continuously over wide areas. There is also throughout the formation more or less secondary deposition of gypsum in small veins.

The thickness of the Spearfish formation can seldom be determined with accuracy, owing to the softness of the material and the predominance of low, variable dips which are difficult to measure. Along the east side of the Black Hills the formation appears to have a thickness of from 350 to 400 feet, but the amount increases to the northward to 492 feet in the well at Cambria, 695 feet in a well at Sturgis, and at least 650 feet in a deep boring at Aladdin. To the southeastward the principal bed of gypsum generally varies from 5 to 15 feet, increasing southward in the vicinity of Hot Springs to the maximum development, in which the principal beds have a thickness of 33½ feet, with a 10-foot parting of red shale between. * * * Along the west side of the uplift there is usually a bed of gypsum at a horizon about 150 feet above the base of the formation, and east of Newcastle for some distance there is a 25-foot bed of gypsum at the top of the formation, * * * several thin beds in its center, and at its base a local thin bed of gypsum lying directly on the Minnekahta limestone. Throughout the Black Hills the formation is distinctly separated from the underlying Minnekahta limestone by a very abrupt change of material, and from the overlying marine Jurassic deposits by a well-marked erosional unconformity.

K 15. IOWA.

Deposits of gypsum associated with red shale and sandstone which occur in isolated areas in the vicinity of Fort Dodge, Iowa, have been assigned to the Permian on the ground of lithologic relations, no fossils having been found. The occurrences are described in detail by Wilder,[929] who considers also the alternative possibilities of Triassic or Cretaceous age.

L 20. NEW BRUNSWICK, NOVA SCOTIA, AND PRINCE EDWARD ISLAND.

The Permian (in some of the reports called "Upper Carboniferous") of Nova Scotia and New Brunswick was described by Dawson,[263e] Logan,[545] and later by Fletcher [334c, 335e] and Bailey.[45e] In Fletcher's later report [335e] he subdivides the Permian as follows:

1. New Glasgow conglomerate.
2. Middle gray sandstone and shale group, with small coal seams.
3. Upper red sandstone and shale group, with thin bands of limestone.

These groups lie in parallel belts along the shore of Northumberland Strait between Merigomish and Wallace, dipping seaward, generally at a low angle, but broken by faults sometimes of considerable magnitude. Between the second and third groups there is no distinct line of demarcation and the subdivision is only one of convenience.

The position of the New Glasgow conglomerate in relation to the productive coal measures (Pennsylvanian) has been a matter of doubt, as it resembles the "Millstone grit" at their base. Fletcher concludes that the "New Glasgow conglomerate is newer than the coal measures." He describes an unconformity between the New Glasgow and the "Millstone grit." The dip of the former is not so steep as that of the latter and "gray sandstone with greenish and reddish tints, dipping 42° to 51°, is overlain by thick beds of very coarse conglomerate which fills depressions in the lower beds." Again the conglomerate, though mostly composed of material from the Devonian, contains large pebbles, some of which "are certainly derived from the Millstone grit or coal measures." This basal conglomerate of the Permian overlaps upon Devonian and Silurian rocks and varies greatly in thickness, being in places perhaps entirely lacking or overlapped, yet elsewhere apparently 1,300 feet or more thick.

Sections of the higher Permian rocks, with a maximum total thickness of 8,000 feet, are given in much detail by Fletcher.

Dawson,[263c] who called these strata "Upper Carboniferous," did not recognize the Permian in Acadia and devotes a brief chapter to the "Permian blank." His description of the "Upper Carboniferous" is included in that of the Joggins section [263d] and of other coal fields of the region.

Bailey [45c] has the following to say in regard to the "Upper Carboniferous" of New Brunswick:

Upper Carboniferous (Permo-Carboniferous ?).—In the Geological Survey maps of southeastern New Brunswick, a considerable area bordering Baie Verte and portions of Northumberland Strait, and extending thence across the Chicgnecto Peninsula to Cumberland Basin and Shepody Bay, is referred to under the above designations, while in the accompanying report (1884) its author, Dr. R. W. Ells, describes the group as consisting generally of soft reddish or purple-brown sandstone, grits, and shales, resting unconformably upon either the Millstone grit or the Lower Carboniferous. Upon the western side of the Merangouin Peninsula, where one of the unconformable contacts is well exposed, they are estimated, by the author named, to have a thickness of 1,250 feet. As seen in the vicinity of Sackville, they are said to resemble very nearly the sandstones and associated beds of Capes Bald and Tormentine and of Prince Edward Island.

Discussion of this area by Ells and Bailey will be found in Chapter VIII (p. 384).

The rocks of Prince Edward Island are discussed by Dawson and Ells. The bulk of the island has been determined by Ells to be of "Permo-Carboniferous" age, though held by Dawson to be Triassic, except for portions along the southern and western coasts. Dawson [266a] says:

The principal addition to our knowledge of this formation is that contained in the report by Dr. Harrington and myself published in 1871.[a] In this we separated as Upper Carboniferous, or "Permo-Carboniferous," an underlying series of red and gray sandstones and shales, holding Carboniferous plants, extending from near Cape Wolfe toward the north point, and a similar series found at Governor's Island and Gallas Point in Hillsborough Bay. These are undoubtedly extensions of the Carboniferous of Nova Scotia. All the rest of the island is occupied with Triassic rocks, in one place (Hog Island, in Richmond Bay) associated with trap. The general relations of these rocks are seen in the sections.

The beds of the Triassic series, as seen in Prince Edward Island, consist chiefly of soft red sandstone, with some buff-colored beds and red and mottled clays. Associated with them are conglomerates and hard calcareous and concretionary sandstones, passing into bands of arenaceous limestone, which is in some places a dolomite. * * * [Section in Orwell Bay and vicinity given.]

The whole thickness of these beds can not much exceed 500 feet. Of this the lowest 270 feet * * * may be referred to the lower division, or "Bunter," and the remainder to the upper division of the formation, or "Keuper." The dips are so low and the beds so much affected by oblique stratification that those of the Trias can not be said to be unconformable to the underlying Carboniferous rocks, and for this reason, as well as on account of the similarity in mineral character between the two groups, some uncertainty may rest on the position of the line of separation. That above stated depends on fossils, or a somewhat abrupt change of mineral character, and on a slight change in the direction of the dip. These beds spread over the greater part of the island, presenting a nearly horizontal attitude or lying in very flat synclinals and anticlinals. They are well seen in the coast cliffs in many places, and several of these coast sections are given in the report above referred to.

Ells [308] in his report on explorations in the Gaspe Peninsula discusses the age of the strata of Prince Edward Island and their resemblance to the rocks of New Brunswick and concludes:

It will be seen by reference to the report on this province by Drs. Dawson and Harrington (1871) that though the larger part of the island was at that time considered by the authors as of Triassic age, certain portions, among which are the coast from West Cape to Nail Pond

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[a] Report on the geological structure and mineral resources of Prince Edward Island.

and the vicinity of Gallas Point, were considered as pertaining to the upper Carboniferous. It is, however, manifest, from a close study of the various strata from Cape North to Point Prim, that both from their lithological character and the stratigraphical evidence no such separation can be carried out. The great similarity also of all the plant remains from so many points tends to confirm the impression that the whole of the strata exposed along the south and west coast must be assigned to the same horizon. The occurrence also of similar beds in the province of New Brunswick, about whose age but little doubt can exist, as well as on the coast of Pictou and Colchester, which have already been assigned to the upper portion of the Carboniferous, strengthens this view. We have therefore from the careful consideration of all these facts been led to remove the great bulk of the island rocks, from the position which they have so long held as Trias and to classify them under the head of Permo-Carboniferous.

CHAPTER XII.

TRIASSIC.

Color, dark green (horizontal ruling).
Symbol, 10.
Distribution: Central America, Mexico, New Mexico, and Texas; Nevada and California; British Columbia and Alaska; Atlantic slope from North Carolina to Nova Scotia.
Content: Marine Triassic of western Nevada and California; marine Triassic of Zacatecas and red beds in Mexico; red beds of Texas and New Mexico; Newark group, North Carolina to Nova Scotia; marine Triassic of the Arctic. In the Canadian Rockies the marine Triassic is mapped with the "Paleozoic undivided" (19, 20). In Oregon, Idaho, middle western United States, and part of Alaska it is combined on the map with Jurassic (9).

Triassic areas.

D 16. HONDURAS AND NICARAGUA.

Sapper,[696a] in his account of the geology of southern Central America, states:

In the department of Tegucigalpa there occurs a series of marine clays, slates, sandstones, conglomerates, and interbedded limestones which have been determined as upper

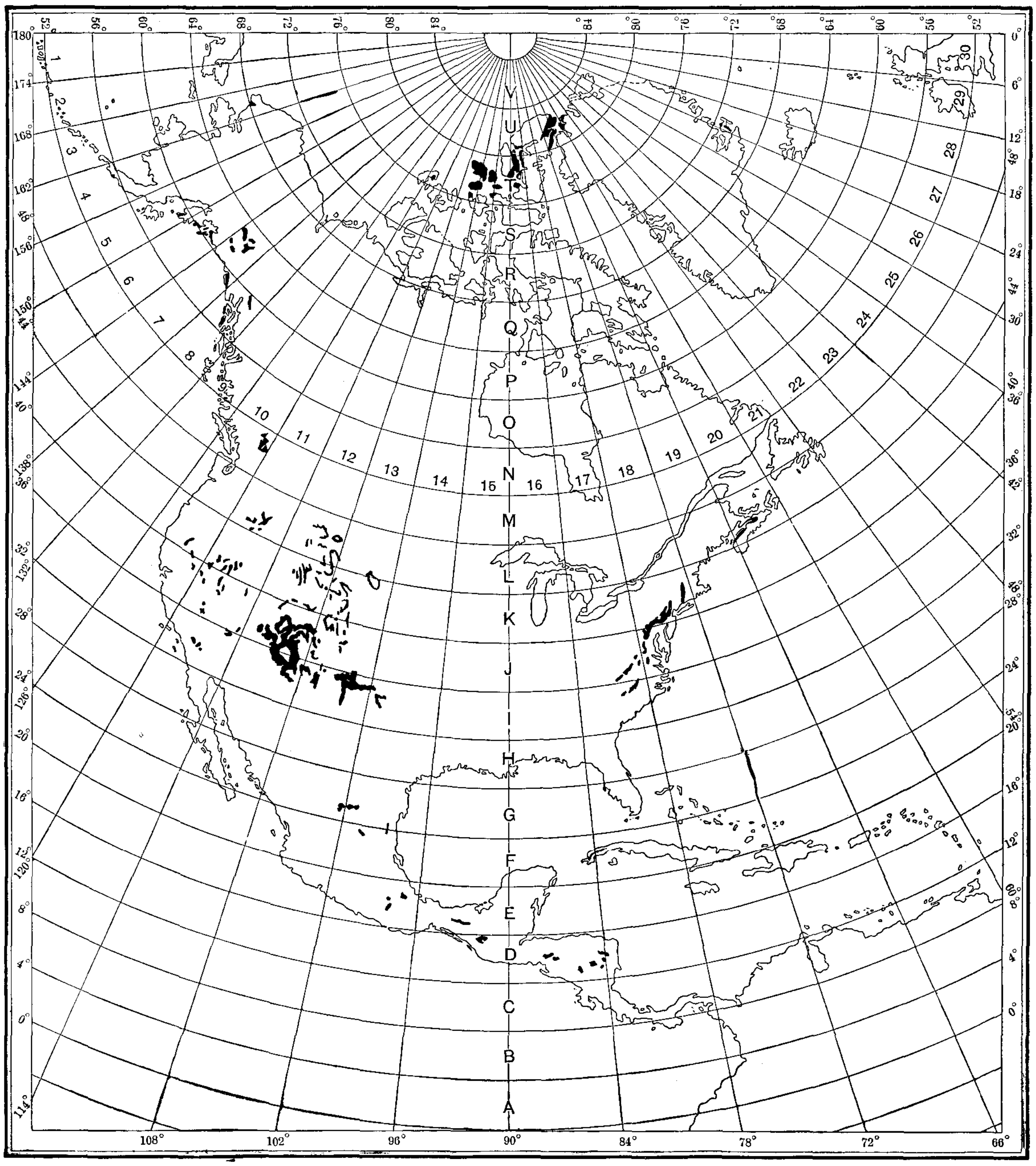

FIGURE 14.—Sketch map showing the distribution of Triassic rocks and of undivided Triassic and Jurassic rocks that are so represented on the geologic map of North America and the key to references in the text.

Triassic on the basis of the discovery of cycads near San Juancito. It remains, however, a mooted question whether these fossils are sufficiently characteristic to establish the age with certainty. [See below.] The thickness is considerable (more than 800 feet) and the petrographic character is very variable. Red colors predominate. According to Leggett the formation occurs not only in the vicinity of Tegucigalpa and San Juancito but also near Sabana, and Dr. Fritzgartner states that it has a wide occurrence in the neighborhood of Danli, where the limestones attain a notable development.

The petrographic resemblance of the Tegucigalpa formation (as it was called by Fritzgartner) with the Metapan terrane [see Chapter XIV, Lower Cretaceous, p. 585], is so great that I was unable, in the absence of fossils, to distinguish them. It may therefore well be the case that a portion of the Metapan terrane, as shown in the departments of Tegucigalpa and Olancho, belongs to the Tegucigalpa formation.

Mierisch described a series of strata observed in Nicaragua which he was inclined to consider as Triassic and which I have therefore designated in my map accordingly. These are beds which in Prinzapolca occur in a horizontal or gently dipping east-west attitude and comprise red fine sandy clays and soft yellowish to white sandstones; soft red sandstones on the Cuicuina River; reddish white to white clays and iron-stained sandstones on the Cuculaia River; fine-grained reddish sandstones which pass over into loose gravelly marls near Ojoche; red sandy clays and gravelly and pebbly strata which are strongly impregnated with iron and contain numerous included quartz blocks near La Guardia; red sandstones below Sirena, on the Rio Grande; soft red clayey sandstones on the Rio Tuma, on the lower Vaspuc; and red sandy clays on the Rio Coco near Saki, Quisalaia, and Saclin. These latter occurrences I have mapped as Tertiary, since the flat position of the completely unfossiliferous strata is in such contrast to the steeply dipping Mesozoic formations of the middle Rio Coco as to indicate without question a younger age. Having in this region begun to doubt the determination of the age by Mierisch, I came to regard his Triassic formation with some question, the more so since he rested his correlation only upon petrographic resemblance with the new red sandstone in the eastern part of the United States, together with the occurrence of splendidly preserved but not very surely determined silicified cycad trunks from the vicinity of Ojoche, as well as upon the intimate relationship between these rocks and the melaphyres, porphyry, and the associated tuffs. * * * It is true that Mierisch calls attention to the fact that the obviously very young "Tertiary" sands, clays, and gravel beds of Prinzapolca rest unconformably upon the Triassic.

Inasmuch as Sapper in several successive publications implies that Newberry's determination of the Rhætic age of the cycads from Honduras should be accepted only with doubt, the present compiler referred the question to F. H. Knowlton, who under date of December 9, 1910, answered as follows:

At your request I have again looked over Newberry's paper on "Rhætic plants from Honduras" and, without going exhaustively into the subject, I see no reason for seriously questioning the correctness of his age determination. Newberry compared this flora with others from various parts of the world and found closest agreement with those of southern Sweden (Bjuf) and India (Rajamahal). There is also a species very close if not actually identical with one in the Triassic (Rhætic) of North Carolina.

In this connection I may add that Dr. Arthur Hollick, of New York, happens to be here now, and I have asked him about this matter. The specimens upon which Newberry based his paper are in the care of Dr. Hollick, and he permits me to say that in his opinion their reference to the Rhætic is justified.

Mierisch [594] states briefly that Triassic rocks occur in Nicaragua. He says:

The path from Muy-muy to Guardia leads through a swampy savannah, "Jicaral," but the district is of geological interest on account of the occurrence of Triassic strata. They are red sandy clays, together with highly ferruginous conglomerates containing numerous quartz blocks; the latter particularly indicate Triassic age, as they are characteristic of a district north of La Guardia, where the age of this formation is placed beyond question by the occurrence of silicified cycad trunks ("Farnstrunke").

Regarding rocks on the River Vulvul, Mierisch says:

Near Ojoche Trias occurs again in the form of a fine-grained red sandstone which is fairly firm. * * * At Ojoche it is rather a loose pebbly mass containing many quartz blocks and fern trunks, which are superbly preserved. Even the bark and attachments of the roots may occasionally be clearly recognized and the internal structure of the wood is retained to the most delicate details. These forms probably belong to the genus Tubicaulis.

The cycads to which Mierisch and Sapper refer were collected by T. H. Leggett and sent to Newberry, who recognized 13 species and assigned them without question to the Upper Triassic. Newberry [612, 613] says:

From the notes furnished me by Mr. Leggett it appears that the plant beds of San Juancito form part of a series of argillaceous shales now converted into hydromica schists several hundred feet in thickness. Below these, limestones crop out which are said to contain Carboniferous fossils, while above them are heavy masses of eruptive rock. The plant-bearing shales are much disturbed and metamorphosed, and are cut by a series of silver-bearing veins which have been worked for many years with considerable success. The outcrops which contain the plants are much decomposed and few good specimens have been obtained from them, but the number of species represented is large and it is evident that further excavation would result in the accumulation of much interesting material.

The age of the deposit as indicated by its plants is plainly Upper Triassic and the flora as a whole has a great resemblance to that of the coal-bearing strata on the Yaki River in Sonora, Mexico, described by me in the report of the San Juan exploring expedition, and to that described by Schenk in "Die fossile Flora der Grenzschichten des Keupers und Lias Frankens" and to Nathorst's "Florau vid Bjuf," a number of the species being identical and others closely allied.

The localities nearest to Honduras where fossils indicative of Triassic age have been before discovered were in Sonora, Mexico, 2,000 miles north, and in the Andes of Peru, where Triassic rocks were found by David Forbes, 2,000 miles south. The plants contained in the collection made by Mr. Leggett are here briefly described.

D-E 15. CHIAPAS AND GUATEMALA.

Sapper [694a] describes the Todos Santos terrane of Central America as a sequence of red or yellow sandy and argillaceous conglomerates, which are but slightly tilted and not apparently conformable to the underlying Carboniferous. They are unfossiliferous but may be Triassic, as similar deposits of that age have been found in Honduras and Nicaragua. Sapper says:

At the northern base of the Sierra Madre in the State of Chiapas one may observe a series of puddingstones, sandstones, and shales, of red or yellow color, which I have called the Todos Santos strata. The beds are but slightly inclined toward the north at various places where I have been able to observe the dip. They do not rest conformably upon the Carboniferous limestone, and it appears that these deposits were laid down after the formation of the first elevation of the Sierra Madre in the margins of a sea later than the Carboniferous but before the Cretaceous, so that they suffered but little dislocation or alteration.

I can not give any exact data in relation to the age of these strata, as I have not found any fossils in them. There are very similar deposits of the Triassic period which have been found in the Republics of Honduras and Nicaragua.

In a later article [698] Sapper stated that he had not been able to observe the contact of the Todos Santos beds with the underlying Carboniferous and could not be sure that the two were unconformable, although that conclusion was probably correct.

Böse [90] in 1906 repeats Sapper's description and adds that the Todos Santos strata appear to belong to the "Triassic-Jurassic," as they are similar in position and lithologic character to strata of those ages which are known in other parts of Mexico (Puebla and Oaxaca) and also in Honduras.

E-F 14. CENTRAL AND NORTHERN MEXICO.

Aguilera [9a] in 1906 thus summed up the occurrences of the Triassic in central and northern Mexico under the heading "Neo-Triassic":

> Marine deposits of the Carnien stage are represented in the vicinity of the city of Zacatecas by siliceous shales and argillaceous and sandy rocks which contain a number of species of Paleoneilo, Halobia, Avicula, Cassianella (Burckhardtia), and some ammonites: *Serenites smithi* Burckh., *Anatomites mosjvari* Burckhardt, Clionites, and Trachyceras. The Triassic beds of Zacatecas are intimately associated with spilitic rocks (greenstones). We may mention in the same connection the marsh and lacustrine deposits of Juravien age which correspond probably to the Keuper and extend up to the Rhætic. They are composed of quartzose sandstones of gray or reddish-brown color, gray, black or varicolored slates, and some beds of red conglomerates with small pebbles in the region of Los Bronches, at the Barranca of San Marcial and San Jose de Pimas in Sonora.

A list of fossils comprising 30 species follows, and Aguilera continues:

> Conglomerates and red sandstones which alternate with gray and black slates and which, inasmuch as they include fossil plants of the same genera and species as those of Los Bronches, are of the same age, have been found in Puebla and Oaxaca, and probably also beneath the beds of Miquihuana, in Tamaulipas.

In the geologic map of North America the occurrences of the Triassic in central and northern Mexico have generally been mapped with the Jurassic in accordance with the manuscript map furnished by the Mexican Survey. (See also quotations under Jurassic in Chapter XIII.)

The Triassic of Zacatecas was described by Burckhardt and Scalia.[111] After describing ancient sericitic schists, whose age they say is probably pre-Triassic, as they are unconformably overlain by beds of the upper Triassic, the authors continue:

> The upper Triassic strata rest in discordance upon the ancient schists forming the central portions of the two recumbent synclines that are open toward the east and which may be observed in the valley of the Pimienta. The existence of these synclines is proved by the arrangement of two bands of Triassic strata intercalated in the ancient schists. One may observe quartzites and quartzitic sandstones of dark-gray color containing fragments of quartz and feldspar in the center of the two Triassic occurrences, while these rocks are limited on both sides by quite a thickness of siliceous and argillaceous schists which are black or dark blue and alternate with green sandstones and greenish or gray argillites. All of these rocks dip toward the east. * * * The Triassic fossils occur in two different localities; the first is situated close to the point where the Arroyo Calavera or Pimienta is crossed by a bridge, the bridge of Ahogado. At that point, in the northern flank of the eastern syncline of the Trias, fossils occur in the black siliceous slates as well as in a gray argillaceous rock. These beds are filled with fossils, especially with small bivalves, while ammonites are rare and fragmentary.

The fossils that were collected at this point were independently determined by Mojsisovics and J. P. Smith as belonging probably to the Carnien stage of the Upper Triassic of Europe. A second collection of fossils was obtained in greenish sandstones and argillaceous rocks in the western syncline of the Triassic. The authors continue:

It is proved by the discovery of these fossils that the upper part of the slates of Zacatecas belong to the upper marine Trias.

A full description of the fauna is given by Burckhardt.[108]

I 11. SOUTHERN CALIFORNIA.

The several areas of Triassic rocks southeast of Los Angeles are described by W. C. Mendenhall for this report as follows:

The Santa Ana Mountains, usually regarded as a southern extension of the Coast Ranges, form a portion of the boundary between Riverside and Orange counties in southern California. The group, which lies for the most part south of the lower course of Santa Ana River and west of the Temescal Wash, culminates in Santiago Peak, 5,680 feet high. Its axis is made up of a series of dark-gray or black slates with minor amounts of interbedded brown sandstones, the whole sparingly intruded by a series of medium acidic dikes and overlain unconformably by remnants of the associated effusives whose aspect is generally that of andesites or slightly more acidic rocks.

The slates exhibit varying degrees of metamorphism. They usually have a well-developed cleavage, which, however, is generally not sufficiently perfect to obscure the original bedding planes. In general appearance they resemble the Mariposa slate of central California, although as a rule they are less extensively altered. These sediments are the oldest rocks of the mountain range in which they occur. The effusives already mentioned overlie the slates but have been affected by a part of the same metamorphism.

Both the sediments and the associated effusives have been intruded and slightly altered by great masses of granitic rocks, and this threefold series after a long time interval, represented by an extensive physical unconformity, has been at least partly buried under Cretaceous conglomerates and shales of Chico aspect that are now entirely unaltered though extensively deformed. These Upper Cretaceous rocks form an encircling outcrop that flanks the dome of older rocks.

The determination of the age of the slates is based on small collections made in Ladd Canyon, on the south slope of the range, and near the mouth of Bedford Canyon, on its north slope. These collections were examined by Dr. Stanton, who reports as follows on the Bedford Canyon collection:

"The two Triassic lots, both from the neighborhood of Bedford Canyon, evidently came from essentially the same horizon. No. 230 contains fine specimens of a large species of Rhynchonella of a Mesozoic type and a single specimen of Spiriferina. No. 321 contains the same species as 230 and in addition a plicate form of Terebratula and fragments of crinoid stems. These fossils taken together clearly indicate the Triassic age of the fauna, but in the absence of ammonites and other diagnostic forms it is not possible to determine the exact horizon, although it is probably Upper Triassic rather than older."

Thus the collections, although meager, seem abundantly sufficient to establish the Triassic age of the slates. Accepting this age, then, as determined, we must assign the later granitic intrusions to the Jurassic or the early Cretaceous.

The Triassic beds probably extend considerably beyond the area in the Santa Ana Mountains where they have been carefully examined. Similar beds are known to occur in Railroad Canyon between Elsinore and Perris, and fragmental masses of them apparently caught up in the widespread granitic intrusions of the area occur farther east in the vicinity of Poloma and Los Alamos valleys, in Riverside County.

I 13–14. EASTERN NEW MEXICO AND WESTERN TEXAS.

The Triassic of eastern New Mexico occurs in the escarpment along the valley of Canadian River, and probably elsewhere as the uppermost part of the red beds beneath strata which are believed to represent the Morrison formation (Jurassic or Cretaceous). The strata are 100 to 200 feet thick and are sandstones of reddish color with lighter-colored balls of clay.[a] Triassic vertebrate remains have been found by Stanton[781b] near Folsom and by Lee[528] at a point southeast of Tucumcari.

The original section of Mount Tucumcari ("Pyramid Mountain") was observed by Marcou and is thus described by Blake:[85]

Pyramid Mountain.—The finest and most complete section of the horizontal strata of the bluffs along the route was obtained at this mountain by Mr. Marcou. The point was peculiarly favorable, being one of the isolated mounds, a remnant of the Llano, and exposing the strata on all sides. It is only one of the many mounds dotted over the wide space eroded by the river from the Llano, and called Plaza Larga by the Mexicans. This mound was ascended by Mr. Marcou, and others of the party, and we find the following record of the succession of the strata in the notes under date of September 22:

Section at Pyramid Mountain.

"Jurassic:"
- White limestone.
- Yellow limestone with bluish-gray bed at the bottom.
- Bed containing Ostrea ——— (?).[b]
- White sandstone.
- Yellow sandstone.
- White sandstone.

"Triassic:"
- Gray and green bed in contact with the superior Trias.
- Red and green sandstone.
- White marls with concretions.
- Red and green marls.
- White.
- Red.

[Thickness,] 500 feet.

Mr. Marcou considers that the base of this mound is formed of the beds of the superior Trias, the upper portion being Jurassic. It does not appear to me that the evidences are quite sufficient to warrant this decision, but the discussion of this subject will be left for a subsequent portion of the report.

A sketch of this mound was carefully taken in colors by Mr. Möllhausen, the tints agreeing as nearly as possible with those presented by the strata. The sketch has been lithographed and is appended. It will serve to convey an idea of the relations of the strata, especially the white and red series, and may be received as an exhibit of the general aspect of the bluffs of the Llano, where the beds are exposed. The section and locality derives great interest from the occurrence of fossils. The bed containing the Ostrea is said to be of grayish-blue clay and subschistose, and 2 inches thick. The Ostrea is subsequently called *Ostrea dilatata*, and is again mentioned in the résumé. This is the fossil called *Gryphæa tucumcarii* in the collection (No. 133) from Pyramid Mountain, and referred to in the résumé under the same name, it

[a] Lee, W. T., personal communication.

[b] The specific name can not be deciphered in the original. It looks like *comanche*.—W. P. B.

being said to have the greatest analogy with the *Gryphæa dilatata* of the Oxford clay.[a] It is probably a new species or a variety of *Gryphæa pitcheri*, and a description of it will be found in Chapter IX, under the name *G. tucumcarii*, originally proposed by Mr. Marcou.

From these various observations we may conclude that the great plateau, the Llano Estacado, consists of horizontal strata of light-colored white or grayish-white and yellowish sandstones and bluish clays and marls, resting conformably upon beds of red clay, red sandstone, and gypsum, and these, according to Mr. Marcou, are intercalated with grayish or light-colored sandstones, as on Rocky Delaware Creek. It also appears that the light-colored sandstones and calcareous beds constitute the main part of the bluffs and that the red marls and clay of the gypseous series are at their base and occupy the space between them and the river.

The strata assigned to the Jurassic by Marcou were by Cummins[197] shown to be Lower Cretaceous. The Triassic age of the lower part of the section is neither proved nor disproved. The strata beneath the Cretaceous may be Triassic, or they may be older red beds (Permian or Pennsylvanian) from which the Triassic beds were eroded.

In western Texas Cummins distinguished and Drake[293] described the Dockum group, of Triassic age, a sequence of calcareous sandstone, clay, cross-bedded sandstone, and conglomerate, deposited on an eroded surface of Permian. Drake recognized three divisions, which he described in detail.

The Dockum beds underlie all or nearly all of the Staked Plains of Texas and southeastern New Mexico, extend farther back into New Mexico northwest of the plains, and have some extension under the Cretaceous area south of them in Texas.

The limit of the plains on the east, north, and west is marked by an escarpment which is usually from 100 to 200 and sometimes 300 or 400 feet high. The basal portion, sometimes nearly all of this escarpment, is composed of the Triassic beds. These beds usually extend 6 or 7 miles from the base of the escarpment and nearly surround the plains by a narrow band.

*   *   *   *   *   *   *   *   *

Sandstones, conglomerates, and clays constitute nearly all of the strata of this formation. The materials composing the different strata vary somewhat in lithological characteristics at different localities and even at the same locality, but the general characteristics are quite uniform and are so different from the underlying Permian and overlying Cretaceous or Tertiary that they are usually easily recognized. This is especially true of the sandstones and conglomerates.

Sandstones.—The sandstones before exposure to weather are generally nearly white, but sometimes gray, red, or bluish in color. Massive, shaly, and false bedding are common. The texture varies from a fine, even-grained to a grit or conglomeratic sandstone. White and a few brown mica flakes, varying in size from a mere speck to one-eighth of an inch in diameter, are nearly always present. This mica is so abundant in some of the rocks as to make them fissile. The sandstones are usually friable but weather with a smooth, flat surface and with an average sharpness of angle for sandstone rocks.

Conglomerates.—The conglomerates are of two kinds. The one most characteristic and widespread is composed of small pieces of brownish, yellowish, or bluish colored subangular indurated clayey sandstone fragments, averaging about the size of a pea, embedded in a matrix of sand or grit, usually calcareous. The other is composed of siliceous pebbles in a matrix of sand and grit. The pebbles are usually small and well rounded and of nearly all shades of color, but white quartz are the most numerous. The quantity of siliceous pebbles varies at different localities from more than half the rock mass to very few. Both conglomerates contain silicified wood at some localities. The bedding of the siliceous conglomerate is usually even and regular or slightly false, while that of the first named is false almost without exception. These two conglomerates graduate into each other, and even where one is the most characteristic the other usually enters into it more or less.

[a] The genus Gryphæa was formerly included with the Ostracea.

Clays.—The clays are a dark red or blue, with some variations of yellowish and purple, and are calcareous and arenaceous. The blue clays are not very common, are nearly always highly arenaceous, and frequently contain vertebrate remains. The red clays are seen at nearly every outcrop and are often more than 100 feet thick, with probably a few thin layers of sandstone distributed through the strata.

Thickness and unconformability.—The slight difference in dip and sudden change in lithological character of the Triassic beds from the Permian point conclusively to a break in the sedimentation of the two formations. At some localities the Triassic beds are overlain by Cretaceous, but generally by Tertiary material. The Cretaceous escarpment or butts resting on the Triassic beds are often 200 feet thick and mostly limestone. The denuding forces that for an immense length of time were cutting these Cretaceous rocks back toward their present limits must have carried away a great deal of the Triassic before it was covered by Tertiary. The strata thus inclosed between two unconformable beds must of necessity vary in thickness, and so we find it varying from a few feet to nearly 400 feet. Even in localities close together the beds vary considerably in thickness. The average, however, will probably reach 200 feet.

Stratigraphy.—The following classification or grouping is not intended as a correlation with any other Triassic beds, but only to apply to the Dockum beds over the area examined. The Dockum may be divided into three beds, though some localities show more, that are more or less well marked. * * * These three main beds are as follows: A lower bed of sandy clay, which is from 0 to 150 feet thick; a central bed or beds of sandstone, conglomerate, and some sandy clay, which is from 0 to 235 feet thick; an upper bed of sandy clay and some sandstone, which is from 0 to 300 feet thick. While these groups represent the different geological horizons over most of the Triassic area, there is nevertheless at some places a thinning out of one, and a thickening of another, which shows that at the same time the conditions of deposition were somewhat different at different localities. The same geological horizon is, therefore, more or less represented in other beds than that which generally represents it. Then, while these three beds do not absolutely represent geological horizons, they do so approximately and are so well marked as to be of much stratigraphical value.

These strata are fresh-water deposits and their age is determined on vertebrate remains by Cope.

I-J 17. NORTH CAROLINA.

Kerr[489] thus described the rocks of the Dan and Deep River belts, the Triassic of North Carolina:

The rocks are sandstones, clay slates, shales, and conglomerates, generally ferruginous and brick-red, but often gray and drab. The shales are occasionally marly, and these and the sandstones are sometimes saliferous. Many of the beds consist of loose and uncompacted materials and are therefore easily abraded.

The most important and conspicuous member of the series is a large body of black shales, which incloses seams of bituminous coal, 2 to 6 feet. This coal lies near the base of the system in both belts and is underlain on Dan River by shales and on Deep River by sandstones and conglomerates, the latter constituting the lowest number of the series and being in places very coarse. And near the eastern margin in Wake County, where the belt reaches its greatest breadth (some 15 miles), the conglomerates are of great thickness and very coarse, uncompacted and rudely stratified, resembling somewhat the half-stratified drift of the mountain slopes, the fragments often little worn and sometimes 10 and 12 inches in diameter, and evidently derived from the Huronian rocks of the hills to the eastward. The conglomerates of the Dan River belt are among the upper members of the series and are mostly fine and graduate into grits and sandstones.

The black shales near the base of the system contain beds of fire clay and black-band iron ore, interstratified with the coal. They are also highly fossiliferous, especially on Deep River. Silicified trunks of trees are very abundant in the lower sandstones, as may be seen conspicuously near Germanton, in Stokes County, the public road being in a measure obstructed by the multitude of fragments and entire trunks and projecting stumps of a petrified Triassic forest; and similar petrifactions are abundant in the Deep River belt, occurring in this, as in the other, among the sandstones near the horizon of the coal.

The Triassic coal-bearing terrane of North Carolina has also been described by Woodworth,[949] as follows:

There are two coal-bearing Triassic areas in North Carolina. These are the eastern or Deep River area, including the Wadesboro detached area, and the western or Dan River area. The principal productive coal beds are found in the Deep River district, in Chatham and Moore counties. The Dan River region is regarded as of little promise. * * *

The Deep River area forms a northeast-southwest belt in the central portion of the State, extending northward nearly to the Virginia line and southward into South Carolina. The productive area, about 30 miles long, lies wholly within North Carolina.

The rocks of the area appear on the north about 6 miles southeast of Oxford, in Granville County, whence they extend southwestward to the Cape Fear River. South of this stream they continue as a somewhat tortuous belt in the Deep River region to within about 10 miles of the Yadkin River. On the Yadkin, and a few miles west of the southern end of the Deep River area proper, the Wadesboro area begins and extends in the same general direction 6 or 7 miles into South Carolina, in the vicinity of Carew. The total length of the whole belt is over 60 miles. Its average width is about 12 miles, its greatest width being as much as 18 miles. The total area has been estimated at between 250 and 300 square miles. Between the larger northern and southern areas are small detached basins of Triassic rocks not known to be coal bearing.

The area displays the prevailing structure of the Triassic belts along the Atlantic coast, the basal strata of one side of the belt reposing on the ancient crystalline rocks of the Piedmont district, the opposite margin bearing evidence of being thrown down by faults. The usual dip of the strata in this area is southeast, the angle being about 15°. According to Russell, the notches in the boundaries probably indicate faults, several of which are exposed in railroad cuts within the area. Evidence of faulting is also seen in the narrow strip of Triassic strata near the western border, in the vicinity of Lockville.

The coal-bearing beds show a distinct curvature where crossed by the Deep River northeast of Cummocks. In other respects the structure, as revealed in workings, appears to be more regular than that of the Richmond area in Virginia.

The strata, numbered from the bottom upward, are given as follows in the State reports:

Strata in Deep River area, North Carolina.

	Feet.
3. Sandstones, grits, and upper conglomerates	3,000
2. Black shales, with coal beds	500 to 600
1. Conglomerates and sandstones	1,500

As in the Richmond and other Triassic areas, the coal beds are near the base of the Newark formation. * * *

Five coal seams have been proved at the Farmville and Hornesville mines. Their thicknesses, beginning with the highest, are given as 3, 1, 3, 2, and 4 feet. At the Cunnock mine there are two beds, one 4 and the other 2 feet in thickness, separated by 2 feet of black-band iron ore. At Taylor's mines three seams were reported, with a thickness of from 18 to 30 inches, 2.5 to 2 feet, and 4 feet, respectively. At Wilcox's the Murchison seam is described as being 8 or 9 feet thick but containing shale. The coal outcrop has been traced for 30 or 40 miles in the central part of the State southwestward from the vicinity of the Cape Fear River.

Chance [a] found at Farmville, N. C., five beds of coal in the following section, which measured 40 to 50 feet from the roof of the uppermost coal bed to the floor of the lowest.

[a] Trans. Am. Inst. Min. Eng., vol. 13, pp. 517–520.

Section of coal beds at Farmville, N. C.

Slate roof.	
Coal, good	3 feet to 3 feet 2 inches.
Black band and slate	1 foot 8 inches to 3 feet.
Coal, poor, shaly	1 foot to 2 feet.
Pure clay floor.	

I-K 12-13. UTAH, COLORADO, NEW MEXICO, AND ARIZONA.

Along the fortieth parallel so-called Triassic rocks were originally distinguished by King and his associates,[505d] whose observations are thus summed up:

In the region of the Rocky Mountains we have seen that the Trias frequently overlaps the older rocks and comes directly into nonconformable contact with the great Archean islands that now form the three ranges of the Rocky Mountain system in our latitude. The Trias is in general a series of sandstones; the upper half is always of lighter colors than the lower half and is always intercalated more or less with beds of dolomitic limestone and gypsum. The series varies from 300 to 1,000 feet in thickness. Wherever it stands at a high dip, it is most compressed in thickness and most compacted in lithological character. Wherever its position approaches horizontality, the texture of the rock is that of a loose, friable sediment. The lower half of the series is usually from brick to vermilion red and buff, with occasional exceptions of white and brilliant vermilion. The intercalated dolomitic and gypsum beds are never continuous but are shallow deposits of no great lateral extension. On approaching the Archean rocks the Trias have always more or less local conglomerates, derived directly from the shores against which they abut. There is considerable variability in color, in thickness, and in special arrangement and sequence of the sediments. From 1,000 feet maximum in the region of the Rocky Mountains the deposit thickens in passing westward, until, in the neighborhood of the eastern part of the Uinta, it is fully 2,000 to 2,500 feet thick. The division between the lower dark-red member and the upper buff or white member is much more distinct in the Uinta region than to the east. Here, however, are still the intercalated gypsums and dolomites in the upper half of the series, the gypsum sometimes reaching 40 feet of pure white crystalline sulphate. There are also in the Uinta considerable intercalations of clayey matter, which are rare in Colorado.

Passing still farther westward, against the Wahsatch, there is again a noticeable diminution of thickness and a corresponding increase of stony compactness. Under the microscope no single specimen was observed that had not a considerable amount of carbon and a trace of crystals of carbonate of lime. In approaching the Wahsatch, also, there is a considerable increase of conglomerates. This constitutes another argument indicating the approach of a land mass to the west, whence detritus is derived. But one fossil, a new species, was found in the entire Triassic series of the east, and that was obtained from one of the limestone beds—a greenish-drab lithographic limestone—a little above the middle of the series, on the south flank of the Uinta. That fossil had a distinctly upper Triassic or Jurassic facies. The upper horizons, especially the uppermost member of all, varying from 200 feet in Colorado to 600 in the Uinta and sometimes more than that upon the flanks of the Wahsatch, is characterized by remarkable cross stratification which is prominent over most of the exposed area east of the Wahsatch. The flow and plunge structure is developed in a perfection rarely seen, the plane of the cross stratification often inclining to the true bedding planes at an angle of 30° to 35°.

The upper half, bearing irregular sheets of gypsum and of dolomitic limestone, is always directly conformably overlain by the Jurassic beds, which, when first seen on the east flank of Colorado Range, vary from 250 to 275 feet in thickness, and increase steadily until on the flanks of the Wahsatch they have reached fully 1,800 feet. There is a very great physical contrast between the general character of the materials of the Triassic and the Jurassic series. The former is, on the whole, free from lime, except in the sulphate and dolomitic beds, and is with the exception of certain parts of the Uinta rather free from intercalated clays. On the other hand, the Jurassic, in the Rocky Mountain region, is entirely made up of soft clays; argillaceous and calcareous marls, and thin intercalations of fine lithographic limestone. In the Uinta and Wahsatch region the lower 600 or 800 feet are a bed of solid but very fine grained, slightly argillaceous limestone, and the upper 800 feet are made of fine calcareous argillites. As a whole the series is a lime and clay deposit.

Later observations have shown that part of the supposed Triassic is Permian, some part is Triassic, there are pre-Jurassic unconformities, and the Triassic and Permian deposits which were considered to be marine are in fact largely continental. Cross has recently reviewed the literature and field evidence of this red-beds problem. His statements regarding the probable correlation and distribution of the Permian have been quoted at some length (pp. 480–484), and extracts from those relating to the Triassic follow. The San Juan district of southwestern Colorado is the type locality of the Dolores formation (Triassic). Of this region Cross [193a] writes:

The Dolores formation embraces the Triassic portion of the red beds of southwestern Colorado, several hundred feet in thickness. It is limited both above and below by planes of unconformity. In most places it rests on the Cutler formation [Permian?] and is overlain by the La Plata sandstone [Jurassic]. It consists of sandstones, shales, and fine-grained conglomerates, all more or less calcareous. There are two divisions of the formation; the lower embraces variable sandstones, conglomerates, and shales, partly greenish or gray in color and persistently fossiliferous at several horizons; the upper portion is a very fine and evenly grained sandstone and shale of strong red color.

The lower portion of the Dolores formation consists of an alternation of reddish sandstones, more or less shaly, with conglomerate, consisting chiefly of very small limestone pebbles. These conglomerates characterize several bands within the lower 300 or 400 feet of the Dolores, and, owing to their fossil content and notable lithologic characteristics, these beds are the most diagnostic of the whole formation. The conglomerate beds are very variable in number. In some places a ledge 20 feet thick may be seen to consist chiefly of conglomerate with numerous sandy partings and common cross-bedding. A few yards distant the same strata may be composed chiefly of sandstone with a number of thin layers of conglomerate.

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The conglomerates are commonly associated with thin-bedded gray sandstones or greenish-gray sandy shales. A complex of such alternating strata 50 to 75 feet in thickness can be traced for long distances on the flanks of the San Juan Mountains. Carbonaceous material is common in the shaly beds, but determinable leaves have not been observed. The lowest stratum of the Dolores is generally more or less conglomeratic and in some localities is a harder stratum, forming distinct ledge outcrops. The thickness of the lower division of the Dolores seems to vary considerably, increasing from the mountains west and southwest toward the plateau country.

The upper member of the Dolores is commonly a very even fine-grained reddish sandstone, free from conglomerate but variably shaly in different places. The shales are, however, always very sandy and there are seldom pronounced division planes of great lateral extent. The bands of parallel massive sandstone are often 20 feet or more in thickness. The material is mainly quartz sand, with a calcareous cement. In color this upper sandstone is usually bright brick-red or vermilion, shading sometimes into purplish above and a dull darker red below. In texture this red sandstone is very much like the overlying La Plata sandstone, and where the latter is highly colored the two formations seem sometimes inseparable, but the La Plata is commonly orange or yellow in color when it departs from the normal gray or white.

The upper member of the Dolores is absent in the Ouray and parts of the Telluride quadrangles but presents an increasing thickness southward through the Rico and La Plata quadrangles. Nearly 500 feet of quite uniform sandstones were observed on the eastern flanks of the La Platas. The variation in thickness and the disappearance of the red sandstones to the north is due chiefly to the post-Dolores erosion.

The limestone conglomerates of the lower Dolores contain scanty but very widely distributed fragments of bones and teeth belonging to vertebrate animals. Much less frequently invertebrate and plant remains of identifiable character occur in the same strata. The vertebrate remains have never been found as connected skeletons, or even closely associated bones belonging to one individual. They are usually worn and often broken. The most common fossils are the teeth of crocodiles and dinosaurs. Material collected from many localities has been studied by F. A. Lucas. The greater number of the remains belong to the belodont crocodiles, while less numerous are those belonging to a megalosauroid dinosaur, perhaps Palæoctonus of Cope. It is probable that the belodont remains belong to the genus described by Lucas under the name *Heterodontosuchus ganei*, or to allied forms. Poorly preserved outlines of Unio have been seen in several places and a small gastropod shell has been found in the Rico and La Plata quadrangles. According to Stanton, the latter belongs to the genus Viviparus or to a closely allied form.

Tracing the various strata from the San Juan district west and north in the plateau country, through the work of Peale and Spencer, Cross[193c] identifies the Dolores formation in the Dolores, San Miguel, and Sinbad valleys.

Below the La Plata, distinguished by Spencer, there occurs a much deeper red sandstone formation, vermilion or brick-red in hue and corresponding to the upper division of the Dolores as it has been described in this paper. Apparently the lower part, characterized near the San Juan Mountains by the variable strata carrying fossiliferous limestone conglomerate, is not, on the Dolores, markedly different from the upper in texture or color. Spencer has found limestone conglomerate rich in bone fragments in several places, and on La Sal Creek this horizon was but about 100 feet below the La Plata sandstone. The total thickness of the nearly uniform Dolores formation is about 1,000 feet in the neighborhood of Sinbad Valley, while much less in other localities.

Over certain areas of the Uncompahgre Plateau in western Colorado the Triassic is lacking, probably in consequence of pre-Jurassic erosion.[193d] Northwest of Grand River in Utah, however, the strata appear with the characteristics of the Dolores formation. Cross[189c] gives the following section measured by W. H. Emmons and L. H. Woolsey:

Section near Grand River, opposite Moab, Utah.

	Feet.
Top	
32. Sandstone, massive or shaly, dark red at base and bright red at top	20
31. Shaly, conglomeratic sandstone, reddish limestone pebbles, the size of a pea or smaller, with few bone fragments	6
Dolores Triassic.	
30. Sandy shale, red and green	5
29. Débris slope, of red shale fragments	20
28. Limestone conglomerate, with a few inches of limestone at top, fossil wood, and bone fragments; pebbles less than 2 inches diameter	10
27. Sandstone, gray, massive	20
26. Limestone conglomerate grading into sandstone	1½
25. Sandstone, gray, massive becoming shaly near top	23
24. Calcareous sandstone and fine-grained conglomerate mainly sandy, with conglomerate near base and top. Pebbles of limestone and sandstone with occasional bone fragments; pebbles vary from size of peas to several inches	9
Permian (?).	
23. Red sandy shales, alternating with sandstone	8
22. Conglomerate, containing pebbles of limestone and sandstone	1
21. Sandstone and shale alternating, red and green, the shales sandy and friable	35
Hermosa Pennsylvanian.	
20. Blue limestone, weathering dirty buff, near top a layer contains pipe coral	10

In the San Juan Valley, in southeastern Utah, the La Plata sandstone (Jurassic) as identified by Gane is in part red and has been mistaken for Triassic. It is underlain by the fossiliferous limestone conglomerate of the Dolores formation (Triassic).[193e]

The Zuni Plateau, in western New Mexico, comprises Permian, Triassic, and Jurassic strata, according to Dutton.[301a] Cross[139g] comments on Dutton's divisions and finds correlatives with the formations distinguished in Colorado.

Comparing the formations of the Zuni Plateau, as described by Dutton, with those of southwestern Colorado, it seems probable that the Zuni sandstones represent the Gunnison group. Dutton's section is not sufficiently detailed to permit a suggestion as to the exact equivalents of the La Plata and McElmo formations, but it is difficult for me to suppose that the Navajo Church is constituted of anything but one of the La Plata sandstone members.

The Wingate sandstone corresponds in position and character to the upper, vermilion-colored sandstone of the Dolores formation. The absence or subordination of cross-bedding and the constancy of the red color both tend to support such a correlation. If the Wingate is upper Dolores, it would appear probable that the "lower Triassic" of Dutton is at least approximately the equivalent of the lower Dolores, and it may well be that the basal conglomerate called the Shinarump by Dutton is actually the same as the basal conglomerate of the Dolores. Dutton does not speak of limestone conglomerates in the Trias, nor did he find fossil remains in it, except the abundant fossil wood.

Regarding northeastern Arizona, Cross[193h] says:

From the Zuni Plateau a wide tract of upland stretches for 150 miles or more northwest to the brink of the Colorado Canyon. On the northeast is the San Juan Valley and on the southwest is the Little Colorado. It is the land of the Moqui and the Navajo Indians. Beneath the Eocene and Cretaceous strata of the higher central plateau appear the Jurassic and Triassic beds, the character of which on the San Juan side has already been considered. That the same systems are represented continuously from the Little Colorado to the Zuni Plateau was long ago ascertained by Newberry, though definite evidence of the Triassic age of any particular strata has been but recently brought to light.

In the paragraphs following the one just quoted Cross refers to vertebrate fossils from northeastern Arizona which had been identified by Lucas.[551, 552] The stratigraphic data relating to this area are taken from Ward,[865] and concerning them Cross[193i] says:

The vertebrate fauna discovered by Ward occurs near the middle of a section some 3,500 feet in thickness, all of which is assigned to the Trias. Ward divides this section into three parts. At the base are the "Moencopie beds," 700 feet in thickness consisting chiefly of dark reddish-brown soft laminated argillaceous shales, nearly destitute of silica (quartz), highly charged with salt and gypsum. Some calcareous beds grade into white impure limestone. No fossils were found in the Moencopie beds, and Ward states that "the whole series, wherever the contact can be found, always rests in marked unconformity upon the underlying Paleozoic rock (Upper Aubrey)."

* * * * * * * * *

Succeeding the Moencopie come 1,600 feet of variable strata called by Ward the Shinarump. Within this he distinguishes two formations, each 800 feet thick, the lower being the "Shinarump conglomerate" and the upper the "Le Roux beds."

The Shinarump conglomerate of Ward is by no means all conglomeratic. His concise characterization is as follows: "Conglomerates and coarse cross-bedded sandstones, with clay lenses interstratified with gray argillaceous shales and variegated marls." In fact, the marls become locally most prominent in zones which are elsewhere strongly conglomeratic.

The Le Roux beds are principally variegated marls, argillaceous and calcareous, followed upward by sandstone, limestone, with flint fragments, and at the top more calcareous marls.

Fossil wood occurs all through the Shinarump group and none is found beyond it. The petrified forests occur within the Le Roux beds and the vertebrate remains were only found in these strata. Bones and fossil wood were found together in many places.

The "Painted Desert beds" of Ward follow the Le Roux beds and consist of sandstones. The lowest stratum, 100 feet thick, is soft, friable, highly argillaceous, and of orange color. Above this come 800 feet of variegated sandstones, regularly stratified and brilliantly colored. Brown cross-bedded sandstones (200 feet) and white massive sandstones (100 feet) form the top of the section studied.

No doubt the Shinarump group of Ward is in a large degree equivalent to the Shinarump of Powell, Dutton, and others, as developed in the plateau country of Utah, and the vertebrate fauna of the Le Roux beds serves to correlate them with the lower Dolores strata containing the same fauna; but until the unconformity reported by Ward at the base of the Moencopie beds has been traced sufficiently to demonstrate the importance of the stratigraphic break it indicates, further correlation of the Moencopie strata is difficult. It is reasonable to suppose that the base of the Moencopie is actually the base of the Triassic section and that deposition began in Arizona much earlier than in southwestern Colorado. On the other hand, it may be that the belodont fauna will be found at horizons lower than the base of the Le Roux beds. If the Moencopie beds are Triassic the stratigraphic break below them accounts for the absence of strata equivalent to the Permian of Kanab Valley found by Walcott. * * *

The lower 900 feet of the Painted Desert beds of Ward may plausibly be referred to the Vermilion Cliff or upper Dolores sandstone, while the brown and white sandstones above probably represent a part of the White Cliff or the La Plata sandstone.

A detailed description of these formations is given by Ward.[866a]

In northern Arizona and southern Utah Permian and Triassic strata are separated by an unconformity as determined by Walcott.[844] (See p. 484.) Cross [193j] gives a detailed section by Walcott of the Jurassic and Triassic of this region, which may be summarized as follows:

Section of Jurassic and Triassic formations in the Kanab Valley, Utah.

	Feet.
White and red sandstone and shale, more or less gypsiferous with a variable conglomerate bed (1-7)	745
Magnesian limestone intercalated with sandy shale, fossiliferous near the top (8-12)	215
White Cliff sandstone (13)	585
Vermilion sandstone (14)	650
Red and gray, often massive sandstone with some shale beds (15-20)	950
Red and gray sandstone with shaly partings, carrying carbonized fragments of wood (21-22)	235
Thin-bedded and massive sandstone with shale layers, fish teeth and other fossils (23-25)	100
Reddish-brown and greenish friable sandstone and shale (26-29)	860
Gray conglomerate and sandstone (30)	50
	[4, 390]

The numbers in parentheses refer to Walcott's detailed section as given by Cross and serve to distinguish the beds on which Cross [193k] comments as follows:

In this Kanab section it is evident that Nos. 1 to 12 inclusive, aggregating 960 feet in thickness, represent the upper Jurassic group called the Flaming Gorge by Powell. No. 13 is the White Cliff sandstone, considered as the lower Jurassic in this discussion but placed by Powell in the Trias. Mr. Walcott comments in his notes upon the absence of a sharp line between this sandstone and that below it. Reasons why an apparent transition at this horizon is natural have been presented. This thickness of the vermilion-colored sandstone, 14 of the section, was found to vary from 600 to 700 feet on opposite sides of the valley where the section was made, a variation which may possibly be due to erosion.

It is noteworthy that the White Cliff sandstone is thinner in Kanab Valley than it is to the east, where Dutton and Powell refer to it as 1,000 feet thick. Beneath the White Cliff sandstone occur 2,845 feet of beds, which are referable to the Trias. It is not certain just what represents the Vermilion Cliff sandstone of Dutton, said by him to be 2,000 feet thick near the Vergen River and 1,400 or 1,500 feet thick in the zone crossed by the Kanab. It would appear, however, that beds 14 to 20, inclusive, in all 1,600 feet of sandstones, represent the Vermilion Cliff of Dutton, although the distinctive color is not present throughout. Assigning the beds specified to the Vermilion Cliff, the remainder of the section, embracing 1,245 feet of beds, must be referred to the Shinarump group of Powell.

The Shinarump of Kanab Valley, thus delimited, carries fossil wood in the basal conglomerate and at various horizons in the upper portion. Far more interesting than the silicified wood, which has not been studied by paleobotanists, are the fish and other animal remains obtained by Walcott in beds 23–25 of the section—that is, in the upper third of the Shinarump.

These fossils were sent to the National Museum, and in the confusion of adequate storage facilities were lost sight of until a few months ago. On being found they were sent to Dr. C. R. Eastman for identification and description. Dr. Eastman's complete identifications are not yet available, but he has published a brief preliminary reference to the ichthyic fauna, from which the following is abstracted:

"These remains * * * are extremely fragmentary and do not permit of accurate specific determination. Of the few genera which are tolerably well indicated, such as Pholidophorus and several Lepidotus-like forms, it can not be said that they evince anything in common with the Triassic fauna of the Eastern States. Some resemblance is to be noted between the Kanab fish fauna and that of Perledo near Lake Como, but the general aspect of the material collected by Dr. Walcott is suggestive of Jurassic rather than of Triassic relations. This might very well happen, notwithstanding the horizon be definitely proved by stratigraphic and other evidence to be of Triassic age, as other instances of pioneer faunas and overlapping contingents are not uncommon.

Associated with the fish remains there were found several representatives of other classes of animal life, concerning which Dr. Eastman has given me the following comments, pending more careful investigation: "There is one ammonite in the collection, or rather the portion of the outer volution of one, which is very suggestive of the Liassic Arietidæ, and in the opinion of Dr. Jackson and Mr. Shimer who have examined it, does not seem to belong to the class of forms known from the Pacific Coast Trias." There are numerous Estheria in the collection and fragmentary saurian teeth, but whether of crocodilian or ichthyosaurian forms Dr. Eastman is unable to determine.

From the statements of Eastman it appears that the Kanab fauna obtained by Walcott is unique and raises several interesting problems for solution. The fossil-bearing strata were traced by Walcott from the Kanab eastward to the Colorado River and thus are known to occur not far from the area in which the saurian fauna of the Little Colorado was obtained by Ward and Brown, both faunas belonging apparently to the Shinarump group. The relations of the two fossiliferous horizons are as yet quite unknown. From the stratigraphic standpoint it is difficult to see how the Kanab fossils can possibly be of Jurassic age, unless there are complications, hitherto wholly unsuspected, in the great section of the plateau country.

In the preceding comments on Walcott's Kanab section of the Jurassic and Triassic, Cross regards the White Cliff sandstone as Jurassic. It had been considered Triassic by Powell, and also by King, Emmons, and C. A. White, in northeastern Utah and northwestern Colorado. Cross [1931] refers to certain "Permo-Carboniferous" fossils collected by Howell from the Shinarump, which were erroneously identified as Jurassic. Weeks [873b] sums up his own observations, as well as those of previous observers in the Uinta Range, as follows:

The Trias was defined by Emmons as consisting of red sandstones with a series of clayey beds at the base, having an estimated thickness of 2,500 feet. Powell did not separate the

Jura from the Trias. He divided the Jura-Trias beds into the Shinarump, Vermilion Cliff, White Cliff, and Flaming Gorge groups, having a total thickness of 3,845 feet. The Trias of the Fortieth Parallel Survey appears to correspond to the Shinarump, Vermilion Cliff, and White Cliff groups of Powell. The writer has classed the shales at the base of the Trias with the Permo-Carboniferous. The line of division between the Trias and the Permian is placed at the base of the massive cross-bedded sandstones.

In the Uinta uplift the Trias, Jura, and Cretaceous strata are largely covered by Tertiary sediments or glacial débris. The principal areas of the outcrop are in the Flaming Gorge Canyon of the Green River in the vicinity of Split Mountain and Ashley and Dry Forks creeks, and on the Duchesne River several miles below the mouth of West Fork, on the south side of the range. The Trias is much thicker in the eastern part of the range. In the western part the clayey beds of the upper part of the Trias were apparently not deposited. The coarse cross-bedded sandstone, 300 to 400 feet thick, is a dark-buff color in the Duchesne region, which varies to lighter color to the eastward.

The Jura is composed of sandstones, shales, and clay beds, with a prominent limestone series having a maximum thickness of 200 to 300 feet, the whole averaging from 600 to 800 feet in thickness, as determined by the Fortieth Parallel Survey. The Flaming Gorge group of Powell is considered to represent the Jura. The writer considers the prominent drab limestones to form the base of the series, the remainder of the Jura being formed of the overlying sandstones, shales, and clays.

The areas of outcrop of the Jura in the Uinta uplift correspond to those of the Trias and appear to have a greater thickness of beds in the eastern part of the range. In the Duchesne Valley the Jura is represented by a compact drab and gray limestone and soft red calcareous shales. The transition from the buff or brown cross-bedded sandstone of the Trias to the Jurassic oolitic and granular limestone is made in less than 10 feet of strata.

In northern Colorado Triassic rocks have been identified by fossils found on Red Dirt Creek, a tributary of Grand River near the headwaters, northwest of Leadville and south of the fortieth parallel.[447] Still farther north, in central Wyoming, Triassic fossils have been collected near Lander from strata called by Williston[941] the Popo Agie beds and described as being from "40 to 80 feet in thickness" and occurring in the red beds, about 200 feet below their top and 600 feet above their base. The type locality is Popo Agie River, near the east end of the Wind River Range, and thus not far from the Owl Creek and Bighorn ranges, in which Darton has distinguished the supposed Triassic under the name Chugwater formation. (See K 12–13, pp. 530, 531.)

Regarding the possible absence of Triassic on the eastern side of the Front Range in Colorado, where the red beds are believed to be largely if not wholly Permian, Cross's views have been quoted. (See Chapter XI, pp. 490–492). Williston[942] refers to the discovery by Marsh[571] of Hallopus in Garden Park, near Canon City, and regards the fossil as significant of the Upper Triassic, although the exact horizon can not be identified.

Fenneman[328] describes the Fountain, Lyons, and Lykins formations of the Boulder district, Colorado (north of the Canon City district), as possibly Triassic. The Fountain, however, is of Pottsville age—that is, lower Pennsylvanian. (See Chapter VIII, pp. 369–370.) The Lyons and Lykins are either Triassic or Permian. Fenneman says:

The rocks in this region, hitherto regarded as of Triassic age and called "Wyoming," embrace three formations—the Fountain, the Lyons, and the Lykins. The term "Red Beds" is popularly used without definite limitations, but the authors of the monograph on the Denver

Basin have conveniently limited the use of this term to the lowest and largest member of the series. The popular use of the term "red rock" is similarly restricted.

The subdivision into "Lower" and "Upper" Wyoming, adopted for the Denver Basin, would also be appropriate to the Boulder area. The lower division, however, clearly embraces two lithological units which it is desired to distinguish in this report. The lower and major part consists chiefly of rather coarse arkose sandstones and conglomerates of reddish color, while the upper and lesser part is a finer-grained quartzose sandstone of white, "creamy," or light-reddish color. The coarse red sandstones were called the Fountain formation by Cross in the Pikes Peak folio, a type section being crossed by Fountain Creek, near Manitou. The summit of the Fountain formation is not exposed in the Pikes Peak quadrangle, but Darton[a] has found the character of the Fountain, as described by Cross, to continue to a white sandstone corresponding with the "Creamy sandstone" of Eldridge, occurring in the Garden of the Gods, to which the name Lyons sandstone is here given.

No Triassic beds are known on the eastern slope from Canon City, Colo., south to northern New Mexico, but in that region, northwest of Santa Fe, first Newberry and later Cope found Triassic fossils in red beds. Cross[193n] comments as follows:

While Marcou and other early explorers of New Mexico announced the presence there of Triassic formations, the first fossils indicating the correctness of this assertion were obtained by Newberry in 1859. The fossils described by Newberry himself were fossil plants obtained from the old copper mines near Abiquiu, a locality on Chama River some 20 miles or less above its junction with the Rio Grande. The plants are mainly cycads and conifers, and as they have not been identified at many other localities they are of less importance to the present discussion than the vertebrate remains described by Cope, to which reference will soon be made.

The formation from which the Abiquiu plants were obtained is described by Newberry as consisting mainly of red sandstones, with conglomerates and many variegated beds of soft shales, with abundant saline efflorescences, which led him to characterize the red beds of New Mexico and Arizona in general as the "Saliferous series." Fossil wood, often in tree trunks, is mentioned.

Although I can not find that Newberry mentioned vertebrate fossils in the Triassic beds of the Chama Valley, it appears that he found some, for Cope, who followed him in the exploration of the region, states that the first invertebrates from the Trias of the Rocky Mountains were collected by Newberry with the Macomb expedition. Cope visited Chama Valley and the Gallinas Mountains, lying west of it, in 1864, while on the Wheeler Survey, and obtained various vertebrate fossils from the Triassic beds.

The fragmentary remains described by Cope embrace teeth and bones of three dinosaurs, two of which were generically determined as Lælaps and Palæoctonus. Similar portions of a belodont crocodile were called *Typothorax coccinarium*. Associated with these were found five species of Unio.

This assemblage of forms suggests the fauna of the Dolores "saurian conglomerate." The locality is less than 100 miles southeast from the easternmost known exposures of the Dolores formation, the intervening country being occupied by Cretaceous formations. It is therefore very natural to suppose that the vertebrate and plant bearing Trias of Chama Valley may be the direct equivalent of the lower Dolores formation. Apparently the fossiliferous strata of New Mexico are not overlain by a massive red sandstone equivalent to the Wingate sandstone of Dutton. The "Variegated marls" of Newberry, which seem clearly to belong to the McElmo or Morrison beds, intervene between the "Saliferous series" and the Cretaceous.

In regard to the Triassic portion of the Shinarump group of Powell in southern Utah and northern Arizona, Cross[191] published the following statement:

The Shinarump is the lowest of three formations or groups assigned by Powell to the Trias, the others being the intermediate Vermilion Cliff sandstone and the White Cliff sandstone at

[a] Bull. Geol. Soc. America, vol. 15, 1904, p. 22.

the top. The Triassic was thus supposed by him to embrace everything present in the great section north of the Grand Canyon between the upper Aubrey (Pennsylvanian) and the marine Jurassic.

Dutton and other writers have referred the White Cliff sandstone to the Jurassic, and this reference is no doubt correct, since the continuity has been established between this very well marked formation and the La Plata sandstone of Colorado, which is in angular unconformity with the Triassic and the entire Paleozoic section.[a] The Triassic age of the Vermilion Cliff sandstone has not been directly questioned, neither has it been fully proved, and it will appear in the course of this discussion that there is some slight basis for the suggestion that it is lower Jurassic.

As for the Shinarump group, Walcott long ago found Permian fossils[b] in the lower beds referred to it by Powell and possibly Jurassic fossils[a] in the upper part, while a Triassic vertebrate fauna occurs near the middle of what Ward refers to the Shinarump.[c] The question as to the real character, scope, and correlation of this group is, then, plainly one requiring further study and consideration.

It has been established that the Dolores formation of the San Juan region of Colorado is of Triassic and probably of upper Triassic age. An angular unconformity has been found below the Dolores by which the whole upper Paleozoic red-bed series and a part of the Pennsylvanian strata are locally cut out. No middle or lower Triassic beds have been found and none demonstrably Permian. The stratigraphic break below the Dolores is thus shown to be of much importance.

The Dolores formation has been traced from the mountains into the heart of the plateau district along two lines of approach. The most important fact established is that the fossiliferous basal member of the formation extends west and northwest from the San Juan Mountains as far at least as Grand River, in Utah, where the angular unconformity below it is very marked, and 1,500 to 2,000 feet of probable Paleozoic beds are gone at some places. An overlap of the basal Dolores conglomerate from Permian (?) beds directly to the pre-Cambrian complex occurs on the western side of the Uncompahgre Plateau, in Colorado, where it was observed by Peale in 1875. The fossiliferous lower strata of the Dolores have also been traced down the San Juan Valley nearly to the Glen Canyon of the Colorado, below the Henry Mountains.

While nothing similar to the Dolores fossiliferous conglomerate has been described from the original area of the Shinarump group in Utah or Arizona, the discovery by Ward[c] on the Little Colorado River of the vertebrate fauna characteristic of the Dolores shows plainly that a correlation of great importance is to be anticipated when the requisite studies have been made.

J 17-18. RICHMOND BASIN, VIRGINIA.

The stratigraphy of the Richmond Basin was first worked out in detail by Shaler and Woodworth.[731] They say:

A casual observer traversing the Richmond area on any one of the section lines described in this report can not but note that there are several leading lithological features displayed in bands by which the strata may be thoroughly grouped. When one seeks to trace out these bands along the strike of the strata the futility of the task is at once apparent. It is only on the broadest possible lines with a considerable error in the placing of boundaries between distinguishable groups of strata that a mapping of the basin can at present be carried out.

The accompanying table of divisions is an expression of the present knowledge concerning the lithological and biologic characters of the area.

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[a] Cross, Whitman, and Howe, Ernest, Red Beds of southwestern Colorado and their correlation: Bull. Geol. Soc. America, vol. 16, 1905, pp. 447-498.

[b] Walcott, C. D., The Permian and other Paleozoic groups of the Kanab Valley, Arizona: Am. Jour. Sci., 3d ser., vol. 20, 1880, pp. 221-225.

[c] Ward, L. F., Geology of the Little Colorado Valley: Am. Jour. Sci., 4th ser., vol. 12, 1901, pp. 401-413.

Formations in the Richmond area.

Lithologic— Divisions.	Lithologic— Subdivisions.	Biologic divisions.	General characters.
Chesterfield group.	Otterdale sandstones	Araucarioxylon beds	Coarse sandstones, often feldspathic, with silicified trunks of Araucarioxylon; well developed north, south, and west of Otterdale. Thickness, 500 feet.
	Vinita beds	Estheria beds	Black fissile shales, carrying *Estheria ovata*, passing upward and intercalated with gray sandstones; in James River bluff, west of Vinita station, on Tomahawk Creek. Thickness, 2,000 feet.
Tuckahoe group.	Productive coal measures	Macrotæniopteris beds	Interstratified beds of bituminous coal (usually three seams), coke, black shales (*a*, fish bearing; *b*, Estheria shales; *c*, vegetal shales), sandstones (feldspathic and micaceous), fossil plants; teeth, bones, and tracks of reptiles. Thickness 500 (?) feet.
	Lower barren beds		Sandstones and shales under coal beds, often with arkose. Thickness variable, from 0 to 300 feet.
	Boscabel bowlder beds		Local deposits; bowlders of gneiss and granite. Thickness variable, 0 to 50 feet.

The divisions are described in much detail and with reference to exact localities in the pages following this tabulation in the report cited.

J-K 10. NORTHERN CALIFORNIA.

The Triassic of Shasta County, Cal., from which fossils were first described by Gabb,[349] has been studied by Smith, who distinguished the Pitt shale (now spelled Pit), Swearinger slate, and Hosselkus limestone. (See table, p. 374, Chapter VIII.) The Pit shale is the upper part of the so-called "Pitt formation," concerning which Smith [762a] writes:

The Pitt formation overlies conformably the McCloud limestone and consists, roughly estimated, of about 3,000 feet of siliceous and calcareous shales, conglomerates, and tuffs. The rocks in most places are highly metamorphosed, very poor in fossils, and folded to such a degree that the stratigraphy is obscure. The general strike is north and south and the dip generally toward the east, since most of the folds are overthrown.

The formation is largely developed in the region near the junction of the Pitt and the McCloud rivers. It contains both Carboniferous and Triassic rocks, in an apparently conformable series, both with a decisive fauna, the presence of Upper Carboniferous and Middle Trias being proved by fossils.

The lower part of the "Pitt formation" consisted of the "McCloud shales" (Carboniferous). This name has now been abandoned by the Survey, the shales being included in the Nosoni formation of Diller[279] (Pennsylvanian). The name McCloud is, however, retained for the underlying limestone (also of Pennsylvanian age).

Details of faunas and local occurrences of the two divisions of the "Pitt formation" are given by Smith in the paper cited above, followed by an account of the

"Cedar formation," comprising the Swearinger slate and Hosselkus limestone. Smith [762b] says:

The Cedar formation was first named by J. S. Diller [a] to include the Upper Triassic slates and limestones of Indian Valley, Plumas County, and Cedar Creek, Shasta County. It therefore includes the original Trias described by Gabb [b] from "Gifford's ranch."

In the Pitt River region the formation is very similar to that in Plumas County, being composed of finely laminated shales overlain by massive limestone, each rich in fossils. It seems to overlie conformably the siliceous shales of the Pitt formation, but the contact could not be observed.

The Triassic of Plumas County, Cal., has been discussed by Diller [271] and Hyatt.[467] In a recent publication on the geology of the Taylorsville region Diller [280] gives the following section:

Triassic:	
Unconformity.	Feet.
Swearinger slate: Dark slaty calcareous shales, with thin limestones and some siliceous beds.	200
Hosselkus limestone: Dark-blue to light-gray limestone	140
Unconformity.	

The Hosselkus limestone is dark blue on fresh fracture but weathers light gray. * * * It is thin bedded and in some places decidedly slaty * * * and characterized by small ammonites. * * * In the Redding region * * * the upper part is lighter colored and more massive, with a Spirifer-like shell, and the lower part thinner bedded and darker, with small coiled forms.

The fossils collected from this limestone by Prof. Hyatt and others in the Taylorsville region have not yet been fully worked up. A partial list is given by Hyatt: [c]

I. Arcestes, phylum of A. tornati.
   Arcestes, phylum of A. galeati.
   Arcestes, phylum of A. bicarinati.
   Arcestes, phylum of A. sublabiati.
Badiolites, allied to B. eryx Mojsisovics.
Juvavites, allied to J. erlichi Mojsisovics.
Tropites, may be young of species occurring in Halobia slates.
Atractites.

"Arcestes (I) is very abundant, but whether the other forms are abundant or not it is difficult to say at present. The materials gathered show that the rock is full of fossils, but these can not be obtained in any reasonable time by means of surface work. Besides the species mentioned, there is a form of Acrochordiceras, with finer costæ than those occurring in the Muschelkalk, a possible Balatonites, like *B. waageni* of the Noric, and some other fragments of Ceratitinæ, all indicating a fauna rich in ammonoids, which will some day yield a good harvest to patient work."

Prof. Hyatt concludes that the age of the Hosselkus limestone as indicated by the fossils is upper Triassic. To this list Spiriferina and fish vertebra, as determined by Stanton, were added last summer. This limestone has not yet been thoroughly examined for reptilian remains, such as J. C. Merriam has found in the Redding quadrangle, but as the limestone of the Taylorsville region is more altered and much less fossiliferous, reptilian remains are less likely to occur. In the Redding region the more massive upper portion of the Hosselkus limestone is characterized by the presence of Spiriferina, while the lower, darker, thin-bedded portion often abounds in small ammonites. * * *

The reference of the Hosselkus limestone to the upper Triassic and the Robinson formation to the upper Carboniferous indicates a decided gap between them, a gap which is at least partially filled in the more complete section of the Redding region, where a great thickness

[a] Lassen Peak folio (No. 15), Geol. Atlas U. S., U. S. Geol. Survey, 1895.
[b] Paleontology of California, vol. 1.
[c] Bull. Geol. Soc. America, vol. 3, 1892, pp. 399–400.

(over 1,000 feet) of andesitic and rhyolitic lavas, with 1,500 feet of overlying shales, sandstones, and tuffs of Triassic age, comes between the horizon of the Robinson formation and that of the Hosselkus limestone. It is evident, therefore, that in the Taylorsville region there is a decided interruption between the Hosselkus limestone and the Robinson formation. It is possible, however, that their contact in the Taylorsville region is a plane of displacement, and that the formations of the Redding region missing in the Taylorsville region may, in part at least, be thus accounted for.

* * * * * * * * *

The Swearinger formation is composed chiefly of dark slaty shale, sometimes becoming more or less calcareous and at others decidedly siliceous, but the thin beds of limestone or chert form only a small proportion of the whole mass. In the side of the Swearinger slate adjoining the Hosselkus limestone thin lenticular beds of limestone become more abundant. They are generally dark, with irregular cherty or sandy layers, and fossiliferous.

* * * * * * * * *

The greatest thickness of the Swearinger slate exposed along Genesee Valley, where measured, is about 200 feet, but the amount cut off by the granodiorite or covered by the overlapping Trail formation we have no means of estimating except by comparison with formations of the same horizon in other regions; such comparison indicates that the thickness is probably not over 400 feet.

The fossils of the Swearinger slate were discovered and described by the Geological Survey of California under Prof. J. D. Whitney. Our knowledge of the fauna was greatly extended by Prof. Alpheus Hyatt, who has published[a] lists of the forms found in the subordinate paleontological horizons within the formation. They need not be repeated here except to note that the form from these beds once regarded as *Monotis subcircularis* is now considered by J. P. Smith and others to be Pseudomonotis. Prof. Hyatt regarded the Swearinger slate as belonging to the upper Triassic, equivalent to the upper Noric of the Alpine Triassic, and as far as I am aware this reference has not been changed essentially by the somewhat later researches of Prof. Smith.

J-K 10-11. NEVADA AND EASTERN CALIFORNIA.

The Triassic section of Nevada was originally described by King[505e] in the following summary of the data stated more at length on other pages of his report.

Passing now to the district of western Nevada, the sections, which often do not reach the base of the conformable series, expose two distinct, easily recognizable groups of the Trias. The Koipato, already described, is made up of siliceous and argillaceous beds, whose chemical peculiarity is the almost total absence of soda and lime and the high percentage of alumina and potash—a series probably derived from the disintegration of the heavy Weber Carboniferous quartzite, which must for a long time have constituted the main surface of the erosion of the newly lifted Mesozoic land. This series has an observable thickness of about 6,000 feet, with an unknown quantity to be added for the bottom unseen beds. Conformably over the Koipato is the great Alpine Trias Star Peak series of 10,000 feet, composed of an alternation of three great limestone zones and three interposed quartzite zones, the lower quartzite closely following the physical and chemical peculiarities of the Koipato series below, the upper two quartzites representing moderately pure siliceous sediment. The fossils of these limestones, as already described, repeat with marvelous exactness the facies of the St. Cassian and Hallstadt beds of the Austrian Alps.

Smith[764a] states that beneath the strata of Middle Triassic age in Inyo County, southeastern California, occur Lower Triassic beds. He says:

In 1896 Dr. C. D. Walcott discovered some ammonite-bearing limestone in Inyo County, Cal., on the east side of Owens Valley, 10 miles east-northeast of Lone Pine, 3 miles southeast of

[a] Bull. Geol. Soc. America, vol. 3, 1892, pp. 397–400.

the Reward Mill, and about 1,500 feet up above the mill, on the Union Wash trail from Independence over the Inyo Range into Saline Valley. The fossils were submitted by Dr. Walcott to the writer for identification, and referred to the Lower Trias, on the basis of the occurrence of several genera characteristic of the Brahmanic stage of the Scythic series in the Oriental region. In a preliminary report the writer did not venture to describe new species or genera, but noted the occurrence of Nannites, Clypites ?, Koninckites, Meekoceras, Kingites, Gyronites ?, Xenaspis, Dinarites, and a new genus of Tropitidæ. Later collections and better material have confirmed most of these identifications, but the form referred to Clypites has proved to be a new genus of the same group; the supposed Kingites is very uncertain; the Dinarites has turned out to be a Paralecanites; and the supposed new genus of the Tropitidæ belongs to the Hungaritidæ.

Later collections, by Mr. H. W. Turner, of the United States Geological Survey, and by the writer, have added greatly to the list of genera and species, bringing out even more strongly the relations of this fauna to the Brahmanic faunas of the Asiatic regions.

At the base of the section seen on the Union Wash are massive siliceous and calcareous beds supposed, on the basis of fossils found in the float, to belong to the Carboniferous; then several hundred feet of calcareous shales with obscure traces of ammonites; then about 15 feet of hard gray siliceous limestone, from which all the fossils listed from this horizon were taken. Above this limestone lie about 800 feet of dark shales with a few impressions of ammonites; then about 5 feet of impure earthy black limestone with numerous ammonites, Ptychites, Hungarites, Acrochordiceras, Xenodiscus, thought by the writer to belong to the base of the Middle Trias, or the Subrobustus beds of the Oriental region.

Lindgren [538] describes the Sailor Canyon formation and associated slates, quartzites, and schist in the Colfax quadrangle, California, west of Lake Tahoe, as "Juratrias," having found ammonites and other shells in the beds.

J-K 18. NEW JERSEY, PENNSYLVANIA, AND MARYLAND.

The Newark group is typically developed in New Jersey, and the rocks occur in several distinct belts from Massachusetts to North Carolina.[683]

The Triassic sediments of New Jersey and New York were described without definite subdivision prior to the work by Kümmel,[511] from which the following extracts relating to the separate formations (Stockton, Lockatong, and Brunswick) and the associated igneous rocks are taken.

The Newark series consists of sedimentary and igneous rocks. The former are chiefly shales, sandstones, and conglomerates; the latter diabase, to which the more general term trap has usually been applied. Along the Delaware River the sedimentary rocks are divisible, on lithological grounds, into three groups, which have been called Stockton, Lockatong, and Brunswick.

Stockton group.—The basal beds of the series are found at Trenton, where they rest unconformably upon the older crystalline rocks. They consist of (*a*) coarse, more or less disintegrated arkose conglomerates; (*b*) yellow, micaceous, feldspathic sandstone; (*c*) brown-red sandstones or freestones; and (*d*) soft red argillaceous shales. These are interbedded and many times repeated, a fact which indicates rapidly changing and recurrent conditions of sedimentation. Although there are many layers of red shale in this subdivision the characteristic beds are the arkose conglomerates and sandstones, the latter of which afford valuable building stones.

In addition to the cross-bedded structure which often prevails in the sandstones, mud cracks and impressions of raindrops occur. The rapid alternation from conglomerates to shales and vice versa, the changes in composition in individual beds, the cross-bedding, ripple marks, etc., all indicate very clearly that these beds were deposited in shallow water in close proximity to the shore. The bulk of the material of which they are composed was derived from the crystalline rocks on the south and southwest, but where they were found to rest upon Silurian shales, limestones, and quartzites, as was the case along the northwestern border north of Flemington, material from these formations has determined their local character. * * *

The rocks of the Lockatong group overlie the Stockton beds conformably. They consist of (*a*) carbonaceous shales, which split readily along the bedding planes into thin laminæ but have no true slaty cleavage; (*b*) hard massive black and bluish-purple argillites; (*c*) dark-gray and green flagstones; (*d*) dark-red shales approaching a flagstone; (*e*) and occasional thin layers of highly calcareous shales. There are all gradations between these somewhat distinct types, so that the varieties of individual beds are almost countless. Both ripple marks and mud cracks occur at all horizons, showing that shallow-water conditions prevailed throughout the time of their deposition. On the other hand, the absence of strong currents or violent shore action is indicated by the extreme fineness of the material.

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In general the Brunswick group consists of a monotonous succession of very soft argillaceous red shales which crumble readily to minute fragments or split into thin flakes. Much of it is porous, the minute, irregular-shaped cavities being often partially filled with a calcareous powder. Calcite veins and crystals are common in some layers. Locally lenticular masses of green shale occur in the red. In size these range up to a foot or two in diameter, and vary in shape from nearly spherical to lenticular masses, narrowing down to thin sheets along cracks. They are undoubtedly due to chemical changes resulting in the leaching of the shale.

Although the majority of this series are soft red shales, there are some hard layers, chiefly near the base, and occasional beds of fine-grained sandstone and flagstones, some of which afford valuable building material. Massive conglomerates along the northwestern border are in part the shoreward correlatives of the red shales.

Evidence that the shales were deposited in shallow water is abundant. Ripple marks, mud cracks, and raindrop impressions occur at many horizons. In some quarries imprints of leaves, of tree stems, or the stems themselves are frequently found. The numerous reptile tracks which have made the Newark beds famous occur chiefly in this subdivision. Typical exposures occur along the Raritan River, particularly near New Brunswick.

* * * * * * * * *

Important lithological changes occur in all these beds as they are traced along their strike. As the northwestern border of the formation is approached, near Pittstown, the subdivisions lose their distinctive characteristics and merge along the strike into coarse sandstones and massive conglomerates. This change is most striking in the case of the Brunswick and the Lockatong groups, where red shales or black argillites change to sandstones and then into conglomerates, the pebbles of which are frequently 6 or 8 inches in diameter. Under these conditions it is impossible to differentiate and limit these groups in this part of the field.

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Important changes are found to occur as the beds are traced along the strike northeastward into New York. The Stockton beds disappear beneath the later deposits a few miles east of Princeton.

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The Stockton beds certainly persist into New York, but the typical coarse arkose sandstone beds apparently thin out, and north of Nyack the group can not be identified with any degree of certainty. The trend of the strata apparently carries the beds of this subdivision beneath the Hudson River.

Northeast of Princeton the outcrop of the typical Lockatong group grows narrower and the thickness is less. Either the rate of deposition was slower to the northeast during the time represented by the Lockatong beds elsewhere, and therefore they are thinner here, or else, the rate of deposition being the same as elsewhere, the conditions favoring the deposition of black argillite and shale did not last so long to the northeast of Princeton as nearer the Delaware. A few miles northeast of Princeton the Lockatong beds also are covered by the Cretaceous deposits, but they have been traced by borings as far as the Raritan River. They do not, however, appear in the region west of the Palisades and north of Newark.

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The Brunswick beds likewise change in texture toward the northeast. They are predominantly soft argillaceous shales from the Delaware River as far as Elizabeth. In some layers an increase in coarseness is noticeable, which continues northeastward along the strike, until in the vicinity of Newark and Orange the beds are chiefly sandstones. Many of these beds resemble the brownstones of the Stockton series—so closely, in fact, that hand specimens can be distinguished with difficulty, if at all, from much of the sandstone at Trenton and Stockton.

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Still farther north layers of conglomerate appear interstratified with the sandstones and shales. In addition to well-marked beds of conglomerate, many layers of the sandstone contain pebbles scattered through them. The pebbles are chiefly of quartzite or sandstone, quartz, slate, limestone, feldspar, and rarely of flint. Not a single gneissic or granitic pebble was found, although a careful search was made for them. The coarse sandstone and conglomerates, with some shale beds, continue through Bergen County, N. J., and Rockland County, N. Y.

Beds of coarse conglomerate occur at a number of points along the northwestern border. Some of these are composed chiefly of quartzite, others of limestone, and in one case of gneissic and granitic material. The quartzite conglomerate contains a few pebbles of limestone, shale, and gneiss, but almost the entire mass of the rock is made up of quartzite or sandstone pebbles, which are well rounded and frequently 6 or 8 inches in diameter. They are best exposed in the "pebble bluffs" along the Delaware River about 5 miles above Frenchtown. The conglomerates are interstratified with sandstones and shales, forming lenticular beds, which thin out within a few rods to be replaced by beds of a different texture. This alternation and rapid change betoken shore conditions.

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The calcareous conglomerate is in appearance almost the exact counterpart of the famous "Potomac marble" quarried at Point of Rocks, Md. The limestone pebbles are usually bluish or gray, sometimes reddish, set in a red mud matrix, so that the rock has a variegated appearance. The average diameter of the larger constituents is 6 or 8 inches, but bowlders 5 feet in diameter have been seen, and at a quarry 2½ miles northeast of Suffern, N. Y., bowlders 12 feet in diameter are reported to occur. The larger fragments are generally rounded, but the majority of the smaller are sharp-cornered or at most subangular. Compared with the pebbles in the quartzite conglomerate, the limestone pebbles are but little worn, a fact of some significance in connection with the origin and sources of the materials, since with equal transportation the softer limestones must have been most worn.

* * * * * * * * *

The relations of these conglomerates to the older rocks along the border are significant of faulting. In some cases the calcareous conglomerates adjoin small areas of Paleozoic limestone, from which the materials may have been and probably were derived. In other cases, and this is true of the largest areas, the calcareous conglomerates abut against the gneissic rocks, and for much of the distance it is certain that no limestone occurs between the gneiss and conglomerate, at least not at the surface horizon. Crystalline pebbles, however, are comparatively rare in the conglomerate. Substantially the same conditions prevail in the case of the quartzite conglomerate. For the most part it adjoins the gneiss, but gneissic pebbles in it are rare. The known areas of quartzite along the border are small, and in general not near the massive conglomerate beds. Lithologically, moreover, they are unlike the bulk of the quartzite pebbles.

It is evident that along the greater part of this border the beds of the Newark series were not derived from the older rocks which now immediately adjoin them. Shore currents doubtless transported more or less material somewhat widely, and yet they do not afford us the complete explanation for these facts. The northwestern border is for the most part marked by faults. Here the dissimilarity of constitution is the most marked. Where the border is not faulted and the newer rocks rest undisturbed upon the eroded edges of the older beds, they are composed of fragments derived from them plus a small contribution by shore currents. Allowance can be made for the work of the currents, but the widespread dissimilarity of constitution is due chiefly to the faulting which has occurred. The waves of the sea in which the Newark beds were deposited did not on the northwest border in general beat against the rocks which now adjoin this area.

The relation of the conglomerates to the shales is also significant. They do not form a single horizon which may be used in interpreting the structure. Instead, they grade either into argillaceous shales, or black argillites, or arkose sandstones. Time and again the pebbly layers were seen to appear in the shales and to increase in thickness and numbers until they become massive conglomerates.

* * * * * * * * *

The trap rocks of the Newark beds in New Jersey and New York have been described more or less in detail by several geologists, and it has been demonstrated that overflow sheets, intrusive sills, plugs, and dikes occur.

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The most important of the overflow sheets are the three concentric ridges forming the Watchung Mountains. These sheets are to all appearances strictly conformable, both to the underlying and to the overlying shales. Nowhere is there any indication that the trap breaks across the sandstone or shale layers. Wherever the basal contact is exposed, and exposures several hundred feet in extent are known, the trap is seen to follow exactly the bedding plane of the shales.

Moreover, the extensive metamorphism of the associated sedimentary beds, a marked feature in the case of all the intrusive sheets, is entirely absent. Locally, the shale is slightly altered for a few inches beneath the trap, but even this is not always the case. When this is compared with the intense alteration which has affected the shales beneath the Palisades, an intrusive sill, for a distance of over 100 feet, the difference between the sheets is emphasized.

Upper contacts have not been observed in many cases, but the upper surface of these sheets is frequently vesicular, amygdaloidal, and scoriaceous. Locally, a thin layer of water-worn trap particles, intermixed with red mud occurs between the vesicular trap and the unaltered typical red shales, or the vesicules are filled with red mud. The overlying shales conform to the slightly irregular, ropy surface of the trap. In frequent exposures the rolling-flow structure, named by the Hawaiian Islanders pahoehoe, is visible. Nowhere have any tongues of lava been found extending from the main sheet into the neighboring shales.

* * * * * * * * *

The Palisades of the Hudson, the Rocky Hill sheet north of Princeton, the Sourland Mountain sheet near Lambertville, and the Cushetunk Mountain near White House are the largest and most prominent of the intrusive sheets. * * * In addition to these, which are demonstrably sills or sheets, there are more irregularly shaped masses northwest of Pennington, near Stockton, and at Point Pleasant (west of Stockton), the precise relations of which to the inclosing beds are not clearly revealed. They are beyond all doubt intrusive masses, but it is questionable whether they are strictly sheets. In the absence of positive knowledge as to their relations with the sedimentary beds, I prefer to speak of them simply as intrusive masses.

The evidence of the intrusive origin of all these masses, sills and others, is as follows. Dikes radiate from the upper part of the sills and penetrate the overlying shales for distances up to 7 miles, as measured on the surface. The sills are locally unconformable to the inclosing strata, although in general they extend for long distances parallel to their strike.

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The adjacent sediments have often been greatly metamorphosed. So intense has been this alteration that at distances, often of 100 feet, the rocks are as completely "baked" as those immediately adjoining the trap. Measured along the surface, traces of metamorphism are frequently found 1 foot from the nearest trap outcrop. The complete absence of scoriaceous rock, of amygdules, of the vesicular or the rolling-flow structure is negative evidence of their intrusive origin which must not be neglected. Moreover, masses of shale and sandstone have been embedded in the trap near both the under and upper surfaces, and the trap itself shows evidence in its texture of having cooled more slowly (and therefore presumably at greater depths) than the overflow sheets.

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The overflow sheets are contemporaneous with the beds between which they lie—that is, the upper third of the Brunswick shales.

The intrusive masses extend, for the most part, well up into the Brunswick shales and are therefore younger than these. Moreover, so far as the evidence goes, they antedate the disturbances which closed the deposition of the Newark beds. There are good reasons for believing that many, perhaps all, of the intrusive masses are younger than the extrusive sheets, although the evidence is not conclusive. From a priori considerations it may be suggested that the lava formed intrusive sheets after the formation became so thick that it could not readily rise to the surface, whereas earlier in Newark time the lava was able to break through the inner beds and overflow.

Kümmel [511a] gives his first careful estimate of the maximum thickness of the sedimentary formation of the Newark group as follows:

	Feet.
Stockton	4, 700
Lockatong	3, 600
Brunswick	12, 000
	20, 300

These figures his later investigations led him to modify, his revised estimate [511b] being:

	Feet.
Stockton	2, 300– 3, 100
Lockatong	3, 500– 3, 600
Brunswick	6, 000– 8, 000
	11, 800–14, 700

The Newark group passes from New Jersey into Pennsylvania in the Trenton quadrangle and is described in detail by Darton [59] in the Trenton folio.

The continuation of the belt northwest of Philadelphia is discussed by Darton,[58c] who says:

The Newark group in Pennsylvania occupies a broad belt extending across the southeastern portion of the State from Delaware River to the Maryland line south of Gettysburg. It is 32 miles wide on the Delaware, 12 miles on the Susquehanna, 4 miles in northern Lancaster County, and 14 miles at the Maryland line. It is bounded by shales, limestones, sandstones, quartzites, mica schists, gneisses, and granites, varying in age from Ordovician to pre-Paleozoic, which it overlaps along irregular boundary lines. In some portions of the area its margin is determined by faults, but these marginal faults appear not to be extensive either in throw or in length. Over wide areas the dips are to the north and northwest, but in some districts there are flexures of moderate amount and extent. The group is traversed by numerous normal faults, mostly extending northeast-southwest and with downthrow on the east side of the fault plane. One of these extending through Bucks and Montgomery counties has a vertical displacement of several thousand feet.

In the rocks of the Newark group in southeastern Pennsylvania, as in other regions, the typical red-brown sandstone and shale predominate, and there are igneous rocks in intrusive sheets and dikes. The classification which has been established in New Jersey is applicable here, and comprises three formations—the Stockton, Lockatong, and Brunswick, the last named being the youngest. A series of names proposed by the Pennsylvania Geological Survey has not been found acceptable because of their indefinite application.

The Stockton formation comprises gray to buff arkosic sandstone, red-brown sandstone, and numerous masses of red shale in no regular succession and presenting many local variations in stratigraphy. It lies on gneiss, schist, quartzite, and limestone, in Montgomery, Bucks, and northern Chester counties. Many of the sandstones are cross-bedded, and the finer-grained rocks exhibit ripple marks, mud cracks, and raindrop impressions, which indicate shallow-water conditions during deposition. The lower beds usually are arkose—a sandstone containing more or less feldspar and kaolin derived from the gneiss. The Lockatong formation consists mostly of dark-colored, hard, compact, fine-grained rocks originally composed of a mixture of clay and fine sand in variable proportions. Some beds are moderately massive, others vary from shaly to flaggy, and many of them exhibit mud cracks and other evidences of shallow-water deposition. Some of the beds contain carbonaceous material. The Brunswick shale consists mainly of a great thickness of soft red shale with some thin sandstone layers.

These three formations are not sharply separated by abrupt changes of materials but usually merge through beds of passage which appear to vary somewhat in thickness and possibly also in stratigraphic position in different areas.

Clark [143] gives the following brief account of the Newark formation in Maryland. The belt passes thence into Virginia. (For a discussion of the Richmond field, see pp. 518–519.)

The deposits of the Newark formation unconformably overlie the limestone and phyllite which have been above described and cover a considerable area along the western border of the Piedmont Plateau. Beginning as a belt some 10 miles in width in northern Carroll and Frederick counties, the formation gradually narrows toward the south, until in the region of Frederick its full width does not exceed 1 mile, while at one point directly to the west of Frederick the continuity of the beds is completely broken. Farther southward, in western Montgomery County, the belt of Newark deposits again broadens to a width of several miles.

The rocks of the Newark formation consist largely of red and gray sandstones and conglomerates of both siliceous and calcareous varieties. The finer-grained and deeper-colored deposits generally have their individual elements united by a ferruginous cement, while the calcareous conglomerate, which is largely made up of rounded limestone pebbles, is generally embedded in a reddish calcareous matrix. All of the deposits present structures which indicate that they were formed in shallow water; the coarse conglomerates, the ripple-marked surfaces, and the tracks of animals all point indisputably to this conclusion.

J–L 10–12. WESTERN UNITED STATES.

A philosophic discussion and correlation of American Triassic stratigraphy has been given by J. P. Smith.[765] The marine Triassic of the western United States is found in Oregon, Idaho, California, and Nevada. Its distribution and relations are summed up by Hyatt and Smith [469] as follows:

The marine Triassic section of [western] America is unusually complete, and its thickness compares favorably with that of any other region. All three subdivisions—Lower, Middle, and Upper Triassic—are represented by calcareous deposits, aggregating approximately 4,000 feet in thickness. Of this amount, about 800 feet belong to the Lower Triassic, about 1,000 feet to the Middle Triassic, and about 2,000 feet to the Upper Triassic.

The entire section is not represented at any one locality, nor is the thickness of each division constant. Furthermore, the marine Triassic is not everywhere developed as a calcareous formation. In the United States the Triassic system is represented by marine deposits only in the Western States, in Idaho, Nevada, Oregon, and California.

The Lower Triassic is known only in Idaho and southeastern California, where about 800 feet of shales and limestones contain fossils characteristic of this series. The most important genera are Meekoceras, Danubites, Columbites, Flemingites, Aspidites, Lecanites, Ophiceras, Nannites, Ussuria, Pseudosageceras, Hedenstrœmia, Cordillerites, Tirolites, and Proptychites, most of which are represented by closely related species in the Lower Triassic of India and Siberia.

The Middle Triassic occurs chiefly in Nevada and southeastern California. In the Inyo Range, southeastern California, about 200 feet of shaly limestones contain the following genera characteristic of the lower horizon of the Middle Triassic: Acrochordiceras, Xenodiscus, Hungarites, Ptychites, Tirolites, Ceratites, and Parapopanoceras.

In central Nevada, in the West Humboldt Range, the higher beds of the Middle Triassic are represented by about 800 feet of shaly limestones, in which the most characteristic genera are Ceratites, Anolcites, Dinarites, Danubites, Celtites, Hungarites, Beyrichites, Acrochordiceras, Balatonites, Eutomoceras, Ptychites, Joannites, Lecanites, and Atractites among the cephalopods, Daonella among pelecypods, and Cymbospondylus among vertebrates.

The Upper Triassic is best represented in northern California, where the Hosselkus limestone and the shales below and above this formation contain characteristic fossils. The Hosselkus limestone and the interbedded shales have a thickness approximating 500 feet. Fossils are very abundant throughout this formation, although much better preserved near the base. The best known fauna belongs to the zone of *Tropites subbullatus*, and contains as its most important members the following genera: Tropites, Paratropites, Discotropites, Juvavites, Sagenites, Leconteia, Trachyceras, Clionites, Arpadites, Polycyclus, Metatirolites, Hauerites, Dieneria, Arcestes, Paraganides, Proclydonautilus, Cosmonautilus, and Atractites among cephalopods, Halobia among pelecypods, and Shastasaurus among the vertebrates.

Above the Hosselkus limestone lie the Pseudomonotis slates, of unknown thickness, characterized by Halorites, Rhabdoceras, Arcestes, and Pseudomonotis.

In the West Humboldt Range in Nevada the Star Peak limestone, about 1,200 feet thick, appears to represent the Hosselkus limestone, although very few fossils have ever been found in it. Above the limestones lie the Pseudomonotis beds, about 800 feet of shales and shaly limestones, in which are found *Pseudomonotis subcircularis*, Rhabdoceras, Halorites, Placites, and Arcestes, an association characteristic of the Noric horizon.

K 12. SOUTHEASTERN IDAHO.

Peale and White first described the probably Lower Triassic rocks of southeastern Idaho occurring in the Blackfoot Basin near John Grays Lake, in latitude 43°, longitude 111° 30′. Peale[630] gives the following section:

General section of Jura-Trias in southeastern Idaho and western Wyoming.

Jura-Trias.	Jurassic.	Belemnites beds.	5. Red and gray shales with green sandstones and irregular greenish arenaceous limestones at the top. Thickness, 700 feet.
		Pentacrinus beds.	4. Laminated limestones, blue at base, passing into gray at top, succeeded above by grayish calcareous shales; many of the layers are probably arenaceous. Thickness, 800 feet.
	Triassic (?).	Red beds.	3. Red quartzitic sandstones with shaly arenaceous and calcareous layers at the base of the section. These are probably the equivalent of the typical "red beds" of the Eastern Rocky Mountains. Thickness, 1,000+ feet.
		Meekoceras beds.	2. Alternations of reddish and greenish sandstones and arenaceous and calcareous shales with blue and gray limestones, generally laminated. Thickness, 3,000+ feet. These with No. 1 are the beds of the section given in Dr. White's paper (as that of locality No. 1). The beds are fossiliferous at four horizons, containing species of a new Triassic (?) genus named Meekoceras by Prof. Hyatt, together with forms that have been heretofore regarded as of Jurassic age.
Carboniferous (?).			1. Massive grayish-blue limestone, overlain by quartzite and dark-blue laminated limestones. Thickness, 1,200+ feet.

The "Meekoceras beds" of Peale are not recognized either by him or by Schultz in western Wyoming, 25 miles east of John Grays Lake. Smith[764] gives the following description of the occurrences in Idaho:

Many years ago Dr. A. C. Peale discovered in southeastern Idaho and southwestern Wyoming a series of fossiliferous beds lying below the red beds and above the Carboniferous limestone. The fossils found in this formation were described by Dr. C. A. White and assigned to the Lower Trias. Cephalopods were found at but two places—locality No. 1, in southeastern Idaho, 65 miles north of Utah, 18 miles west of Wyoming, and 5 miles west of John Grays Lake; locality No. 2, 15 miles east of south from locality No. 1.

The section at locality No. 1, according to Dr. C. A. White, is as follows:

	Feet.
A. (Uppermost beds.) Limestones and shales, with *Terebratula semisimplex* White, *T. angustata* Hall, *Aviculopecten idahoensis* Meek	1,000
B. Limestones, with *Eumicrotis curta*, and *Aviculopecten idahoensis* Meek	
C. Greenish and reddish shales and sandstones, with *Aviculopecten pealei* White	850
D. Bluish-gray limestones, fossiliferous near the base, with *Meekoceras gracilitatis* White, *M. mushbachanum* White, *Arcestes? cirratus* White	700
E. Reddish and greenish sandstones	400
F. Dark-blue sandstone	800
G. Quartzite	
H. Massive gray limestone	400

At locality No. 2 were found *Meekoceras gracilitatis* White and *M. aplanatum* White, in limestone similar to that marked D in locality No. 1, and this part of the section unquestionably belongs to the Lower Trias, although it is not likely that the entire thickness of beds there is referable to this division. In a later paper Dr. C. A. White expressed the opinion that the Meekoceras fauna of Idaho ought possibly to be placed in the Permian rather than in the Trias, because of the conformity with the Carboniferous beds below, and because of the presence in the fauna of certain Carboniferous elements. These were precisely the arguments used 10 years later by F. Noetling for placing the Lower Triassic faunas of India in the Permian, but there is just as little ground for this in the one region as in the other. This question has been fully discussed by the writer in a recent paper.

In 1888 Prof. Alpheus Hyatt discovered a third locality for Lower Triassic ammonites in southeastern Idaho, in the Aspen Mountains, in Wood Canyon, about 9 miles east of Soda Springs. In 1900 and 1903 the writer visited this same locality, which lies only a few miles southwest of locality No. 2 of White. The joint collections of Prof. Hyatt and the writer yielded the following ammonites:[a] *Danubites whiteanus* Waagen, Danubites sp. nov., *Meekoceras gracilitatis* White, Meekoceras, three new species (of which one may be identical with *M. boreale* Diener), *M.* (*Koninckites*) *mushbachanum* White, *M.* (*Gyronites*) *aplanatum* White, and two other species of the same subgenus, Aspidites sp. nov., Flemingites sp. nov., Ophiceras sp. nov., Hedenstrœmia sp. nov., Clypites sp. nov., Ussuria two new species, and Nannites sp. nov. Besides those here listed there were found several new genera of the same families.

This fauna is intimately related to the Lower Triassic faunas of India and eastern Siberia, with several species that may even be identical with those from Asia. It contains several genera hitherto known only from the Lower Trias of India, and others previously found only in the Proptychites beds of Ussuri Bay in Siberia; it is therefore referred with certainty to the Brahmanic stage of the Scythis series. It may be correlated with the Ceratite marls and the lower part of the Ceratite sandstone of the Salt Range of India.

The following notes are contributed to this manuscript by C. L. Breger:

The "Meekoceras beds" are in southeastern Idaho nearly 3,000 feet thick and include Lower Triassic and apparently also Middle Triassic, while at the top, underlying the red beds, is a zone which appears to be of Upper Triassic age, containing *Myophoria* cf. *lineata* Mstr. and

[a] The new genera and some of the species of this fauna have been described in Prof. Paper U. S. Geol. Survey No. 40, by Hyatt & Smith.—B. W.

Spiriferina cf. *lippoldi* Bittner. If this identification is correct, the overlying red beds (corresponding to the Nugget formation of Veatch and the Teton formation of the Yellowstone Park), which have by some writers been classified as Triassic, would perhaps find a more suitable resting place in the lower Middle Jurassic.

The Pentacrinus shaly limestones of Peale, of the Hayden Survey, correspond to the Twin Creek formation of Veatch and the Ellis formation of the Yellowstone Park-Montana district. They are commonly regarded as of Upper Jurassic age. In southeastern Idaho their thickness is much greater than that given by Peale, reaching 3,000 feet or more.

K 12-13. WYOMING AND ADJACENT AREAS.

Triassic strata are not generally distinguished in this region, but they are assumed to be represented in the upper part of the red beds, the lower portion being assigned to the Permian. (See pp. 490–492, Chapter XI.) An exception to the general uncertainty is found in the beds near Lander to which Williston applied the name Popo Agie, and in the highest strata of Red Mountain near Laramie, from both of which Williston has described Triassic vertebrates.

Of the Park City district, Utah, Boutwell [93b] states:

> Within this district no sediments have been found which carry Triassic fossils. To the north and northwest, however, the Park City formations pass upward through several hundred feet of red shale into brown, red, pink, and white sandstones. These are frequently massive and heavily bedded, in striking occurrences are coarsely cross-bedded, and toward the top are quartzitic. Disregarding possible faulting, they aggregate about 1,550 feet thickness. The age of these sandstones has always been regarded as Triassic, as they overlie Permian and underlie Jurassic.

In western Wyoming Veatch [839b] distinguished as Triassic (?) the Nugget formation, consisting of red shales below (since correlated by Gale [356] with the Ankareh shale) and lighter-colored sandstones above (to which the name Nugget is now restricted).

Throughout the Bighorn Basin and Mountains the red beds are known as the Chugwater formation. Both Darton [239c] and Fisher [331] place the formation doubtfully in the Triassic but cite fossils from the lower portion which suggest Permian. (See p. 495, Chapter XI.) Darton [244c] says:

> Fossils found at various horizons in limestones in the Chugwater red beds do not afford conclusive evidence as to age. Those in the lower limestones in the Bighorn Mountains and other uplifts are believed to be "Permian" in the sense in which the term is used in the Mississippi Valley. Many fossils occur in the limestone 150 feet below the top of the formation, on the east bank of Bighorn River, 3 miles below Thermopolis. According to Dr. G. H. Girty, the principal species is *Natica lelia*, usually considered diagnostic of the Triassic, but probably it is older. Bakewellia and probably Pleurophorus may also be present, and an Aviculipecten occurs resembling *A. curticardinalis*, which is characteristic of the Permo-Carboniferous of Utah. Dr. Girty is inclined to correlate the fauna with the Permo-Carboniferous of the Wasatch Mountain section. The 150 feet of red shales and sandstones which overlie this limestone may possibly represent part of the Triassic. In the lower portion of the Chugwater formation, 10 miles southwest of Casper, a cast of *Schizodus wheeleri* was found. This form is usually regarded as Pennsylvanian.

The Chugwater formation also occurs in the Laramie Basin, where Darton has recognized it and included in it 200 feet of light-colored sandstone not typical and not observed to the northeast. The top of the formation nearly everywhere in this region is the base of the fresh-water Morrison formation,[247] the intervening Sundance formation (Jurassic) generally being absent.

Darton [244b] has traced the Chugwater throughout central Wyoming and, describing it under the heading "Permian-Triassic," gives its general relations as follows:

The Chugwater formation ranges in thickness from 900 to 1,200 feet and consists of sandy shales or soft, massive sandstones, nearly all of bright-red color. Gypsum deposits occur in most places. There are extensive exposures along the lower northeastern slope of the Wind River Mountains in the Owl Creek, Bridger, and Rattlesnake uplifts, in the flexures south of Casper and Douglas, above Alcova, in the Shirley and Freezeout hills, in the anticlines north and east of Medicine Bow, and along the east side and across the south end of Laramie Basin. It appears also at intervals along the east slope of Laramie Mountains. In the greater part of the south-central Wyoming region the Chugwater formation lies on Tensleep sandstone, but in the southern end of the Laramie Basin it lies on red beds of the Casper formation, from which in places it is not easily separated.

Detailed descriptions of the formation for all the ranges mentioned are given in the paper cited.

In the red beds thus placed by Darton in the Chugwater formation, in the ranges between Rawlins and Lander, Wyo., Williston [941a] has traced a series of beds near the top of the formation carrying Triassic vertebrates. He says:

The University of Chicago paleontological expedition to Wyoming the past summer was fortunate in securing a valuable collection of stegocephalian and reptilian remains from the Trias, a part of which is described in the present paper.

The beds whence the fossils were obtained, from 40 to 80 feet in thickness, are about 200 feet below the top of the red beds and about 600 feet above their base. Their description will be given in a later paper by Mr. N. H. Brown, their discoverer, and the writer. Meanwhile the horizon may be distinguished by the name Popo Agie beds, as suggested by Mr. Brown, from the Popo Agie River, along whose branches they are most characteristically shown.

The forms described comprise *Dolichobrachium gracile, Eubrachiosaurus browni, Brachybrachium brevipes,* and *Paleorhinus bransoni.*

Williston [942a] also found Triassic vertebrates in the red beds (Chugwater) of Red Mountain south of Laramie. He says:

We found there numerous fragments of bones scattered along a thin stratum near the top of the red beds. The marine Jurassic is here wanting, as at Canon City, the sandstone of the Morrison or Atlantosaurus beds overlying the red beds without marked unconformity. The lower members of these beds consist of a grayish or yellowish sandstone and are unfossiliferous, the first vertebrate fossils occurring 75 feet or more above the red beds horizon. [This stratum yielded] very characteristic labyrinthodont plates and vertebræ, proving conclusively the Triassic age of the deposits.

The differences of these fossils from those obtained in the Lander region [Popo Agie beds of Williston] from a horizon fully 250 feet below the top of the beds, are such that their contemporaneity of deposition is very improbable. * * * I am much inclined to believe that the Popo Agie beds, which may be contemporaneous with those yielding vertebrate fossils in Utah, Arizona, New Mexico, and Texas, are of early Keuper age, while the Connecticut Valley, the Red Mountain, and Hallopus beds of southern Colorado are later in time.

Darton in a later note [242] states that the red beds of Red Mountain grade into upper Carboniferous sandstones and limestones, which along the Rocky Mountain front become the Lower Wyoming division of Eldridge and the Fountain formation of Gilbert and Cross. Darton cites Knight's discovery of upper Carboniferous fossils in the red beds of the Laramie Basin and concludes that the evidence is contradictory.

Knight's article [506] contains a very detailed section, measured "in the vicinity of Red Mountain," from the pre-Cambrian granite on which the red beds rest. The section shows the typical variations of sandstone and conglomerate, prevailingly red or reddish. At 728 feet from the base occurs a fossiliferous layer of "grayish to reddish sandstone containing the following genera of fossils: Allorisma, Pleurophorus, Bellerophon, Myalina, Aviculopecten, Dentalium (?), Pleurotomaria (?), several small gastropods, and some remains of vertebrates." Knight says:

> The genera [in the fossiliferous layer in his section] are so characteristic that it is not necessary to discuss their geological position; they belong to the Paleozoic and resemble to a marked degree the fossils of the Kansas and Nebraska Permian. This places all the strata below the fossiliferous band in the Paleozoic. There remains a formation of about 800 feet in thickness [total 850 feet as measured, comprising red sandstone, shales, and gypsum beds], with the gypsum beds at its base, in a questionable position, and some may wish to retain these beds in the Triassic.

On the evidence of the fauna found by Knight 850 feet below the top, and the vertebrate remains collected by Williston near the top, we must conclude that the passage from Permian to Upper Triassic occurs in the upper half of the red beds.

K 18. CONNECTICUT AND MASSACHUSETTS.

The Triassic of the Connecticut Valley belongs to the Newark group. (See pp. 522–527.) Davis [248] discussed the conditions of deposition. Emerson [319a] classified the strata and described them in detail, particularly with reference to their occurrence in Massachusetts. He says:

> The Triassic rocks have been divided by the author in an earlier publication as follows:
>
> 1. The Sugar Loaf arkose, or the sandstone and conglomerate made up of the débris of granite.
> 2. The Mount Toby conglomerate, or the coarse conglomerate made up of large schist and quartzite pebbles.
>
> These two numbers are, speaking generally, the west and east shore deposits.
>
> 3. The Longmeadow brownstone, or the red sandstone generally marked by so-called fucoidal forms, which are probably concretions.
> 4. The Chicopee shale, or the calcareous red shale.
>
> These two are the offshore and central beds of the series.
>
> 5. The Granby tuff, or the diabase tuff.
> 6. The Holyoke and Deerfield diabase beds.
> 7. The Black rock volcanic necks and the posterior diabase beds.
>
> The last three distinctions cover the fragmental, interbedded, and intrusive occurrences of the diabase, respectively; except that the posterior sheet is placed with the injected necks, with one of which it is directly connected.

Russell [683] considered these particular strata in comparison with those of New Jersey and other localities where the Newark occurs.

In the Pomperaug Valley in western Connecticut is a small outlier of the Newark group which has been described in detail by Hobbs, [456] who distinguishes the following formations in descending order:

Posterior shales.
Main basalt sheet.
Anterior shales.
Anterior basalt sheet.
South Britain conglomerate.

K-L 13. BLACK HILLS, SOUTH DAKOTA.

The Spearfish formation, the uppermost division of the red beds in the Black Hills, was described by Darton [232c] as probably Triassic. He states:

The formation consists of from 350 to 500 feet of red sandy clays, with intercalated beds of gypsum which sometimes are 30 feet thick. * * * It is thought to be Triassic in age because it lies unconformably beneath marine Jurassic deposits and is underlain by the Minnekahta limestone, which is known to be of Permian age.

The tendency is now to correlate the Spearfish formation with the upper part of the Chugwater formation, which is also regarded as Triassic, the lower part of the Chugwater probably belonging to the Permian.

L 11. NORTHEASTERN OREGON AND WESTERN IDAHO.

Lindgren [540a] discusses briefly the occurrence of the Triassic in western North America and describes the Triassic strata in eastern Oregon and adjacent Idaho as follows:

With widespread Triassic areas in California, Idaho, and Nevada, and with similar areas north of the international boundary line, it seemed strange that no rocks of the same age were found in Oregon or in Washington. This gap has been partly bridged by the discovery of very extensive Triassic beds in the Eagle Creek Range, extending from there across Snake River into Idaho, to the vicinity of the Seven Devils. If the sedimentary rocks in the vicinity of Huntington belong to the same age, as is possible though by no means certain, the area of the Triassic would be still further extended.

A characteristic feature of the Triassic of the Eagle Creek Range is the occurrence of large masses of limestone and some shale, with an abundance of more or less altered lavas poured out during the time when these beds were being deposited.

The Triassic sediments are best exposed on Eagle Creek. All along the foothills of the lower Powder River the Triassic lavas contain smaller bodies of limestone and shale, but on Eagle Creek below the forks, the sedimentary series prevails and consists of calcareous shales and limestone in horizontal or slightly inclined position. Volcanic breccias are interbedded with the limestone. The total thickness of the series, including the volcanic beds, is probably several thousand feet. Many of the exposed limestone masses are several hundred feet in thickness. Above the junction * * * the limestones become converted into marbles and the volcanic breccias into schists, while the whole series acquires a dip of 60° E.

Dr. T. W. Stanton examined fossils collected one-third mile below the mouth of East Eagle Creek and reports them to consist of numerous specimens of Halobia and two indeterminable fragments of an ammonite. The Halobia is apparently an undescribed species, but the genus itself is characteristic of the Trias. Another lot, collected from the limestone bluff on East Eagle Creek 2½ miles above its mouth, contains Pentacrinus columns with spines and fragments of tests of echinoids. From the Miles placers, 1½ miles below the mouth of East Eagle Creek, I obtained through Mr. F. R. Mellis, of Baker City, a cast of a gigantic gastropod found in the limestone bedrock during drifting operations on this claim. Dr. Stanton remarks that it has the form of a very large Turritella or Pseudomelania. Nothing of this character approaching it in size has been described from the west coast, but similar forms described as Chemnitzia and Pseudomelania are known from the Trias and Jura of Europe. The total length of this cast is 8 inches and its diameter at the thickest end 3 inches.

Along Snake River canyon, below the mouth of Pine Creek, Triassic lavas and tuffs are again exposed in the bluff below the Neocene basalt flows which cap the hills. These Triassic igneous rocks contain thin beds of black shales and limestone with imprints of a large species of Daonella or Halobia. A limestone mass 4 miles below Ballard Ferry contained a Lima with fragmentary imprints of a Halobia (?), and is also probably Triassic. The last two fossils were obtained from Mr. E. Antz, of Ballard Ferry.

From these data and from what is known of the field relations of the strata it is safe to conclude that a Triassic series is developed on a large scale in this region; but from the paleontological evidence at hand it would not be possible to say which one of the numerous subdivisions of the series is present.

J. P. Smith states[a] that he visited the Triassic beds of the Blue Mountains in 1908 and determined them as certainly of Upper Triassic age (Karnic and lower Noric of Europe).

L 12. YELLOWSTONE NATIONAL PARK.

The occurrence of Triassic strata in the Yellowstone Park region is doubtful. Between the Ellis formation (which is now known to contain a Middle and Upper Jurassic fauna) and the Quadrant quartzite (Carboniferous) occurs the Teton formation, which is thought to be at least in part of Triassic age. The section exposed on Cinnabar Mountain in Yellowstone Park is, according to Iddings and Weed.[393a]

Section of the Mesozoic sedimentary rocks exposed in Cinnabar Mountain and Electric Peak.

			Feet.
Cretaceous.	Dakota.	Dakota conglomerate and sandstone	175
Juratrias.	Ellis.	Reddish shales and impure limestones	85
		Limestones and calcareous sandstones, occasionally a conglomerate; carries an abundance of fossil remains, which are generally fragmentary near the base	75
		Red argillaceous shale	8
		Gray calcareous shales and impure limestones, characterized by an abundance of fossil remains, particularly in the upper strata. The beds are separated near the center by oolitic limestones	132
		Green and red shales	50
	Teton.	Sandstone, saccharoidal in texture, generally light gray or buff in color, but red or brown on weathered surface	50
		Red beds, consisting of very fissile sandstones and impure arenaceous clays	75
		Limestone, compact in texture, gray in color, and carrying remains of lingulas	20
		Limestones, dark gray in color, generally fetid, often arenaceous and frequently characterized by rod-like masses of chert, which are seen to consist of grains of sand embedded in the siliceous matrix, the concretions having a white chalky surface	125
		Quadrant quartzites. [These are not a part of the Teton formation and in this table were bracketed with it through a typographic error.]	

In the Yellowstone National Park folio[392] the Teton formation is said to be the "probable equivalent of the well-known red beds of Wyoming and Colorado" and is described as follows:

> The formation consists of the basal sandstone, usually dull brown in color and more or less calcareous, characterized by rods and rolls of white chert, and carrying interbedded gray limestones containing linguloid shells. Above this basal bed are gray and greenish calcareous shales, often micaceous and capped by a red arenaceous shale that forms a conspicuous part of the formation. This series of beds is capped by a sandstone, generally bright yellow, with red weathered surface, this rock delimiting the overlying Ellis formation.

Lithologic resemblances and similar stratigraphic relations suggest correlation of the Teton with the Nugget and other formations of southwestern Wyoming. (See p. 530.)

[a] Personal communication.

Concerning the scanty paleontologic evidence of the age of the Teton formation Stanton[393f] says:

The Teton formation, of supposed Triassic age, yielded a few specimens of a Lingula at a locality on the summit of Quadrant Peak. This fossil resembles *Lingula brevirostris* M. and H., from the Jurassic of the Black Hills, but in the absence of other fossils it should be given little weight in determining the age of the beds. Linguloid shells are so slightly differentiated that it would not be safe to distinguish, by them alone, even between Paleozoic and Mesozoic. The determination of the age of this formation must, for the present at least, rest on the evidence of stratigraphy and lithology. The paleontologist can only say that the underlying beds yield Carboniferous fossils, while the overlying formation has a well-developed Jurassic fauna.

L 20. NOVA SCOTIA.

The Triassic of Nova Scotia comprises the rocks which have long been known by the descriptive term "New Red sandstone" and which belong to what is now called the Newark group. According to Dawson,[263] the terrane consists "principally of coarse and soft red sandstones with a calcareous cement. * * * In the lower part of the formation there are conglomerates made up of well-worn pebbles of the harder and older rocks." The Triassic strata lie with gentle dip, in marked unconformity to the subjacent steeply dipping Carboniferous rocks. They are associated with sheets of trap rock, in part massive, in part amygdaloidal or tuffaceous. Describing the characteristic relations as they are exposed at Cape Blomidon, Dawson[263a] says:

The history of this fine precipice is, then, shortly as follows. In the Triassic era, thick beds of sandstone were deposited off the coasts of Horton, just as the red mud and sand of the flats are now deposited. Volcanic phenomena on a great scale, however, broke forth from beneath the waters, scoriæ and dust were thrown out and spread around in thick beds, and currents of lava were poured forth. Subsequently the whole mass was elevated, to be again submerged under the bowlder-bearing sea, by which and the present atmospheric and aqueous agencies it was worn and wasted into its present form.

Dawson's account of the general relations of the Triassic of the Bay of Fundy[263b] is as follows:

The red sandstones now described appear to have been deposited in an arm of the sea, somewhat resembling in its general form the southern part of the present Bay of Fundy but rather longer and wider. This ancient bay was bounded by disturbed Carboniferous and Silurian strata, and the detritus which it received was probably chiefly derived from the softer strata of the Carboniferous system. The arenaceous nature of the New Red sandstone, as compared with the character of these older deposits, indicates that the ancient bay must have been traversed by currents, probably tidal like those of the modern bay, which washed away the argillaceous matter so as to prevent the accumulation of muddy sediment. When we consider the large amount of land in the vicinity of the waters in which the New Red sandstone was deposited, the deficiency of organic remains in its beds is somewhat surprising, though this is perhaps to be attributed rather to the materials of the deposit and its mode of accumulation than to any deficiency of vegetable or animal life at the period in question.

The volcanic action which manifested itself in the bed and on the margin of the bay of the New Red sandstone is one of the most remarkable features of the period. It has brought to the surface great quantities of melted rock, without disturbing or altering the soft arenaceous beds through which it has been poured and whose surface it has overflowed.

Reports later than Dawson's give much local detail regarding the Triassic as it occurs in the counties of Nova Scotia adjoining the Bay of Fundy. Fletcher[335f] describes the distribution and states:

The relations of the sedimentary rocks of this formation, with their associated traps, to the older formations have also been described in great detail by Jackson and Alger, Gesner,[a] Sir J. W. Dawson,[b] and others. The contact with the older rocks is always clear and unmistakable, so that there is no ambiguity with regard to the limits of the formation. Sometimes, particularly on the north side of the basin, this junction is a fault; sometimes coarse beds lie at a low angle upon and fill inequalities in the underlying rocks of which they are composed. Many of the sandstones are very calcareous. The total thickness of the formation is doubtful.

In Clifford Brook, east of Valley station, the lowest Triassic rock is a pea and nut conglomerate lying horizontally on the red slates of Union. On the road to the Telegraph road east of the manganese mines, and also in the neighborhood of the mines, many pieces of Triassic sandstone are in the soil and perhaps point to outliers among the Devonian.

From the railway station at Valley across the bridge and out the road to the Telegraph road the strata are Triassic, and to the eastward along the Telegraph road and for some distance up the river these rocks are also exposed. In Half Moon Hill Brook the contact with the Devonian is well seen, the Triassic being bright-red, crumbly, coarse sandstones, scarcely more coherent than the sand of a sand pit, with layers of grit, less bright than the other beds, containing pebbles an inch in length derived from the red argillites. Lower down is a gray, crumbly, flaggy pebbly sandstone, dipping at a low angle, with thin beds and blotches of light green.

In the branch of Farnham's Millbrook which flows from Penny's Mountain are dark brick-red, soft, marly, very fine sandstones, containing patches of gray calcareous sandstone and of coarse conglomerate, with a vertical dip which appears to indicate a fault. In another little brook farther west, brick-red sandstone and nut and egg conglomerate form ledges which dip at a very high angle.

M 9-10. VANCOUVER ISLAND.

In 1885 Dawson made a reconnaissance of the northern portion of Vancouver Island and determined the presence of Triassic limestone and argillite in an immense series of volcanic rocks, all of which are penetrated by granite intrusions. In 1902 the west coast was reconnoitered by Webster[868] and Haycock,[415] who identified the same series of rocks but added nothing to Dawson's original description,[256a] from which the following extracts are made:

By far the greater part of the area of the northern portion of Vancouver Island is occupied by rocks of volcanic origin, which at first sight and as judged by eastern American analogies might often be supposed to represent formations occupying a very low stage in the geological scale. These volcanic rocks, originally composed of minerals already crystalline, have since been subjected to metamorphism more or less intense, to which, in consequence of their composition, they have easily yielded, and now form, for the most part, rocks which might be spoken of as "traps and greenstones." These frequently show locally little or no evidence of their bedded character. Such rocks, however, when closely examined and followed from point to point, are found to form portions of a stratified series of great thickness, which includes, besides the preponderant volcanic materials, certain argillites and limestones, holding Triassic fossils.

The greater part of this old volcanic series appears to have been built up of basaltic and trachytic lava flows, alternating with rough volcanic breccias and tuffs largely composed of fragments derived from such flows. These rocks are now represented by hard amygdaloids and agglomerates of general dark-greenish colors, though often grayish and sometimes reddish or purplish; by felsites, more or less porphyritic; and by hard, regularly stratified ash beds, which, where the alteration has been most pronounced, are locally changed to hornblendic or micaceous schists.

* * * * * * * * *

[a] Geology and mineralogy of Nova Scotia, p. 239.
[b] Acadian geology, p. 99; Geol. Jour. London, vol. 4, p. 50, with a map.

In association with these volcanic rocks limestones, argillites, and quartzites occur, possibly at several different horizons, but one of these, which is of considerable thickness and great persistency and possesses very distinctive characters, has now been recognized at a number of places, from the northern part of the Strait of Georgia round the north end of the island and in Quatsino Sound. This intercalated zone is of considerable thickness, having been estimated at 2,500 feet at one place on the north coast of the island, where it appeared to be fully displayed. Massive limestones, which, when the strata are considerably altered, pass into marble, form its lower portion. The upper part of the limestone becomes interbedded with argillites in regular flaggy layers, and black flaggy argillites interbedded with quartzites overlie these. Where the top of this argillite series is seen it often holds tufaceous and fine agglomeratic beds, and is followed in ascending order by a great thickness of the altered volcanic rocks. In other localities, the limestone is found to become interbedded with volcanic materials beneath, and though no complete section of the entire series can be offered, it is quite clear, from observations made in a great number of places, that these sedimentary materials form an intercalation in the great volcanic series.

The importance of this fact is apparent when it is stated that the only means of fixing the age of the entire series is afforded by the fossils obtained from the limestone and argillite intercalation. These occur chiefly in the argillites and in passage beds between these and the more massive limestones, and are referable to the so-called Alpine Trias. No fossils except these of this age have yet been found in association with this sub-Cretaceous series in the northern part of Vancouver Island, while the Triassic forms have been recognized in numerous localities. The evidence on which these rocks are, therefore, colored as Triassic on the map, is identical with that on which the reference of the precisely similar series of the Queen Charlotte Islands is based. It is quite possible, in both cases, that the lower portion of the series may include rocks of greater age than Triassic, and the association of Triassic and Carboniferous volcanic rocks in the southern part of the interior of British Columbia lends a degree of probability to the conjecture that rocks of the Carboniferous period may form a portion of those here described. There is, however, no direct evidence of this, either in the northern part of Vancouver Island or in the Queen Charlotte Islands.

The rocks beneath those of the Cretaceous age in the southern portion of Vancouver Island are likewise, in great part, altered volcanic materials, which are interbedded with limestones and in some places with argillites. The conjecture that beds of Carboniferous age may occur together with those referable to the Trias, in the Queen Charlotte Islands and the northern part of Vancouver Island, is strengthened by the fact that the late Mr. J. Richardson obtained a few poorly preserved fossils from limestones interbedded with the altered volcanic rocks of the Ballinac Islands, between Nanaimo and Comox, and at Mount Mark, in the center of Vancouver Island, between Qualicum and Alberni, which were supposed by Mr. Billings to be either Carboniferous or Permian, and probably the former.

Though an unconformity has been proved to exist in at least one place between the Triassic and Carboniferous volcanic rocks of the southern interior of the province, no such break has yet been found in any part of the sub-Cretaceous series of Vancouver Island, and if rocks of both these periods actually occur there, they can not be at present separated.

The series as a whole indicates throughout a continuance or recurrence of volcanic phenomena on an enormous scale, and must be at least several thousand feet in thickness.

As a convenient name for the whole I shall employ the term "Vancouver series," including for the present under this name not only the entire mass of volcanic materials which unconformably underlie the Cretaceous but also the interbedded limestones and flaggy argillites and quartzites. This name may also be understood to include the similar beds of the Queen Charlotte Islands, as well as those of the southern part of Vancouver Island, to which it was originally applied by Dr. Selwyn in 1871. If this great mass of rocks should eventually prove separable into Triassic and Carboniferous portions, I would suggest the retention of the name Vancouver series for the former.

The beds of the Vancouver series are the oldest known to occur in the district here described and in the Queen Charlotte Islands and are frequently found in contact with or resting on granitic rocks. They have not, however, been deposited upon a granitic floor, as the granites are evidently later in date than the rocks of the Vancouver series, and nothing whatever is known of the character of the surface upon which its volcanic and other associated beds were originally formed.

The fossils obtained from the Vancouver Triassic are described by Whiteaves.[913,914]

M 10. KAMLOOPS DISTRICT, SOUTHERN BRITISH COLUMBIA.

The Nicola formation, which consists largely of volcanic rocks with associated fossiliferous marine sediments, was originally assigned by Dawson in 1878 to the Triassic on somewhat meager evidence. In 1894 Dawson[261a] reviewed all the evidence which had then accumulated and concluded:

It will be observed that the original reference of the series as a whole to the Triassic has been gradually strengthened by later discoveries. These, taken in connection with the stratigraphy, in fact seem to show that while the great bulk of the Nicola formation is undoubtedly equivalent to the Triassic, it passes up in a few places into rocks of Lower Jurassic date. The structure and lithology do not appear to afford any means of separating the two faunas or of drawing any line through the great mass of rocks, chiefly of volcanic origin, in which they occur, and it is therefore appropriate and necessary to treat of the Nicola formation as a whole, although recognizing the fact that it probably extends higher than the typical Trias.

An unconformity is indicated between the lowest strata of the Nicola and the underlying Paleozoic rocks. Regarding the composition of the Nicola formation Dawson says:

Within the area of the Kamloops sheet the Nicola formation consists essentially of a great mass of volcanic deposits, with a total thickness of probably 10,000 to 15,000 feet. In the lower part of the formation some thin and probably irregular beds of limestone occur. Here and there throughout the formation a limited thickness of argillites is found, and, forming the summit, so far as yet ascertained, is another bed of limestone.

The greater part of the volcanic rocks may be described generally under the useful name of "greenstones." Lithologically, these rocks are for the most part found to be altered diabases, with, exceptionally, augite porphyrites, also considerably altered. In regard to their state of aggregation, these volcanic materials represent all the usual products of eruptions, including effusive rocks, sometimes amygdaloidal, and tuffs. There is also, throughout the entire series, more or less evidence of subaqueous deposition and bedding, while no proof has so far been obtained in this district of the existence of subaerial accumulations.

The following summarized general sections, based on more detailed descriptions given in the sequel, best represent what is known of the Nicola formation, in the eastern and western parts of its area respectively. The sections are in descending order.

Thompson River, south of the Ashcroft Cretaceous area.

	Feet.
Limestone (20 feet or more)	20
Fine-grained feldspathic rocks, sometimes well bedded, generally gray	1,800
Tuffs, or ash rocks, passing into agglomerates, with some fine-grained felsites, gray, purplish and green; a few small limestone beds near the base	7,840
Chiefly green diabase agglomerates, often coarse. Several calcareous beds and limestones. Dark felsites at base	3,930
Approximate total	13,590

Vicinity of Nicola Lake.

	Feet.
Fine-grained feldspathic rocks, generally well bedded	1,200
Diabases, chiefly effusive and sometimes amygdaloidal; some tuffs; two thin beds of limestone near the base	3,700
Chiefly green diabase agglomerates, occasionally amygdaloidal. Thickness at least 2,600 feet and possibly 6,000 feet (say)	2,600
Approximate total (minimum)	7,500

In explanation of the above sections, it may be added that although placed in parallel columns, the equivalency of the several groups of beds is intended merely to be suggested in the most general way. If the maximum thickness be assigned to the lower group in the Nicola section, there would be a nearer approximation to correspondence in total thickness, but the rendering of this part of the section is doubtful. Further it must be noted as possible that the amphibolites and argillites of the Douglas Lake vicinity, with a thickness of about 7,000 feet, may eventually have to be added to the Nicola formation in that region. * * *

In the year following that in which the Triassic age of these rocks was recognized in the inland region of British Columbia and the name Nicola series proposed for them, Triassic rocks of essentially the same character were discovered in the coast region, in the Queen Charlotte Islands. At a still later date, the formation last referred to was found to be continued to the southeastward, in the line of the same mountain axis, and to form the greater part of the older rocks of the northern portion of Vancouver Island. Like the Nicola formation, the Vancouver formation, as it was then called, is chiefly composed of old volcanic products. * * * [See pp. 536–538.] With these volcanic products limestones and argillites holding characteristic Triassic fossils are interbedded.

In the Vancouver formation, or series, the limestones and argillites are somewhat more important than in the Nicola formation, but otherwise the resemblance between the two, both in regard to their original mode of production and their present appearance, practically amounts to identity. Notwithstanding this fact, it is believed to be appropriate to retain distinctive local names for the two great developments of Triassic rocks in British Columbia. In both cases the lower and upper limits of the formation remain more or less indefinite, chiefly because of the absence throughout the great masses of the strata of any organic remains, and thus one may extend in its lower or upper beds through a part of the geological time scale considerably greater than the other. It is moreover found to be a general rule in this part of the Cordillera that exact equivalency of formations is scarcely to be sought for at any considerable distance across the prevalent northwest and southeast trend of the main orographic features, and in this case the nearest recognized representatives of the two formations are separated by a gap of about 150 miles transverse to this direction.

In an immediately succeeding paragraph Dawson refers to the occurrence of "Triassic" red beds in latitude 49° 30′ in the Rocky Mountains. The rocks are described in an earlier report,[255] and were later placed by Willis[940] in his Kintla formation, which belongs to the Belt series (pre-Cambrian).

N 8–9. QUEEN CHARLOTTE ISLANDS.

On Dawson's map of 1878 the southern portion of the Queen Charlotte Islands is represented as consisting of Triassic rocks. The report states:[252a]

In a preceding report on British Columbia it has been found necessary to include for the present the Paleozoic and Triassic rocks under a single heading.[a] They lie together unconformably beneath well-characterized Cretaceous beds but are so much involved that no attempt has been made to separate them except locally. In the southern part of the interior of British Columbia both Carboniferous and Triassic fossils have been found among these older rocks, but no forms of greater antiquity. In the Queen Charlotte Islands, now reported on, fossils have been discovered in the rocks unconformably underlying the Cretaceous in a number of places. These serve to characterize a certain zone of argillites and limestones, which is frequently repeated in sections along different parts of the coast, as distinctively Triassic, and show it to represent the so-called Alpine Trias which is so largely developed in California and Nevada. No forms distinctively Carboniferous or Paleozoic have yet been discovered, but from the intimate association of Carboniferous and Triassic rocks in the southern part of the province, and more particularly from the occurrence of great masses of rocks largely volcanic

[a] Report of Progress, 1877–78.

in origin and believed to be Carboniferous in age, in the southern part of Vancouver, which forms part of the same axis of elevation with the Queen Charlotte Islands, it is highly probable that the rocks of this age may come to the surface in some places. Mr. Whiteaves, who has examined the fossils, does not find any clearly Triassic forms among those from Rose Harbor, the old copper mine in Skincuttle Inlet, and the south end of South Island in Skidegate Inlet. The limestones of these localities may therefore possibly be of Carboniferous age, and if so a large portion of the associated rocks of volcanic origin must be attributed to the same period. As it is at present impossible to unravel the structural complexity of the sub-Cretaceous rocks of the islands, it has been thought best to color them together on the map as Triassic, in correspondence with their characteristic fossils.

Though no report is here made on observations in the northern part of Vancouver Island, it may be mentioned that Triassic forms identical with those from one of the localities on Houston Stewart Channel, have been obtained on Forward Inlet and Browning Creek, Quatsino Sound.

Any unconformity which may have existed between different beds of this sub-Cretaceous mass of rocks may now be masked by their complete folding and the great disturbance and fracture to which they have been subjected. The occurrence of great masses of contemporaneous volcanic material during both the Triassic and Carboniferous periods, in British Columbia, has been demonstrated in former reports; and in the event of the lower and possibly Carboniferous rocks proving to be really Triassic, their general character would accord closely enough with that of those known elsewhere.

* * * * * * * * *

Tabular view of formations represented in the Queen Charlotte Islands.

Post-Pliocene.	Sands and gravels. Plastic and bowlder clays, gravel beds, etc.
Unconformity, with evidence of some flexure and disturbance of Tertiary beds.	
Tertiary, probably Miocene.	Volcanic rocks of the north part of Graham Island. Sandstones, with marine fossils and lignites of Skunun Point. Shales, clays, and lignites of Ma-min River and Chin-oo-kun-dl Creek.
Complete unconformity, with evidence of great disturbance. Chief period of mountain making.	
Cretaceous.	A. Upper shales and sandstones. B. Coarse conglomerates. C. Lower shales and sandstones. D. Agglomerates. E. Lower sandstones.
Unconformity, but without evidence of great disturbance.	
Triassic, but possibly passing below into Carboniferous.	Agglomerates and ash rocks of Logan Inlet, etc. (These possibly represent subdivision D, supra.) Flaggy calcareous argillites and thin limestones. Massive limestones. Massive dioritic and feldspathic volcanic accumulations, probably including minor limestone beds, occasionally schistose.

TRIASSIC.

The rocks seen in the shores of Houston Stewart Channel are everywhere very much disturbed, shattered by faults, and traversed by innumerable dikes. This region lies in the line of the mountainous axis of the islands, and though no extensive granitic masses appear here, the intensity of the force brought to bear on this region is well exemplified. About the middle of the southwest reach of the channel, in a bay on the southeast side, are extensive exposures of limestones and flaggy argillites, with general westerly dips. The limestones are generally in thin beds, bluish black on fresh fracture, and frequently fetid when struck. They are cherty and contain blackish rounded or rootlike concretions of silica and blend with the shales or flaggy argillites, which appear to occupy a superior position. The argillites are calcareous throughout, and generally each bed is a few inches thick, though in some cases finely shaly. Fossils were found in abundance in some of the shaly layers and in the limestones. Mr. Whiteaves enumerates the following species from this locality. They are evidently synchronous with the so-called Alpine Trias of Nevada:

1. Amplexus (?) sp. nov.
2. Monotis subcircularis Gabb.
3. Halobia lommeli Wiss.
4. Sphœra whitneyi (?) Meek.
5. Arcestes gabbii Meek.

6 and 7. Fragments of two species of ammonitoid shells, one of which appears to be new. They probably belong to different genera.

8. Belemnites sp. nov.

Feldspathic dikes, generally of pale greenish-gray color, traverse the rocks in all directions and stand out like ruined walls when the softer beds have been weathered away from them. These so complicate the section as to render accurate measurement impossible, but there is probably 500 feet or more in thickness of the limestones and argillites.

Detailed descriptions of various occurrences of so-called Triassic rocks, which probably include Paleozoic rocks also, are given on the succeeding pages of Dawson's report. In 1905 Ells [316] examined the coal fields of the northern (Graham) island, but he did not investigate the pre-Cretaceous rocks except incidentally.

N–O 11. PEACE RIVER PASS, BRITISH COLUMBIA.

On Peace River, in the canyon by which it traverses the eastern ranges of the Rocky Mountains, McConnell [562a] noted the presence of "dark Monotis-bearing calcareous shales and impure limestones of Triassic age." This occurrence is in the range of the Triassic strata on the Liard. (See O 9, pp. 542-543.)

O 5. COOK INLET, ALASKA.

Stanton and Martin [786a] describe the Triassic of Cook Inlet as follows:

Upper Triassic rocks have been seen on the north shore of Bear Cove and on Bear Bay, both on the west shore of Cook Inlet, and on the Alaska Peninsula at the entrance to Cold Bay and extending several miles eastward. They are also probably present at numerous localities on the south shore of Kachemak Bay, as at Halibut Cove and Seldovia, where there is a great development of thin-bedded and contorted cherts, with some siliceous limestone and igneous rocks. This series is tentatively correlated with the fossiliferous Trias on the west shore of Cook Inlet on account of lithologic and structural resemblances and because of its association with the Lower Jurassic.

The Triassic rocks of Cold Bay, Bear Cove, and Bear Bay, whose age has been definitely determined by fossils, consist of thin-bedded chert, limestone, and shale of varied colors. The chert and limestone are usually dark (black, green, or dark red) when fresh, but weather to lighter shades. No measurement of the thickness has been made, but it is estimated to be at least 2,000 feet in the exposures seen by us, in which the base was always cut off by intruded igneous rocks.

These rocks are always closely folded and are frequently crumpled. They are usually cut by numerous dikes of diverse character and composition, varying from granite to andesite and basalt. The more acid dikes are apparently characteristic of the Triassic rocks and were intruded soon after the folding which must have closely followed Triassic time, for they do not cut the younger rocks. * * *

The Triassic fauna of the region as now known is almost limited to the single species *Pseudomonotis subcircularis* Gabb, which is very abundant in certain layers of shale and limestone at Bear Cove and Cold Bay. Specimens from the latter locality were described and figured by Fischer as *Monotis salinaria,* which it resembles in its general features, but a comparison of a large series of specimens from Alaska with a similar series of Gabb's California species shows that they are not separable. The species belongs to the group of *Pseudomonotis ochotica,* which is characteristic of the Upper Triassic of Siberia and the boreal regions generally.

In California *Pseudomonotis subcircularis* is confined to the Swearinger slates, which form the uppermost Triassic formation of that region. Similar beds with the same fossil occur in Vancouver and Queen Charlotte islands and on the mainland of British Columbia, and they cover considerable areas in the Copper River region of Alaska.

At Bear Bay the much-folded Triassic limestone yielded imperfect specimens of a Halobia, and at Cold Bay a few imperfect ammonites not generically determined were obtained in beds overlying the Pseudomonotis layers, but possibly still within the Triassic.

O 7-8. SOUTHEASTERN ALASKA.

The first determination of Triassic in Alaska was made by Paul Fischer [330] in 1872. Rocks of this age in the Mount St. Elias Range are also described by C. W. Hayes.[416] Referring to the "Vancouver series," Brooks [101g] says:

It is to be expected that this Triassic series will be found in the adjacent parts of Alaska, but up to the present time it has not been positively identified. It has been shown that certain metamorphic terranes carry Permian fossils, and it is quite possible that the Triassic beds may be infolded with these, as is the case with the Carboniferous of Queen Charlotte Islands. This view is borne out by some obscure fossils (probably Mesozoic) which have recently been found by Prindle near Fort Wrangell. While reconnoitering the southern part of the Alexander Archipelago a succession of conglomerates, black shales, and slates was encountered and called the Gravina series, from the name of the island where they occur. These rocks are closely infolded with the Vallenar series (Devonian), but the two formations are probably separated by an unconformity. So little was learned of the distribution and structural relations of this horizon that the wisdom of giving it a distinct name now seems open to question. The Gravina was correlated with Dawson's Queen Charlotte group (Cretaceous), but on reviewing the evidence its identity with the Vancouver series (Triassic) seems equally probable. In 1904 Wright found a conglomerate and slate series on Admiralty Island which yielded Lower Cretaceous or Jurassic forms.

In the same insular region there are large areas of massive, basic igneous rocks, chiefly of effusive origin, which were grouped together under the name Kasaan greenstone and were provisionally assigned to the Mesozoic. On the Queen Charlotte Islands, to the south, rocks of a similar character occur in both the Triassic and in the Cretaceous, and the Kasaan effusives may belong to either period, but in the report cited were provisionally placed in the Cretaceous and correlated with the rocks of the Queen Charlotte group.

O 9. DEASE AND LIARD RIVERS, BRITISH COLUMBIA.

Certain strata, "consisting of regularly bedded, dark, calcareous, flaggy argillites, alternating with gray flaggy and massive limestones" were observed "at the second great bend" of the Dease in 1887 by Dawson,[258a] who notes their lithologic resemblance to the "Triassic of the west coast" but, not having found fossils, regards the evidence as "too imperfect for a reference of the beds."

On the Liard McConnell [560a] obtained more definite information:

Beds holding Triassic fossils occur along the Liard in the eastern foothills of the Rocky Mountains. They consist of dark shales, usually rather coarsely laminated, and passing into calcareous shales interstratified with sandstones and shaly and massive limestones. The latter are moderately crystalline, are dark in color, and are usually very impure. They are harder than the shales and at Hell Gate narrow the valley into a canyon. The beds undulate, usually in easy folds, along the valley, and are exposed in numerous disconnected sections, but it was found impossible in hurrying through to make even an approximate estimate of their thickness. Triassic fossils were found at the Rapids of the Drowned, at Hell Gate, and at one intermediate point. It is probable, however, that a considerable portion of the barren shales east and west of these points are also of Triassic age. All the fossils collected have been examined by Mr. Whiteaves, and the following list of species, nine of which are described by him in volume 1, part 2, of the "Contributions to Canadian paleontology," is furnished by him:

Spiriferina borealis.	Nautilus liardensis.
Terebratula liardensis.	Popanoceras mcconnelli.
Monotis ovalis.	Trachyceras canadense.
Halobia (Daonella) lommelli Wissman.	Trigonodus? productus.
Halobia occidentalis.	Margarita triassica.

Triassic beds were not detected along the eastern edge of the Liard Cretaceous basin. They are also absent from the valley of the Mackenzie, as the Cretaceous rocks were found there in a number of places resting directly on the Devonian.

P 7. WRANGELL MOUNTAINS, ALASKA.

The Triassic of the Wrangell Mountains and adjacent regions comprises the Chitistone limestone, which was formerly referred to the Carboniferous, and the overlying black shales and limestones, up to the unconformity with the Kennicott formation (Upper Jurassic or Lower Cretaceous). The facts have been discussed in successive Alaskan reports, of which the latest is one by Moffit and Maddren,[601] who quote from earlier investigators and say:

In 1907 fossils were collected from the Chitistone limestone at a number of localities between Kotsina River and Chitistone River, and they definitely determine its age as Triassic. Part of these fossils were found in place, but a majority were collected from the talus débris below cliffs of the limestone, yet there was no place where it seemed possible that the limestone fragments containing the fossils could have come from any other source than the cliffs above them, and no hesitation is felt in accepting their evidence for the age of the Chitistone. The fossils were determined by T. W. Stanton, who describes them as follows:

"Several different localities are represented in the collections, but the fossils, with one exception, are all said to be from the Chitistone limestone and closely associated formations. The collection is small and somewhat fragmentary, but it has proved sufficient to show quite conclusively that the beds in question are of Triassic age. The ammonites, especially, are all characteristic Triassic types, and the few brachiopods obtained are also Mesozoic. There is no indication of Paleozoic fossils in any part of the section represented."

Schrader and Spencer,[709] who included the Chitistone limestone in the Carboniferous, said:

The Chitistone formation is composed of very massive limestones, without any important intercalations of shale. When weathered, it has a white or gray color, which makes it prominent in contrast with the greenstone upon which it lies, but when broken it is found to have a blue color, which is indicative of considerable carbonaceous material in its composition. In texture it is fine grained throughout. * * *

Studies of the Carboniferous and Triassic strata of the Wrangell district have not been sufficiently detailed to afford evidence as to where the line between these two formations should be drawn. Above the massive basal series of limestones there is a series of thin-bedded limestones with shaly partings, which is apparently in perfect conformity with the underlying beds and which passes by gradation into the black shales above. These black shales contain the fossils by means of which the Triassic age of the formation has been determined. The provisional and arbitrary line between the two formations has been placed at the top of the massive limestone series. The thickness of the Chitistone formation, as thus defined, is somewhat variable. Its maximum development is probably in the region of Nizina River, where it reaches a thickness of approximately 2,000 feet. In the Kotsina and Strelna region its thickness is somewhat less, but it can not be made out that there is any progressive thinning toward the west. * * *

The rocks which have been included in the Triassic series comprise all the strata that lie above the Chitistone limestone and below the unconformable Kennicott formation, of Jura-Cretaceous age. In the lower part, and resting conformably upon the Chitistone limestone, is a series of thin-bedded limestones, in strata from a few inches to a foot or more in thickness, supported [separated ?] by thin partings of black shale. The thickness of this member is approximately 1,000 feet, and the limestone, so far as observed, did not contain fossil remains. Above the thin-bedded limestones, and sharply defined from them, are black shales containing occasional bands of impure limestone, locally affording fossils, from which the age of the formation has been determined. The thickness of the upper member of the Triassic is very great, possibly more than 3,000 feet, but no opportunity was offered for its direct measurement, since its occurrence as the surface formation beneath strata lying unconformably upon it, together with the attitude which it has assumed as the result of folding and faulting, renders its relations complicated and obscure. A few thin flows of greenstone, similar to that of the Nikolai series, were observed here and there interbedded with the black shales of the Triassic. The Triassic series may be easily recognized from its general homogeneous nature and the fine-grained character of its black carbonaceous shales.

Locally the thin-bedded limestones are very intricately folded and contorted.

P 8. STEWART RIVER SECTION, YUKON PROVINCE.

Keele [474a] assigns to the Triassic certain rocks in the northern Rocky Mountain section, where the map of North America shows undifferentiated metamorphic Paleozoic. He says:

The crystalline limestone, provisionally classed as Upper Paleozoic, rests unconformably on the crystalline schists, while it is apparently overlain by Triassic rocks. No fossils were found and the contact with the Devonian rocks to the north was not seen. A similar rock mass occurs on the Macmillan River which was classed as Carboniferous from evidence of some fossil remains found in that locality.

This occurrence also overlies crystalline schists unconformably and is followed by what are probably Mesozoic rocks.

The rocks grouped as Triassic are almost altogether of sedimentary origin. Thin bedding and diversity in the color and composition of the beds are characteristic features. They have been greatly folded and crumpled in some localities, while in other places they are horizontal. Cleavage planes have been developed and certain of the beds have undergone slight alteration during the processes of mountain building.

The rocks which underlie the eastern extremity of the area marked Triassic on the accompanying map sheet are chiefly made up of sandstones, grits, red slates, limestone, and some volcanics, while toward the western end shaly argillites with thin quartzite and limestone beds prevail. Beds similar to the latter also occur in the section to the west.

The evidence gathered from the study of a few fossils found in the area, while not conclusive, is in favor of referring at least a portion of the series to the Triassic.

A group of rocks similar in many respects to the above occurs along the Macmillan River 40 or 50 miles to the south, but the black chert beds found in that area are absent in the Stewart River series.

R 3. CAPE THOMPSON, NORTHWESTERN ALASKA.

In describing the section of Carboniferous and Triassic strata which lie in a syncline south of Point Hope and Cape Thompson, Kindle [500a] says:

The higher beds of the Cape Thompson section are brought in contact with the beds already described [Carboniferous] in the midst of a zone of rather local but complicated folding and possibly of faulting, which renders it impossible to give even an approximate estimate of their thickness as seen from the top of the southeastern portion of the Cape Thompson cliffs; but between the second and the fourth deep ravines separating the high ridges just southeast of the cape along the coast the exposures are continuous for 2 miles, exposing a section of northerly dipping beds in which the dip decreases from 35° to 0 near the middle of the synclinal. We find in the series of cliffs which face the sea to the southeast of the second ravine below Cape Thompson a section which passes without structural complications from the fossiliferous Carboniferous limestones to the top of the highest beds exposed in this vicinity. This section is as follows:

Section 2 miles southeast of Cape Thompson.

	Feet.
(*e*) Soft black shales	500+
(*d*) Dark cherts and thin-bedded cherty limestones with some greenish bands	25
(*c*) Argillites with bands of black, green, and dull red cherts	600
(*b*) Light-gray limestone, weathering buff, with some bands of dark chert; apparently barren of fossils	2. 000+
(*a*) Light-gray limestone similar to the above, but with less chert and containing numerous fossils in which corals are conspicuous	3, 000+

In the upper part of the lowest division of this thick limestone series, *a* of the section, fossils are fairly abundant. * * * Only a few were collected, however. These are given in the following list by Dr. Girty, whose remarks on the general faunal relations of these faunas have already been given.

Lot 15 A.—Zaphrentis sp., *Spirifer* aff. *striatus*, Composita? sp.

The close physical resemblance of the second division (*b*) of the limestone series to the lower leaves little doubt that it is also of Carboniferous age. It may represent the Upper Carboniferous, which has not been recognized anywhere on the northwestern coast of Alaska, though known on the Yukon and in southeastern Alaska.

The lithologic change at the top of this limestone series is abrupt. The beds included in *c* and *d* are essentially similar, and represent the same formation, although there is less of the calcareous element in the lower beds. Fossils were found, however, only in the upper beds marked *d* in the section. They occur in great abundance in certain strata in this portion of the section. About 7 feet near the top are composed almost exclusively of shells which have been largely altered to chert. Dr. T. W. Stanton has furnished the following report on the fossils secured from this horizon:

"Lot 15*d*. Mouth of creek 2 miles southeast of Cape Thompson.

"This collection consists of limestone fragments with numerous specimens of aviculoid shells referable to *Pseudomonotis subcircularis* (Gabb) or to a closely related species. No other recognizable species are associated with it. This species occurs in an Upper Triassic horizon in California, and it has been accepted as sufficient evidence for the Triassic age of rocks containing it at Cold Bay and in the Copper River region of Alaska. In my opinion, the horizon which yielded it at Cape Thompson is also Upper Triassic.

"Among the collections obtained by Mr. Collier in the Cape Lisburne region some years ago there are several small lots consisting mainly of a form that seems to be identical with

Pseudomonotis subcircularis and probably comes from about the same horizon as this Cape Thompson locality. These fossils were at that time identified as Aviculopecten and referred to the Carboniferous, chiefly because of the stratigraphic relations they were supposed to hold with well-characterized Carboniferous faunas. If Mr. Kindle's interpretation of the structure is correct the horizon in question at Cape Thompson is above all the Carboniferous faunas and offers no stratigraphic difficulties in its reference to the Triassic."

(See Chapter VIII, pp. 396–399.)

R 27. NORTHEAST COAST OF GREENLAND.

The facts which are known regarding the Jurassic rocks of eastern Greenland have been summarized by Skeat.[742] According to the observations of the Danish expedition of 1891–92, at Neill's Cliffs there is a succession of strata which comprises the following:

1. At the base a green sandstone, not found north of Cape Stewart.
2. Next a gray sandy clay shale, with many fossil plants. This is seen in the valley, 160 to 180 feet above sea level, and also crops out immediately below on the shore.
3. The next part of the slope is completely obscured by weathered fragments, which conceal the underlying beds.
4. Above is a very impure reddish-colored limestone, very rich in fossils. The limestone varies very considerably in different parts. It may be sandy and unfossiliferous; or full of small pebbles sometimes rolled and sometimes angular, so that the rock is now a conglomerate and now a breccia; lastly, it may be a typical shell breccia, crammed with fossils of Jurassic age. These variations occur near each other and pass over into each other. The bed is 7 feet thick and occurs at a height of 186 feet above sea level.
5. Above this is a sandy shale without fossils.
6. Next comes a sheet of basalt 10 feet thick.
7. This is overlain at the end of the valley by a yellow sandstone, 6 feet thick, with a few carbonized plant remains, which forms the uppermost deposit at Cape Stewart.

Continuing along Hurry's Inlet, Neill's Cliffs get higher and higher, owing partly to the position of the beds, but probably also to the fact that other beds crop out both above and below those already mentioned.

The members of the expedition landed toward the northern end of the inlet, approximately southwest of the Fame Islands. Here the lowest bed exposed was a flaggy sandstone with, once more, the fossiliferous limestone above. The limestone in this exposure is pure toward the middle but conglomeratic or brecciated upward and downward. Not far but yet not immediately above this limestone is the basalt again, which here appears at a height of 1,300 feet, with alternating layers of sandstone and dolerite above. Several beds which are seen here belong to a higher horizon than those of Cape Stewart, and farther inland yet newer deposits occur. The fossils obtained were mainly lamellibranchs and brachiopods; many were new species, but certain typical Middle European forms, namely, *Avicula munsteri* cf. Goldf., *Limea duplicata* Sow., *Ostrea sandalina* cf. Goldf., were interspersed among them, the former in large number. These species are of Middle Jurassic or Callovian age, and the fauna is altogether characteristically Callovian; moreover it has close affinities with the Middle European type. Lundgren, who examined the fossils collected on this occasion, identifies the Cape Stewart beds with the Callovian of Kuhn Island; the lowest shales containing plant remains were proved by Hartz to be of Rhætic or Rhætic-Lias age.

The Swedish expedition of 1899 under Nathorst reports Rhætic plant remains and a yellow sandstone with numerous Ostreas and Belemnites. The map which is published with Nathorst's work represents horizons of the Keuper, Rhætic, and Jurassic.

The Danish expeditions of 1898 and 1900 reported numerous fossils including many ammonites and others of Jurassic or Cretaceous age. Fossils comprising plant remains of Rhætic or Liassic age, and marine fossils of various divisions of the European Jurassic are cited by Skeat. The principal occurrences of the Jurassic are assigned to the Callovian. A clearly older fauna occurs at Mount Nathorst, which is probably of upper Bajocian or lower Bathonian age.

In Jameson's Land there is evidence of the white Jura or Upper Jurassic, approximately of upper Kimeridge or Portland age. Of the Triassic of this region Nathorst[609b] writes:

It is supposed that Rhætic layers may possibly be present at Falsche Bay, mentioned above, from which locality Payer brought home a piece of sandstone with *Rhynchonella fissicostata* Suess. * * *

One of the most important geological results of the Danish expedition was the announcement that rocks belonging to the Rhætic and Jurassic system occur on the west side of Hurry Inlet from Cape Stewart northward. They are the same rocks that Jameson referred to the Carboniferous.

At Cape Stewart the lowest layers are Rhætic, consisting of a gray, somewhat sandy clay slate that in certain beds is quite rich in fossil plants. It is supposed to be underlain by a greenish sandstone and is thought to be at least 45 to 55 meters thick. The fossil plants are described by N. Hartz, who has called attention to their Rhætic age. Several of these are to be found in the coal-bearing beds of Skone, Sweden. As characteristic may be mentioned *Cladophlebis roesserti* Presl. sp. var. *grœnlandica, Equisetum munsteri* Sternb. sp., *Pterophyllum subæquale* Hartz, *Podozamites lanceolatus* Lindl. sp., and *schenkii* Hr., *Czekanowskia rigida* Hr. and *setacea* Hr., *Stachyotaxus septentrionalis* Agardh sp., besides others.

(See also R–S 27, Chapter XIII, pp. 577–578.)

T 11, 13–16. ARCTIC ARCHIPELAGO.

Low[550i] summarizes the available information regarding the Mesozoic of the Arctic Archipelago:

The discovery of the Sverdrup group of islands has greatly extended our knowledge of the Mesozoic rocks of the Arctic basin. The Franklin search parties discovered rocks of this age on the northern shores of the Parry Islands; at Point Wilkie, in Prince Patrick Island; Rendezvous Hill, near the northwestern extreme of Bathurst Island; and at Exmouth Island and places in the vicinity, near the northwest part of North Devon. The explorations from the *Fram* now show that these are but the southern edge of a wide basin of rocks which form the islands of King Oscar, Ellef, and Amund Ringes, while they constitute the lowlands of Axel Heiberg and the western shores of Ellesmere along both sides of Eureka Sound. There they consist largely of sandstones with shales, schists and limestones.

For a general discussion of the faunal relations of the Arctic Triassic, especially with reference to that of Siberia and its affinities with North American faunas, see papers by Mojsisovics.[603, 604]

U 18–21. GRINNELL LAND AND NORTHERN GREENLAND.

The Cape Rawson beds of Grinnell Land have been classed as "Huronian or Lower Cambrian," and lately as probably Triassic, at least in part. Dawson,[257] commenting on the original description by Feilden and De Rance,[326a] says:

After noting the Laurentian system as the fundamental one for the region [Ellesmere Land, Grinnell Land, and the neighboring coast of north Greenland] and as forming Cape Isabella (latitude 76° 20′) and the entire east coast of Ellesmere Land, they give the name Cape Rawson beds to an important overlying series which occupies the coast of Grinnell Land from Scoresby Bay to Cape Cresswell, in latitude 82° 40′ north. These rocks are described as being thrown into a series of sharp folds, with a general west-southwest strike, the beds being often vertical and frequently cleaved. The rocks consist of jet-black slates, with impure limestones traversed by veins of quartz and chert, and of a vast series of quartzites and grits. They are compared to the gold-bearing series of Nova Scotia, and doubtfully referred to the Huronian system. Their lithologic character, however, as compared with the Canadian rocks, and in view of the occurrence elsewhere to the north of a great Lower Cambrian series, appears to me to favor their inclusion in that series rather than in the Huronian.

Schei[707a] discovered extensive exposures of "quartz sandstones with subordinate schists and limestones" on both shores of Heureka Sound (between Grinnell or Ellesmere Land and Heiberg Land) which he describes as Mesozoic. They contained ammonites and lamellibranchs, among others possibly *Daonella lammelli.*

Chapter XIII.

JURASSIC.

Color, greenish blue (horizontal ruling).
Symbol, 9a.
Distribution: Central America, Mexico, California, Oregon, Alberta, and parts of Alaska.
Content: Jurassic limestone and shale of Nevada; Mariposa slate, Sierra Nevada; Franciscan formation, Coast Range, California; Jurassic of Mexico; Chinitna shale and Tuxedni sandstone ("Enochkin formation"), also Naknek formation, of Alaska Peninsula. The Jurassic of Humboldt Range, Nevada, and the marine Sundance formation of the Rocky Mountains are mapped with the Triassic, as "Triassic and Jurassic" (9), the areas being too small to distinguish the system separately.

Jurassic areas.

D 16. GUATEMALA.

Dollfuss and Mont-Serratt [286] cited the identification of Jurassic fossils reported to have been collected on the shores of Lake Isabel in eastern Guatemala and contained in the collections of the Collegio Tridentino, but Sapper does not mention any such occurrence, and the rocks described by Dollfuss and Mont-Serratt under the Jurassic appear to be Cretaceous.

E 14. OAXACA.

At Tlaxiaco, in Oaxaca, according to Felix and Lenk,[327c] Jurassic strata constitute the greater part of the Cerro Titania. At the base are thin-bedded clay slates

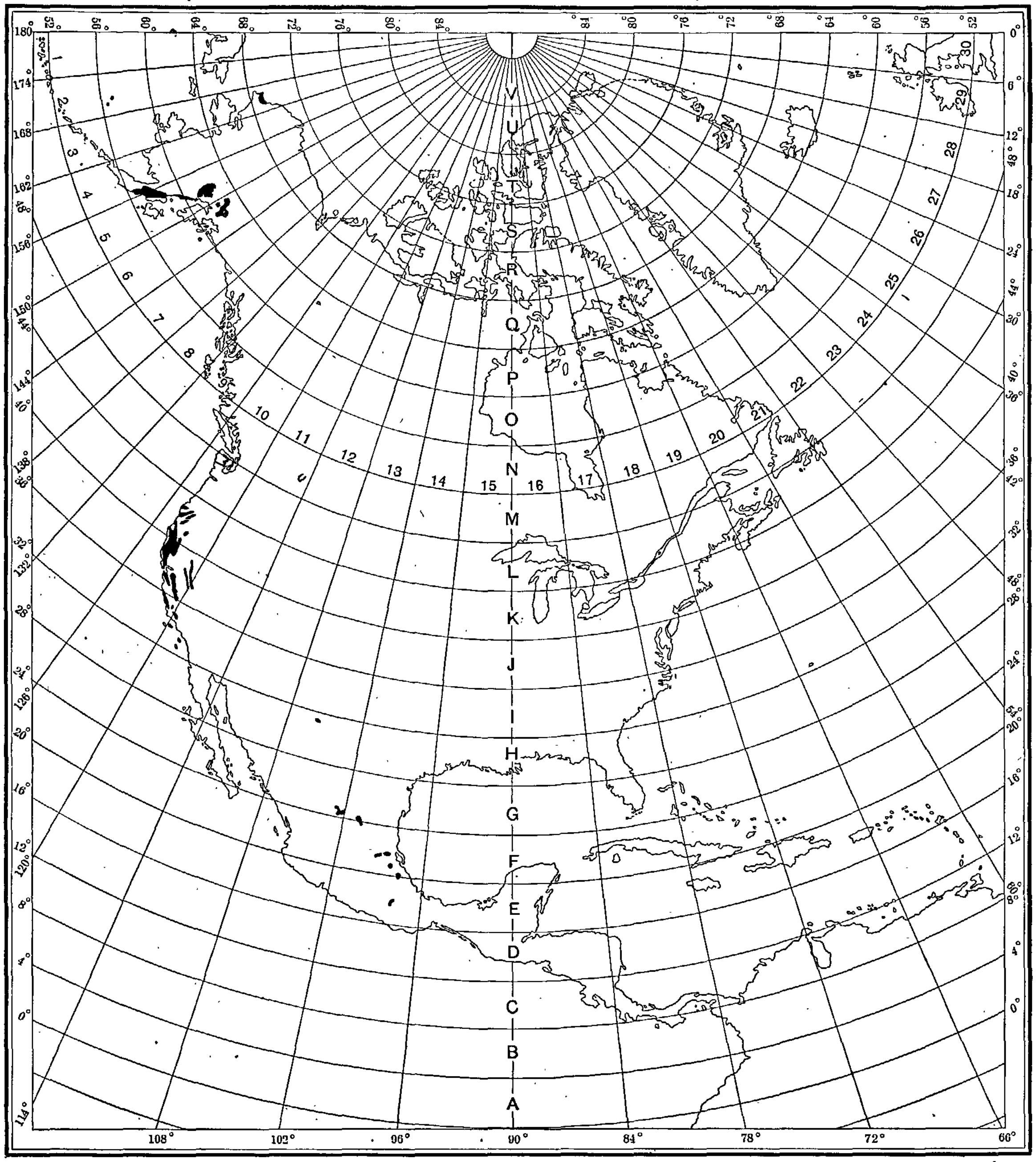

FIGURE 15.—Sketch map showing the distribution of Jurassic rocks that are separately represented on the geologic map of North America and the key to references in the text.

of bright-red and greenish tints which suggest the European Triassic as well as some Jurassic clays. As they are unfossiliferous their age is not determinable. Above them lies a great thickness of calcareous and in part marly deposits, which are without doubt of Jurassic age. They include dense light-gray limestone which appears in general to be unfossiliferous with the exception of the remains of a small Exogyra that could not be more exactly determined. Above this lower sequence outcrop certain marly strata which contain numerous thin lenses of brown iron ore and which like the preceding are very poor in fossils. They have yielded an impression of an Apiocrinus stem and an ammonite, *Stephanoceras paucicostatus*. This species belongs to a group of the ammonites whose youngest representatives do not range above the Oxfordien, and the marls therefore belong either to that horizon of the white Jura of Europe or are to be assigned to the brown Jura of Europe.

The crest of the Cerro Titania is formed by gray marly limestone which is highly fossiliferous. The character of the contained fauna is that of the white Jura and probably represents the European Sequanien.

E-F 14. PUEBLA AND VERA CRUZ.

According to Felix and Lenk [327b] the late Mesozoic is represented in the states of Puebla and Vera Cruz by fossiliferous strata containing fauna related to that of the Lias (Lower Jurassic) of Europe. Most of the specimens found belong to *Arietites jamesdanae* Barcena, and are as a rule but poorly preserved. The rock is a black to yellow clay slate which contains no lime but which on the other hand includes plates of mica and is somewhat metamorphosed, so that it resembles Paleozoic rocks rather than Mesozoic.

Felix and Lenk give a list of nine localities at which fossils have been found. The Lower Jurassic strata are overlain by black calcareous slates interbedded with black limestones that contain Perisphinctes and are assigned to the Upper Jurassic. These in turn are followed by limestones of the Lower Cretaceous. According to a section through Barranca de la Calera and Barranca del Rio Potrero Seco, both in Vera Cruz, by Böse, the strata are conformable from Lower Jurassic to Lower Cretaceous.

F 14. SIERRA DE CATORCE, SAN LUIS POTOSI.

Felix and Lenk [327a] state that the Jurassic is widely distributed in Mexico but does not appear anywhere to form areas of great extent. The occurrences are small in area and widely separated, and they are also notably different in faunas.

In the Sierra de Catorce, in San Luis Potosi, certain unfossiliferous gray slates are succeeded by late Mesozoic strata which have been separated by Castillo and Aguilera [132] into two divisions, and the lower of these has been again divided into two terranes—an upper one, the Cieneguita, and a lower, the Alamitos.

The Alamitos formation consists of fine sandstone and marly or clayey slate interbedded with each other. It contains numerous fossils, a list of which is given in both of the works cited. The Cieneguita formation also consists of marly slates and sandstones which contain more or less carbonate of lime. A number of fossils have been found. The upper of the two major divisions contains in the upper part ash-gray compact limestones which are more or less siliceous. The lower part is shaly and the whole is very poor in fossils. The Alamitos and Cieneguita formations are regarded as representatives of the Russian Volgien (Jurassic) and in a general way the Alamitos corresponds with the lower Volgien or Tithon, but the Kimmeridge may be represented in it. The Cieneguita, which is distinguished by an abundance of Aucella, represents the upper Volgien or Neocomien (Lower Cretaceous).

F 17-18. CUBA.

T. W. Vaughan contributes the following notes on the Jurassic of Cuba:

Strata of Jurassic age have been reported from Cuba and the Isle of Pines since the time of Humboldt. Recently Dr. Carlos de la Torre has collected Jurassic ammonites, referred by him to the genus Idoceras, in the vicinity of Viñales, and has published excellent photographic illustrations.[a] Dr. T. W. Stanton agrees with De la Torre in considering these ammonites of Jurassic age. Jurassic limestone forms the axial portion of the Sierra Organos, in the Province of Pinar del Rio, and is the oldest geologic formation revealed in a cross section of the island taken along a line passing through Viñales, in the vicinity of which are excellent exposures. The limestone is hard and blue, and, though not distinctly crystalline, it is intersected by small white veins of calcite.

Overlying the Jurassic limestone, south of Viñales along the road to Pinar del Rio, are reddish argillaceous schists, which form two parallel ridges. These schists were evidently derived from the metamorphism of a shale series that contained a few beds of sandstone and some layers of limestone.

G 13-14. SIERRA DE MAZAPIL, ZACATECAS AND COAHUILA.

Burckhardt[109] has classified and described the Jurassic and Cretaceous of the Sierra de Mazapil district, in the "Mesa Central" of Mexico, as follows:

Jurassic and Cretaceous series of the Sierra de Mazapil and Santa Rosa.

Formation.			Lithologic character and thickness.	Principal fossils.	Age.
Cretaceous.	Upper Cretaceous.	Shales with Inoceramus.	Shales and limestones; 150-200 meters.	Inoceramus sp.	Turonien.
	Middle Cretaceous.	Cherty limestones. (b) Limestones with gastropods. (a) Limestones with open ammonites.	Gray limestones with black cherts; 400-500 meters.	Scaphites sp., Schloenbachia acutocarinata (Shum.) Marcou, open ammonites (Hamites).	Middle Cretaceous.
	Lower Cretaceous.	Parahoplites beds.	Clear yellow marls and gray limestones; several meters.	Parahoplites cfr. milletianus Pict. (non D'Orb.), Parahoplites cfr. aschiltaensis, Anthula cfr. treffryanus, Anthula (non Karsten), Parahoplites, many undetermined species.	Delimiting beds between the Aptien and the Gault.
		Grayish limestones with large cherts; bluish limestones.	400-500 meters.	Holcodiscus sp.	Lower Cretaceous.
		Holcostephanus beds.	Yellowish marls with nodules of oxide of iron and gray and yellowish limestones; several meters.	Astieria aff. psllostoma N. and U., A. cfr. atherstoni Sharpe, Hoplites aff. michaelis Uhl., H. cfr. hystricoides Uhl., H. cfr. neocomiensis D'Orb., H. cfr. thurmanni P. and C.	Valanginien.

[a] An. Acad. cien. Habana, Rev. cien., vol. 47, July, 1910, pl. facing p. 22.

Jarassic and Cretaceous series of the Sierra de Mazapil and Santa Rosa—Continued.

Formation.			Lithologic character and thickness.	Principal fossils.	Age.
Upper Jurassic.	Portland.	Whitish marly limestones with chert.	10 meters.	Perisphinctes cfr. koeneni Steuer, P. permulticostatus Steuer, Hoplites cfr. calistoides Behr, H. many species of the group of H. calisto D'Orb.	Base of the Berriasen?, Upper Portland.
		Grayish phosphatic limestones. (c) Cucullæa horizon. (b) Fossiliferous limestones with Perisphinctes. (a) Limestones with bivalves.	Fossiliferous and highly cherty limestones, grayish; black limestones; 5–6 meters.	Perisphinctes santarosanus nob., P. victoris nob., burkarti nob., Hoplites cfr. rjasanensis Lah., Hoplites cfr. wallichi Gray, Neumayria subrasilis nob.	Upper and Lower Portland.
		Reddish phosphatic limestones.	1–2 meters.	Phylloceras apenninicum Can., Eurynoticeras zitteli nob., Perisphinctes cfr. danubiensis Schlosser, P. nikitini Mich., Virgatites mexicanus nob., Aspidoceras cyclotum (Opp.) Steuer, A. fallax nob., A. phosphoriticum nob., A. cajense nob., A. zacatecanum nob.	Base of the Portland.
	Kimeridge.	Shales with Waagenia.	Brownish shaly clays, highly ferruginous; 10–30 meters.	Waagenia cfr. harpephora Font, W. aff. beckeri Neum., W. cfr. knopi Neum., W. cfr. harpephora Neum.	Summit of the Kimeridge.
		Haploceras fialar beds.	Black compact limestones; 1 meter.	Oppelia cfr. trachynota Font. (Oppel), O. aff. strombecki Oppel, Haploceras fialar Oppel, H. many species, Craspedites mazapilensis nob.	Upper Kimeridge.
		Aucella horizon.	Brownish shaly limestones, slightly phosphatic.	Aucella, many species of the groups of A. pallasi Keys and A. bronni Rouill.	Upper Kimeridge.
		Idoceras beds.	Shaly clays and marls with lenses and nodules of compact black limestone; 15–30 meters.	Neumayria profulgens nob., Oppelia aff. nereus Font., O. flexuosacostata Qust., Macrocephalites epigonus nob., Simoceras cfr. doublieri D'Orb., Aspidoceras contemporaneum Favre, A. bispinosum Qust., A. cfr. acanthicum Oppel, Idoceras laxevolutum Font, I. balderum Oppel, Aulacostephanus zacatecanus nob., etc.	Delimiting beds between the lower and upper Kimeridge.
		Limestones with Nerinea.	At the summit a stratum of black and reddish limestone with Trigonia. The principal mass is grayish massive limestone with interbedded gray marls containing bivalves and beds of coral; of great thickness.	Nerinea various species, corals with the marine bivalves (Pholadomya, Trigonia, Astarte, Opis), gastropods (Harpagodes), and brachiopods (Terebratula). At the top of the limestone Simoceras cfr. doublieri Loriol (D'Orb.).	Upper Jurassic (probably Sequanien).

Burckhardt's description[110] is as follows:

The Jurassic and Cretaceous series of the Sierra de Mazapil is composed of four great natural subdivisions. At the base one may observe heavy-bedded limestones which attain great thickness and are the limestones with Nerinea. These are the Upper Jurassic limestones which form the center of the anticlines of the two ranges and which, since each chain is composed of a single anticline, occupy generally the highest portions, the peaks and crests of the sierras.

The flanks of the two chains are also formed by heavy masses of limestone of great thickness which locally resemble the limestones with Nerinea, but which, even so, may be readily distinguished by their petrographic character. These limestones are generally well stratified and contain a great deal of chert in beds and lenses which alternate with them. The fossil fauna of these limestones indicates that they correspond to different divisions of the Lower and Middle Cretaceous.

Between the two masses of limestones which have been described there occurs a zone of less compact strata composed of clays, marls, and slates, with intercalations of limestone. * * * The colors of these rocks are generally dark and contrast strikingly with the clear colors of the limestone masses between which they occur. The beds are very fossiliferous and have furnished a large number of well-preserved specimens, which demonstrate that they belong to the Kimeridge and Portland.

The latest stratigraphic division which may be observed in the region, in the valleys and at the foot of the sierras, covers the Cretaceous limestones that have been cited. It consists of shales, in part sandy and in part argillaceous, of which the lower portion, the shales with Inoceramus, belongs to the Upper Cretaceous (Lower Turonian).

H 13. TEXAS.

In southwestern Texas, just north of latitude 31°, near the line of the Southern Pacific Railroad, Malone Mountain rises from the desert plains north of the Quitman Mountains and is formed in large part of Jurassic strata. The fauna was discovered and described by Cragin,[177] and the general geology of the region has been stated by Stanton in a brief chapter in Cragin's report, which contains also a detailed section. Stanton says:

The most complete section that I observed, in which the thicknesses were estimated with some care, extends across the mountain from a point on the east side about one-half mile south of Malone station. The eastern face of the mountain shows an apparent thickness of about 1,200 feet of blue and gray limestones, with a few intercalated beds and bands of conglomerate and sandstone, the beds all dipping strongly westward with increasing dips until they become vertical on the crest. On the west slope there is a succession of limestones, conglomerates, and gypsum beds, nearly vertical, and not well exposed, and farther down these are apparently repeated with a westerly dip, overlain by conglomerates, limestones, etc., fairly well exposed and not much disturbed in the lower ridges to the west. The gypsum beds and the limestones immediately associated with them appear to be the oldest rocks exposed.

I-K 10-11. COAST RANGE, CALIFORNIA.

The Franciscan formation of the Coast Range of California is regarded by Lawson as of Cretaceous age but is generally placed in the Jurassic. The basis for Lawson's view is the relation of the Franciscan formation to the Montara granite, which is one of stratigraphic unconformity. Lawson correlates the granite tentatively with the late Jurassic granite of the Sierra Nevada and infers accordingly that the sedimentary Franciscan formation, which rests unconformably upon the granite, is probably Cretaceous. (See table of the geologic formations of the Coast Range of California in the vicinity of the bay of San Francisco, p. 816, Chapter XVII.)

For a description of the Franciscan, we may refer to Lawson's original account.[524] According to that statement, it consists of the following petrographic elements:[a]

(1) A basal formation of conglomerates, coarse grits, sandstones, shaly sandstones, shales, and argillaceous limestones, exposed in the vicinity of San Pedro Point. These rocks require no detailed discussion.

(2) The San Francisco sandstone, the dominant sedimentary formation of the series, consisting of a moderately fine grained sandstone, fairly uniform in character over large areas, with subordinate beds of shale and conglomerate. The sandstone is uniform, not only in its lateral extension, but vertically for great thicknesses. In the older writings it has commonly been referred to as the San Francisco sandstone, and the term is here adopted from that usage. It is interbedded with the formations 3–5 which are named below.

(3) Foraminiferal limestones.

(4) Radiolarian cherts.

(5) Volcanic rocks, including basaltic lavas, diabases, pyroclastic accumulations, etc. Besides these there are intrusive rocks of a corresponding character, some of which are probably connected with these extravasations, and also intrusive peridotites and pyroxenites, now serpentinized.

In addition, there are certain metamorphic schists, which are the products of the local alteration of the sedimentary or volcanic formations of the series and, according to the writer's interpretation of them, do not constitute a separate formation. There are also a few patches of a peculiar veinlike rock associated with the San Francisco sandstone, but of rather uncertain genetic relations. In his field notes the writer has been in the habit of referring to this as silica-carbonate sinter, and it will be further described under that designation.

J 10. SIERRA NEVADA, CALIFORNIA.

Along the western base of the Sierra Nevada in California the Mariposa slate forms three narrow bands. The strata are prevailingly clay slates, which are sandy and contain pebbles of rocks from the Calaveras formation (Carboniferous). Tuffs from contemporaneous porphyrite eruptions also occur in them. The fossils of these beds, such as Aucella and Perisphinctes, indicate a late Jurassic age.

In the folio describing the Sonora quadrangle Turner and Ransome [815] give a detailed account of the characteristics of the rocks in the three bands in which the formation outcrops, especially as observed at localities within that quadrangle. Lindgren [538] describes a more northern occurrence of the Mariposa in the Colfax quadrangle, where it succeeds the Sailor Canyon formation (Triassic). He states that it consists of black shales or slates, usually not very fissile, alternating with dark-gray sandstones of coarser or finer grain, and a great number of conglomerate beds. The rocks are tuffaceous and contain much iron. The conglomerate beds, though rarely very thick, are very abundant and contain pebbles of chert, quartz, slate, and limestone evidently derived from the older Calaveras formation. The Mariposa was clearly deposited in a gulf or shallow bay, the conglomerates indicating immediate proximity of the shore line.

The fauna contained in the Mariposa formation has been discussed by Hyatt[468a] and by James Perrin Smith.[763]

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[a] For a detailed description of the subdivisions see the work cited.

J 11. HUMBOLDT RANGE, WESTERN NEVADA.

The Jurassic of western Nevada was briefly described by Hague [390] and King.[505b] The latter says:

In the Nevada province the Jurassic consists of a limestone between 1,500 and 2,000 feet thick and overlying slates probably about 4,000 feet thick.

Louderback[547] refers to the Jurassic as composed chiefly of gray to greenish-gray slate with subordinate limestone, which in Muttleberry Canyon carries Arietites sp. nov., referred by Smith[764b] to the Lower Jurassic or Lias of Europe.

J 12. SOUTHERN UTAH AND PLATEAU DISTRICT, COLORADO.

Dutton [300] describes the Jurassic of the High Plateaus of Utah in part as follows:

The Jurassic series consists of two members, the lower being a massive sandstone of great thickness, the upper a series of calcareous and gypsiferous shales from 200 to 400 feet thick. Underneath the sandstone is a small group of shaly beds, which are presumed to be of Jurassic age, but no determinable fossils have been taken from them. * * * Comparing the Jura-Trias section of the Uintas with that of the High Plateaus and Kaibabs, we find a concordance in the several members.

	Uinta section.	Kanab section.
	Feet.	*Feet.*
Calcareous shales, limestone and gypsiferous shales [a]	1,000	500
Massive, cross-bedded white sandstone	1,100	1,400
Thin calcareous shale	100	50
Vermilion Cliff series	1,100	1,500
Upper Shinarump shales and conglomerate	1,000	750
Belted shales	400	400
Lower Shinarump shales	300	500

[a] T. W. Stanton makes the following comment on the manuscript: "The marine Jurassic fauna ranges through the lower 250 feet of the uppermost member of this section."

The lithological characters of the Jurassic white sandstone render it a very conspicuous formation. Through a thickness of more than 1,000 feet, sometimes of nearly 2,000 feet, it is one solid stratum, without a single heterogeneous layer or shaly parting. * * * The color of the rock is almost always gray, verging toward white. Occasionally it is a very pale cream color, and again pale red. The red becomes more common as we recede from the old shore line toward the east. But of all the features of this rock the most striking is the cross-bedding. It is hard to find a single rock face which is not lined off with rich tracery produced by the action of weathering upon cross lamination. The massive cliff fronts are etched from summit to base with a filagree as intricate and delicate as frost work. The same phenomenon is seen in the Vermilion Cliff sandstones below, often so rich and complex that it excites constant admiration. Dr. Newberry speaks of it with enthusiasm as presented in the Triassic sandstones of New Mexico. But it is far less wonderful than the cross-bedding which the Jurassic presents at every exposure. * * * The Jurassic sandstone was deposited over an area which can not fall much short of 35,000 square miles, and the average thickness exceeds 1,000 feet. The imagination is utterly baffled in the endeavor to conceive how a mass so vast and at the same time so homogeneous and intricately cross-bedded throughout its entire extent could have been accumulated.

The cross stratification of the Jurassic sandstones of southern Utah has been discussed by Huntington [466] as an evidence of wind action. Dutton continues:

Overlying the white sandstone is a series of beds which may be called shales with some reservation, and here we find for the first time an abundance of distinctive fossils. They are clearly of Jurassic genera and species and enable us to correlate the horizon with confidence. They belong to a well-marked formation, which is represented not only throughout the greater part of the plateau province, but also in Colorado, Wyoming, and northern New Mexico. From many large areas, indeed, it has been denuded, but throughout Utah it is never wanting from those exposures where its presence could be looked for.

The constancy of lithological character which is so conspicuous in older Mesozoic members does not prevail in this one, for it is highly variable not only in the mass but also in the constitution of the beds. In some exposures it is more than 1,000 feet thick; in others, it is less than 200. Where its volume is greatest it is more arenaceous, and where the volume is less the beds are shaly, marly, and calcareous. Usually several seams of limestone occur, and in these the fossils are found, often abundantly. One notable feature is the small amount of cement in the arenaceous layers, which are, therefore, very poorly consolidated, and the rock weathers and wastes away with extreme facility. Gypsum and selenite occur abundantly in these beds and especially noticeable is the latter mineral, which is seen sparkling and glittering in the sunlight in the badlands to which the decay of the strata gives rise.

A section of the Triassic and overlying Jurassic observed by Walcott in the Kanab region is quoted by Cross in an article on the red beds. (See I–K 12–13, Chapter XII, p. 514.) Stanton [a] comments on Cross's suggestion that the La Plata sandstone of southwestern Colorado may be correlated with the White Cliff sandstone of Utah and says that in that case the La Plata is well down in the Jurassic, because the White Cliff sandstone underlies marine Jurassic beds that are of the same age as the Twin Creek, Ellis, and Sundance formations.

In western Colorado at the east end of the Uinta uplift Gale [353b] has found marine Jurassic fossils in a white sandstone which he correlates with the White Cliff and the La Plata.

In southwestern Colorado the Jurassic is represented by the La Plata sandstone and probably by the McElmo formation, although the age of the latter is not definitely known to be Jurassic; it may be Lower Cretaceous. The La Plata and McElmo are equivalent to the Gunnison formation farther north. Cross [189] gives the following classification and descriptions:

[a] Comment on manuscript.

Correlation of formations.

<table>
<tr><th colspan="3">San Juan folios, U. S. Geological Survey.</th><th>Peale.</th><th>Holmes.</th><th>Powell.</th></tr>
<tr><td rowspan="2">Cretaceous.</td><td colspan="2">Mancos.</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Dakota.</td><td>Dakota or Upper Dakota.</td><td>Upper Dakota.</td><td>Henry's Fork.</td></tr>
<tr><td rowspan="3">Jurassic.</td><td rowspan="3">Gunnison.</td><td rowspan="2">McElmo.</td><td>Lower Dakota.</td><td rowspan="2">Lower Dakota.</td><td rowspan="2">Flaming Gorge.</td></tr>
<tr><td>Jurassic.</td></tr>
<tr><td>La Plata.</td><td rowspan="2">Triassic.</td><td rowspan="2">Triassic.</td><td>White Cliff.</td></tr>
<tr><td>Triassic.</td><td colspan="2">Dolores.</td><td>Vermilion Cliff.</td></tr>
<tr><td rowspan="2">Carboniferous.</td><td>Permian?</td><td>Cutler.</td><td>Permian, Permo-Carboniferous, or Upper Carboniferous.</td><td rowspan="2"></td><td>Shinarump group (all assigned to Triassic).</td></tr>
<tr><td>Pennsylvanian.</td><td>Hermosa.</td><td>Middle Upper Carboniferous.</td><td>Aubrey.</td></tr>
</table>

All geologists who have examined the Mesozoic section of western Colorado have been impressed with the strong lithologic resemblance exhibited by several hundred feet of strata occurring immediately below the Dakota to the fresh-water Jurassic beds found along the eastern base of the Front Range and characterized by the wonderful dinosaurian fauna exploited by Marsh and others. With one exception to be considered below this lithologic similarity and the corresponding stratigraphic position have been considered sufficient to warrant the assignment of the western slope beds to the Jurassic.

The first to give a formation name to those strata was Eldridge, who called them the Gunnison formation. In the San Juan region it was found better to divide the Gunnison into the McElmo and La Plata formations, the former to include the alternating sandstones and variously colored marls and shales of the upper part of the section and the latter the heavy sandstones of the lower portion.

Before the McElmo beds were so named they had been studied in the Telluride quadrangle, at the head of San Miguel and Dolores Valley, and had been traced for some distance down each stream.

They are continuously exposed down the canyon of the former to the Dolores River and have a wide distribution in the Uncompahgre Plateau, about the La Sal Mountains and in the lower Dolores and the Grand River valleys. This is clearly stated by Peale in the report for 1875. * * *

The McElmo beds in characteristic development were seen by us in Dry Valley and on the eastern flanks of the La Sal Mountains, in Dolores Valley, and in many places on Uncompahgre Plateau, as far north as Unaweep Canyon. To the north from that locality Peale refers to the formation as maintaining the same general character. No representative of the marine Jurassic reported by Powell and others from Utah was observed by us.

Rumors of large bones, presumably in the McElmo beds, have come to my attention several times in recent years, but never with the exact locality named, and no trace of such remains has been found in the San Juan region.

The McElmo beds of Dry Valley are fossiliferous, locally at least, as proved by Newberry, who found saurian bones in place at about 500 feet below the Dakota in the southeastern branch of Dry Valley, named by him Cañon Pintado or Painted Canyon. From Newberry's description of the locality and our own observations of the Cañon Pintado from the mesa to the west, as well as on the route traversed through Dry Valley, it is certain that the saurian bones came from the McElmo. Newberry expressed no positive opinion as to the age of the bone-bearing horizon, but called it "Jurassic (?)" in his "General section of the valley of the Colorado."

The saurian bones found by Newberry were described by Cope as the type of *Dystrophæus viæmalæ*, and were said in positive but quite unwarrantable terms to have come from the Triassic, with no suggestion of the provisional assignment to the Jurassic by Newberry. Cope states that Newberry excavated the bones of Dystrophæus "from the red and green rocks usually referred to the Trias, hence from the same formation which yielded the Typothorax already described." The Typothorax in question was found in New Mexico with belodont crocodile and other forms, almost demonstrating that its horizon is the fossiliferous zone of the Dolores Triassic formation, the place of which in the Grand River section is nearly or quite 1,000 feet below the McElmo beds, as will be shown in a later section. Cope adds emphasis to his error as follows: "More than usual interest attaches to this fossil. It is the first one found in the Triassic beds of the Rocky Mountain region. * * * The rock is described by Prof. Newberry as the same as that which I have identified in New Mexico as the Trias and is of the usual red color." In harmony with the occurrence of *Dystrophæus viæmalæ* in the McElmo beds it has recently been pointed out by F. von Huene that its affinities are Jurassic rather than Triassic.

That the McElmo beds contain vertebrate fauna of the "Atlantasaurus beds" of Marsh has been demonstrated by Riggs, who discovered many dinosaurian remains in that formation near the junction of the Grand and Gunnison rivers at the northeastern base of the Uncompahgre Plateau. While this vertebrate fauna has not as yet been described, it is referred to by Riggs as clearly the same which characterizes the Jurassic beds of Wyoming and the eastern base of the Front Range in Colorado. It is said that "representatives of a single genus (Morosaurus) have been observed to range through the entire series," meaning a section some 500 or 600 feet in thickness below the Dakota. * * *

The term La Plata formation has been applied in the San Juan folios and other publications to the lower part of what Eldridge described as the Gunnison formation.

The La Plata consists of two massive sandstone members with an intermediate member of more thinly bedded sandstones and a variable amount of bluish fresh-water limestone. The sandstones are commonly not indurated, as in the Elk Mountains; instead they are rather friable and crumbling, although of homogeneous texture. Cross-bedding is a marked feature, and not infrequently a massive ledge as much as 100 feet in thickness has no prominent division planes. Of the two sandstone members the lower is commonly the thicker and much more massive than the upper. The latter is in fact occasionally thin bedded and shaly and may be inconspicuous.

The calcareous member is very variable in character. On the San Miguel River, in the Telluride quadrangle, it is in some places a pure massive blue-gray limestone in several beds and with almost no shale. Usually dark calcareous and bituminous shales and thin-bedded sandstones, with more or less of massive limestone, occur between the two main sandstones and sometimes reach a thickness of nearly 100 feet.

The total thickness of the La Plata formation varies, in the area we have examined, from about 100 feet in the Ouray and Telluride quadrangles to 500 or more in the La Plata Mountains, and it is known that to the west all members increase still further in thickness.

The sandstones are almost wholly quartzose, and their normal color adjacent to the San Juan Mountains is white or gray; but yellow, orange, or red tints have been observed in that region. The cement is often calcite.

In the Red Beds paper were given the observations of Spencer, who traced the La Plata sandstones to Paradox and Sinbad valleys, west of the Dolores, and of Gane, who followed them down the San Juan Valley to the Colorado Canyon. Both noted the prevalence of orange or pink color in the lower country.

On the strength of these observations and a study of literature it was concluded that "the La Plata formation is seemingly equivalent to the White Cliff sandstone. Its local assumption of red color has led to confusion with the Vermilion Cliff in certain districts and a reference to the Trias." This correlation is considered to be amply substantiated by the recent observations. * * *

The continuity of the La Plata sandstone from the San Juan Mountain flanks down the Dolores and San Miguel valleys, around the La Sal Mountains to Grand River valley, may be said to be perfectly plain and incontestable. In this distance the most notable change in the formation is its increased thickness. The massive texture and even grain of many strata, cross-bedding, variation in color, and other marked features are but emphasized by the greater volume. The intermediate strata are most variable in character, yet everywhere the two great massive sandstone members are separated by beds distinguishable through their thin bedding, darker color, and richness in calcareous cement or development of limestone.

From the district covered by our reconnaissance the ledges of gray, pink, or orange La Plata sandstone can be seen stretching to the west and south into the belt traversed by Green and Colorado rivers, where Powell has described the White Cliff sandstone. This great unit in the plateau country section was never described accurately nor in detail for any given locality, but there seems to be no ground for questioning the assertion of Powell that this formation is continuous with persistent characters from northeastern Utah to the great esplanade bordered by the White Cliffs in southern Utah, facing the Grand Canyon. The characters of the White Cliff repeatedly emphasized are its massiveness, "oblique lamination" or "false stratification," and its white, golden, orange, or light-red colors, which are so brilliant in the desert air.

The upper boundary of the White Cliff is the basal marine limestone of the Flaming Gorge group of Powell. The lower boundary is less clearly defined in the statements of Powell and others, but, with recognition of the stratigraphic break soon to be mentioned and the marked color line apparently everywhere present at the summit of the Triassic sandstones, it may be hoped that no great difficulties in drawing the base of the White Cliff will be experienced when the attempt is seriously made.

The far-reaching unconformity below the fresh-water Jurassic beds of central Colorado, by which they overlap all older Mesozoic and Paleozoic beds and in many places rest on the pre-Cambrian granites and schists, is well illustrated by the Hayden maps. This overlap is particularly well exhibited in the southern Elk Mountains and some of its details are shown in the Anthracite-Crested Butte folio.

The fact that no Paleozoic formations are present in the Uncompahgre Plateau was recognized by Peale and expressed on the Hayden map. If, however, the greater part of Peale's "Triassic" in that area be now referred to the La Plata Jurassic, as has been done in the preceding discussion, the question arises as to whether evidence of erosional unconformity between the La Plata and the underlying Dolores Triassic exists in that area or not. Our observations on this point were quite limited but tend to show that such a break does occur. It is certain that in the vicinity of the Unaweep Canyon the dark-red Triassic strata are much thinner than in the Dolores Valley to the west, and this decreased thickness appears to be principally due to erosion of the massive red sandstone forming the upper part of the Triassic.

On the north side of West Creek, which is the western stream flowing out of Unaweep Canyon, Messrs. Emmons and Kay found the La Plata to rest on granite near the shore line of the Permian (?) beds, which will be discussed in another part of this article. At the head of West Side Creek a few miles south of the Unaweep the pink La Plata sandstone rests on thin-bedded sandstones and shales belonging to the lower part of the Dolores formation, as shown by the presence of the fossiliferous "Saurian conglomerate." Near the head of Atkinson Creek on the western side of Uncompahgre Plateau, the La Plata seems to rest on gneiss. * * *

These facts and the evident variation in thickness of the massive Dolores sandstone, which we noticed at many places, seem to speak for a relation of the La Plata and Dolores very similar to that existing on the western and southwestern slopes of the San Juan Mountains. But much more careful observation is needed in the Uncompahgre Plateau to determine to what extent the absence or variable thickness of the Triassic beds is due to pre-La Plata erosion. Personally, I believe that the Triassic beds were originally deposited over the Uncompahgre Plateau and indeed all of western Colorado, and that they were in some places entirely removed by the erosion under discussion, but this view is not yet supported by enough evidence to warrant a positive assertion.

K 10. UPPER SACRAMENTO VALLEY, NORTHERN CALIFORNIA, AND SOUTHERN OREGON.

In northern California several minor but interesting occurrences of the Jurassic have been described by Diller.[279] The Modin and Potem formations occur in the Redding quadrangle. The Modin consists of a basal conglomerate, followed by a succession of tuffaceous beds, which are overlain by gray shaly sandstones and shales with small limestone lentils. It rests unconformably upon the Triassic, and the tuffaceous beds include fragments of the underlying limestone and other older formations. The Potem formation consists of shale and thin-bedded sandstone with small limestone lentils, and it also includes some tuffaceous conglomerate. The thicknesses are stated by Diller at 3,000 feet for the Modin formation and probably several thousand feet for the Potem.

In the Taylorsville district, just north of the fortieth parallel, the Jurassic is represented by seven distinct formations. According to Diller[280a]—

> The Trail formation is the oldest; then follow the Hardgrave sandstone, Thompson limestone, Mormon sandstone, Bicknell sandstone, Hinchman tuff, and Foreman formation in regular succession. With the exception of the last their surface distribution is limited to a comparatively small area about Mount Jura, and * * * it may be stated here that the whole set of beds have been overturned and that the Hardgrave sandstone apparently lies on top. * * *
>
> The Trail formation includes a mass of strata composed largely of slaty shales with some interbedded sandstones and conglomerates. * * * The shales are often purplish or red but perhaps more frequently gray, with pencil structure locally developed, and contain in places numerous cherty nodules of carbonate of lime. Well-marked slaty structure is not uncommon. The sandstones are generally fine, often somewhat slaty, are thin-bedded, and vary from gray to almost black. The conglomerates of slate and sandstone pebbles, sometimes 3 inches in diameter, generally contain much volcanic material. Approaching the contact with the granodiorite in many places the fine sediments become darker and more compact, with conchoidal fracture, and pass into regular hornfels. * * * Some of the beds of tuff are well defined, ranging from 10 to 50 feet or more in thickness, and occasionally coarse. Tuffaceous conglomerates are most abundant on the side toward the Swearinger slate but extend throughout the formation, and a strip of 50 feet of slaty conglomerate occurs in the volcanics which bound the sediments on the northeast. * * * The thickness of the Trail formation was measured on the prominent spur next north of Hornfels Point descending into the sharp bend of Hosselkus Creek and found to be about 2,900 feet.

Undeterminable traces of plants and some small bivalves, possibly Estheria, but not any fossils which would determine its horizon, have been found in the Trail formation. It appears to be unconformable to the Swearinger slate, and thus to occupy essentially the same relative position as the Modin formation, at the base of the Jurassic sediments.

The Hardgrave sandstone is red or gray in color. It varies from fine shaly sandstone to conglomerate and is almost wholly of a tuffaceous character. The most common color is red, ranging from brick-red to dull brown, but much of it is gray, and the two colors are intermingled irregularly in the same bed. The bedding is generally well marked, but in a few localities the massive outcrops show little trace of stratification. Where the sediments are fine the sandstone passes into shale, which occasionally shows a decided slaty cleavage and breaks up into long, slender, pencil-shaped fragments. Generally the sandstone is so fine as not to appear granular and breaks with a splintery fracture. * * * When the coarser forms of Hardgrave sandstone are broken the fracture generally passes around the grains instead of through them, allowing them to stand in relief upon the fracture surface and make it rough. Rarely it is hard and flinty, much fractured, and veined. * * * Carbonate of lime is the principal cement, but in the red and weathered forms oxide of iron plays an important part. * * * Coarse gray sandstone and fine conglomerate are much less abundant than the finer forms. * * * [The material] is mainly volcanic sand, made up of crystal fragments of plagioclase feldspar with many lapilli, usually more or less vesicular, and often filled with minute lath-shaped crystals of feldspar, which are for the most part so altered that their polysynthetic twinning, if present, can not be seen. Many of the feldspar fragments are plagioclase, but a somewhat smaller number appear to be orthoclase and possibly some quartz. One of the striking features of this sandstone, apparent only on microscopic examination, is the paucity of quartz. * * * The maximum thickness of Hardgrave sandstone as measured half a mile north of Donnerwirth's may be 850 feet but is possibly much less.

According to Hyatt [280b] the Hardgrave sandstone contains many fossils having affinities with the lowest or infra Lias, and some which might even have occurred in the uppermost Triassic or Rhætic. Hyatt further says:

On the other hand, some forms have very close relations to the same genera as they appear in the Mormon sandstone, or Oolite, of the same locality. Pinna, Gervillia, Ctenostreon, Entolium, Trigonia, and Cidaris show an assemblage of upper Lias types. The species of Entolium and Ctenostreon are closely related to those of the oolite above, and one species of Trigonia resembles the young of a species from the Oolite of western Europe. The most conclusive evidence, however, is furnished by the single well-preserved specimen of Glyphea * * * and the Goniomya, allied to *G. v-scripta* Agassiz.

After giving a list of 28 species and discussing the significance of Glyphæa, Hyatt says:

Such forms as these and the evidently close alliance and probable continuity of the fauna through migration with that of the Mormon sandstone suggest that the Hardgrave sandstone should be classed as upper Lias in spite of the large number of forms which are represented by species occurring also in the lower and middle Lias in Europe.

Diller continues the description of the Jurassic strata as follows:

The Thompson limestone is gray and somewhat shaly, and on its weathered surface in places are round, oblong, or irregular patches of darker, more or less granular calcite, which at once suggests fossils, though their specific determination is a matter of difficulty. Where shaly it is generally red, highly argillaceous, and locally full of long, slender gastropods, which weather out and leave the porous argillaceous skeleton of the limestone full of "screw holes." * * * The relation of the Thompson limestone to the meta-andesite that bounds it upon the west may be clearly seen on the northern slope of Mount Jura, near the end of the lime road, where the red calcareous beds, full of slender gastropods, come into direct contact with the altered andesite. The fossils lie parallel to the surface of the volcanic rock, practically against it, without showing any alteration due to the presence of the igneous rock. This relation evidently indicates that the limestone was deposited upon the meta-andesite and is of later age. It has already been shown that the same meta-andesite is younger than the Hardgrave sandstone. The general dip of the Thompson limestone is to the southwest beneath the meta-andesite by which it is bounded in that direction, and both pass beneath the Hardgrave sandstone. All have been overturned together.

Hyatt's comment on the age of the Thompson limestone, which he called the Opis bed, is as follows:

Mr. Diller's close and repeated investigations of the stratigraphy have placed the Opis bed below the Mormon sandstone in the chronologic series, and my studies, although they led me to incline to the opinion that the fauna was younger, have not succeeded in bringing to light any evidence that can be said to contradict his conclusions. The presence of a large form of Nerinea with the columella, showing the typical ridges of the normal forms of this group, indicates that this limestone is not older than the inferior Oolite, and if, as seems to be the case, it is older than the Mormon sandstone, it will probably be proved to be a member of the inferior Oolite.

A large species of Opis is as abundant in some places as the Nerinea, and this genus, which is recorded in Europe as beginning in the Trias, is usually small throughout the lower and middle Jura. The only European species approximating to that of this limestone is the *Opis paradoxa*, as figured by Buvignier, which occurs in the Corallian of the upper Jura. A species of Terebratula, apparently identical with the large characteristic species of the Mormon sandstone, also occurs abundantly in this bed. There are also a number of small gastropods and other fossils requiring further investigation.

The Mormon sandstone consists prevailingly of sandstone, passing on the one hand into conglomerate and on the other into more shaly beds. The most common and characteristic member is a gray compact sandstone so fine that to the naked eye it does not appear granular. Its color becomes brown on weathering and the rock frequently contains casts of a small Rhynchonella. Among the grains of which it is composed there are many of quartz and of feldspar, some of which is clear plagioclase with distinct twinning lamellæ. A few of pale-green augite, but most of them are of indefinite clouded material in which here and there small lath-shaped crystals of feldspar may be seen, indicating their derivation from igneous rocks. There is a small amount of carbonate of lime present, and it becomes somewhat more abundant in the coarser forms. The conglomerate of the Mormon sandstone is generally greenish but sometimes reddish. Its pebbles are in a few places mainly quartzite, but at most localities they are chiefly of meta-andesite with a few of metarhyolite, and range from one-eighth of an inch to 18 inches in diameter. Several pebbles of limestone were observed, but none contained fossils. In the conglomerate are masses of fine shaly red sandstone with decided pencil structure parallel to its stratification. This same sort of material occurs also to a limited extent entirely independent of the conglomerate, and in such cases it is thin bedded and finely stratified. * * * At a narrow point in the wavy belt across the western slope of Mount Jura the following section was observed: Adjoining the eastern side of the Thompson limestone is 45 feet of massive gray sandstone with a rich fauna. This is succeeded farther up the slope by 30 feet of conglomerate and finally by about 20 feet of finely stratified red shaly sandstone, the "Inoceramus bed" mentioned by Prof. Hyatt. The total thickness of this belt a short distance farther south increases to about 225 feet, and the conglomerate becomes more prominent but farther along again diminishes and is scarcely noticeable near the south end.

The maximum thickness of the Mormon sandstone noted by Diller is 550 feet. Diller quotes Hyatt at length in regard to the fossils and age of the Mormon sandstone, and Hyatt concludes that the horizon is that of the upper part of the inferior Oolite of Europe.

The Bicknell sandstone is composed chiefly of red and gray sandstone associated with some dark shales and tuffaceous beds. The dark brownish-red sandstone is largely feldspathic and contains much red oxide of iron, with more or less carbonate of lime. It somewhat resembles the red Hardgrave sandstone but is darker colored, and though much of its material may be derived from igneous rock, its particles are not characterized by the presence of numerous small crystals of feldspar as in the Hardgrave sandstone. Sandstones, mottled gray and red, form transitions to the gray sandstone which is the most abundant rock of the formation. Much of it is fine dark bluish gray, very compact and hard, breaking with a conchoidal fracture, and flecked here and there by small particles of pyrite. It looks so much like hornfels that one is surprised to find it locally full of large shells. Associated with this form is more or less black shale, some beds of which weather white and look like fine volcanic dust. A thin section, however, shows no characteristic volcanic material, but instead extremely fine sediment with a multitude of minute microscopic crystals of rutile which have developed in the sediment since it was laid down.

A coarser variety of the sandstone is light gray or greenish and passes into a rock which is full of small white crystals of feldspar with a few scales of gray mica embedded in a dark groundmass, and the general aspect is decidedly igneous. The fact that it contains distinct fossils shows that it is fragmental, and it locally becomes coarse, so that its real character is more evident. In thin section under a microscope the fine fossiliferous rock is clearly fragmental, and much of the sediment was evidently derived from the erosion of volcanic rocks.

The maximum thickness of the Bicknell sandstone is probably over 1,000 feet, but its thickness decreases both north and south of Mount Jura, so as to average less than 500 feet. Hyatt finds some elements of its fauna comparable with the youngest faunas of the Jurassic in Europe but concludes from the evidence of the ammonites that it may be really synchronous with the Callovian.

The Hinchman sandstone is composed essentially of coarse sandstone with shaly parts and some conglomerate which is generally fine and derived chiefly if not wholly from andesitic rocks. Much of it is decidedly tuffaceous. The most common form is greenish gray and contains darker-colored shaly patches but is not conspicuously fragmental. Examined microscopically it is found to be made up largely of fragments of feldspar, augite crystals, and varying proportions of andesitic rock, fragments of which are clearly microporphyritic. The feldspar is generally much altered. Some of the augite is fresh, but most of it is altered to chlorite, giving a greenish color to the rock. It is never coarse like volcanic agglomerate, though it is sometimes made up largely of ejected volcanic material, some of which is clearly pumiceous. The grains are rarely well rounded by attrition, though it is evident that they have been transported and loosely aggregated on the sea floor, affording corners and cavities where corals, belemnites, and a number of other marine forms flourished. Remains of these animals are not confined to one horizon but are scattered throughout the formation. The conglomerate locally becomes coarse and composed of pebbles, some of which are well rounded; others are angular. The largest pebbles are rarely a foot in diameter. One of the most abundant types is a reddish, decidedly microporphyritic andesite. Others less common are dark and macroporphyritic, with either feldspar or hornblende phenocrysts. Limestone pebbles or nodules occur sporadically, but none could be found with fossils.

In thickness the Hinchman sandstone appears to range from 50 feet to more than 500 feet. The most characteristic fossils are corals of the genus Stylina, related to species of the Corallian of the Upper Jurassic of Europe.

The Foreman formation is a succession of shale, sandstone, and conglomerate in which the sediment is for the most part derived from rocks which are not clearly volcanic. The shales are often slaty and locally have "pencil structure" and range in color from dark carbonaceous with traces of leaves through gray, which predominates, to shades and tints of red and yellow. A remarkable feature of the shales locally is their pencil structure, which is particularly well developed in the summit of Evans Peak. The beds of red and gray sandy shales making the summit of the peak break up into small columns, often of lead-pencil size but generally smaller. * * *

Almost as abundant as the shales are the sandstones, most of which are very fine and decidedly shaly. They are reddish brown and gray, sometimes mottled with darker spots, chiefly carbonate of lime. * * * Occasionally the gray sandstone is more siliceous and contains irregular particles which give to the mass the appearance of a fine tuffaceous conglomerate.

Conglomerate is less abundant than either shale or sandstone and is usually in thin beds of small extent scattered throughout the formation. The most characteristic conglomerate of this formation is composed almost wholly of small pebbles of cherty quartz, black and gray in color, and rarely over half an inch in diameter. Of this there are but few beds ranging from 5 to 12 feet in thickness. A more abundant form of conglomerate contains locally many shale fragments and well-rounded pebbles chiefly of meta-andesites and rhyolites, with a few of fossiliferous limestone. The majority of the beds are small and are made up of small pebbles, rarely as large as 3½ inches in diameter. Associated with the limestone pebbles in the conglomerate are concretionary nodules of carbonate of lime, which occur also in the shale and sandstone. They do not contain fossils and grade into the inclosing rock instead of having a sharp contact, as is the case with the limestone pebbles.

The Foreman formation contains fossil plants, which were studied by Fontaine, who placed them in the Mesozoic and considered them as most probably older than Cretaceous. An examination of later collections by Knowlton led him to question some of Fontaine's determinations, and marine invertebrates in the formation suffice to prove that it is Middle Jurassic or later. Stanton is of the opinion that it may represent the youngest Jurassic of the region, and this view is confirmed by Diller's study of the stratigraphy.

The Myrtle formation of southwestern Oregon and the Knoxville of northern California are regarded by Diller, Stanton, and Knowlton as of the same age, but it is a mooted question whether they are wholly Cretaceous or in part Jurassic. According to Stanton, the Aucellas (*Aucella piochi* and *A. crassicolis*) show that the formations are not older than Lower Cretaceous. According to Knowlton, the plants which are associated with the Aucellas at some localities are characteristically Jurassic.[a] The Myrtle and Knoxville are indicated on the map as Lower Cretaceous, largely to distinguish them from the adjacent Franciscan areas, which are colored as Jurassic, and without any intention of indicating a decision as to their Cretaceous or Jurassic age.

K 12. SOUTHWESTERN WYOMING.

In the survey of Uinta County, in southwestern Wyoming, Veatch[839c] distinguished the Twin Creek formation and the lower part of the Beckwith formation as Jurassic. The Lower Cretaceous appears to be missing or to be represented in the upper part of the Beckwith, as the Bear River formation (Upper Cretaceous?) immediately succeeds the Beckwith, apparently without unconformity. Veatch gives a general description, which is quoted in the table on page 676, Chapter XV. From his report we take the following notes:

The fossiliferous marine Jurassic, to which has been given the local name Twin Creek formation, from the excellent exposures on that creek between Sage and Fossil, here consists for the most part of dark calcareous shales and thin-bedded shaly limestones, though occasionally showing lighter-colored sandstone layers. These are sharply limited above by the thick red beds which mark the base of the Beckwith formation. The thickness of the Twin

[a] See quotations under K 10 in Chapter XIV, pp. 617-621.

Creek beds north of Twin Creek on two carefully measured sections was found to be 3,500 and 3,800 feet. * * *

The Beckwith formation, which directly overlies the Twin Creek, has been so named from its occurrence and extensive development on leased State lands now forming part of the Beckwith ranch, situated just east of Beckwith station on the Oregon Short Line. It is here and throughout the west side of this area composed of two rather distinct members, a lower red-bed member, composed of interbedded sandy clays, sandstones, and conglomerates 2,500 feet thick; and an upper member, composed of rather light colored interbedded sandstones and clays. The sandstones are commonly rather light yellow and the clays vary from yellow to light pinkish red. * * * The upper member has a thickness of 3,000 feet or more.

In the eastern belt of older rocks these two phases merge; in the area along the west side of the great fault just west of Hilliard these beds, while having a predominant reddish cast, are all light in color. The conglomerates, which near Beckwith are deep red, are here white to yellow. These reddish beds are exposed along the whole of the eastern side of the eastern belt just east of the Cretaceous exposures, and for the most part form the crest of the pronounced anticline which skirts this region on the east. These beds here reach a total thickness of 4,000 feet. * * *

This formation is lithologically distinct from the very fossiliferous, dark-colored beds which overlie and underlie it, and compared with them is essentially unfossiliferous. Dr. Stanton has found marine Jurassic fossils at two points in beds which are regarded as in the lower part of the Beckwith formation. At old Bear River City, just west of the great fault line and east of the principal conglomerate bed at this point, Dr. Stanton found *Belemnites densus* M. and H., *Trigonia quadrangularis* H. and W., *Myacites* (*Pleuromya*) *weberensis* Meek (?). In the exposures north of this point this horizon appears to be distinctly underlain by the characteristic unfossiliferous Beckwith beds, and unless it represents a portion of the Twin Creek which has been faulted up—and this is not regarded as probable—it is distinctly in the Beckwith formation. This fossil-bearing layer is here about 1,600 feet below the Bear River formation and 2,400 feet below the Aspen shales. South of Rockport, on Weber River in Utah, Dr. Stanton found a specimen of *Trigonia quadrangularis* H. and W. (?) about 2,000 feet above the characteristic fossiliferous blue thin-bedded limestone and shale of the Twin Creek formation and 3,500 feet or more below the lowest observed black shales with fish scales, representing the Aspen formation, which here, in the absence of the Bear River, is the base of the known Cretaceous.

The lower part of the Beckwith formation is thus clearly upper Jurassic, and the remainder probably contains time equivalents of the lower Cretaceous and Dakota beds, if these occur in this area.

Veatch gives a list of fossils from the Twin Creek formation.

K 12-13. NORTHWESTERN COLORADO.

In describing the Rangely oil district, Colorado, Gale[353a] gives an account of the Jurassic strata which constitute the White Cliff and Flaming Gorge formations of Powell. He says:

Immediately below the Dakota sandstone is a mass of variegated badland-forming shale and clay, including some harder beds of limestone and sandstone, together with a peculiar dark cherty, siliceous conglomerate almost exactly like that commonly found with the Dakota formation above. The shale or marl is prevailingly of greenish and pinkish shades, with some beds that weather yellow. The lower 100 to 150 feet of this formation is composed of darker-colored beds, fine greenish sandstone and calcareous rock. Limestone layers composed largely of shells are present near the base, although the general character of the beds seems to indicate much limy or marly material throughout. These beds have an approximate thickness of 800 feet, as measured near the base of Blue Mountain. * * * The lower strata of these variegated beds are of marine origin, as shown by the fossils they contain; the upper part, by analogy with other and better-known sections, is supposed to be composed largely of fresh-water deposits.

The variegated and shaly beds are limited at the base by a second group of sandstones which, like the Dakota, usually forms a steep rocky ridge. * * * It is usually very white and massive and cross-bedded to an extreme degree.

The variegated beds are of Jurassic age and probably correspond in their upper or supposedly fresh-water part to the Morrison formation east of the Rocky Mountains. They have also been variously named "Flaming Gorge," McElmo, and in part Gunnison in the Uinta Mountain and western Rocky Mountain regions. * * * The cross-bedded white sandstone is also of Jurassic age, as is shown by fossils obtained from this field. It is with little doubt the equivalent to the "White Cliff" sandstone mapped by Powell on the north side of the Uinta Mountains, and also seems to be with almost equal certainty equivalent to the La Plata sandstone of the southwestern Colorado sections.

Gale gives a list of fossils which are regarded as characteristically Jurassic.

K–L 13. WYOMING AND SOUTH DAKOTA.

The Jurassic is represented in the Bighorn Mountains and throughout central Wyoming by the Sundance formation and possibly by the Morrison formation, although the latter may prove to be of Cretaceous age. (See Chapter XIV, pp. 606–608.) Darton[237e] states:

Typical marine Jurassic deposits, with an abundant fauna, extend continuously around the Bighorn uplift, and they are so similar to the deposits in the Black Hills that the same name is applicable. The thickness averages about 300 feet and the succession comprises a sandy series below and a considerable thickness of greenish fossiliferous shales above. At or near the base there is usually a hard fossiliferous limestone layer having a thickness of from 3 to 5 feet, increasing locally to 25 feet. Next above are soft sandy beds often containing large numbers of *Gryphæa calceola* var. *nebrascensis*. The greenish shales above contain thin layers of highly fossiliferous limestones and a few thin sandy layers.

In another paper[244d] Darton describes the Sundance formation as follows:

The Sundance formation occupies a large area in central Wyoming, but it is absent in the Laramie Basin south of Rock River. In Wind River Basin it is mostly covered by Tertiary, but it outcrops extensively near Fort Washakie, Lander, and Dallas. It appears along both flanks of Owl Creek Mountains, on the north slope of Rattlesnake Mountains, in southeastern Natrona County, in northeastern Carbon County, in the flexures south of Douglas and east and northeast of Medicine Bow, and along the east side of Laramie Mountains from Iron Mountain station to Crow Creek. Although there is a long time interval between the Sundance and Chugwater formations, marked erosional unconformity is rare and in places it is difficult to draw the line between them. This is probably because the first sediments of the upper formation were derived from the one below. The upper limits are similarly ill defined. There is no discordance in dips of underlying or overlying formations.

In the Owl Creek Mountain region the Sundance formation consists of about 200 feet of soft gray sandstones and green shales with conspicuous hard layers. * * * The local stratigraphy varies somewhat. At the base are sandstones, the middle and upper beds are mainly shales, and there is more or less sandstone for about 40 feet at the top. The shales are greenish or dark gray and contain limestone in concretions and thin layers, often highly fossiliferous.

Section of Sundance formation on Owl Creek 7 miles northwest of Thermopolis, Wyo.

	Feet.
Green soft sandy shales and hard greenish fossiliferous sandstone in alternating layers	70
Gray sandstone	4
Green sandy clay	20
Gray limy sandstone	2
Dark greenish-gray sandy clay, with many belemnites	40
Greenish-gray sandstone, with occasional hard layers	30
Green sandy shale	20
Greenish-gray sandstone, thin bedded	4
Hard buff impure limestone, breaking into small rectangular blocks	2
Green sandy shale lying on "Red beds"	2
	194

Along the slope of Wind River Mountains and in the uplifts passing east of Fort Washakie and Lander the Sundance formation is about 300 feet thick and consists of greenish-gray shales and sandstones, with thin but prominent ledges of impure, highly fossiliferous limestone in their upper part. In the northern foothills of the Rattlesnake Mountains, where the thickness is about 300 feet, there are gray sandstones at the top, and part of the medial sandy shales are of pronounced reddish tint, as in the Black Hills and some other districts in Wyoming.

Platte Valley to Rock River.—The Sundance formation presents most of its usual features along the south side of Casper Mountain, in Muddy Creek valley, and on Wagonhound Creek and North Platte River south of Douglas. In the extensive exposures in the big bend of the river south of Douglas there are 30 feet or more of massive gray sandstone, overlain by 30 feet of pale-greenish sandy shale, 5 feet of soft greenish massive sandstone, 40 feet of soft sandstones of bright-reddish tint, 15 feet of massive buff sandstone, and about 200 feet of green shale with three hard beds of fossiliferous limestone. * * *

Section of Sundance formation near Alcova, Wyo.

	Feet.
Green shale	65
Slabby, hard limestone	10
Green shale	10
Limestone	10
Green shale	75
Sandstone	5
Shale, part pink, part green	100
Sandstone, white (on Chugwater red beds)	25
	300

In the Freezeout Hills and Rock River region the lower beds of the formation are predominantly sandy, while the upper part consists largely of green shales with hard fossiliferous layers. In an extensive exposure east of Medicine Bow the strata are as follows:

Section of Sundance formation in Como Ridge, 6 miles east of Medicine Bow, Wyo.

	Feet.
Morrison shales.	
Limestone and shale	15
Massive disintegrated sandstone, in part shaly	10
Drab shale with few lumps of brown limestone	30
Buff shaly sandstone	5
Yellow sandy shale with belemnites	42
Buff shaly sandstone	5
Yellow shale (lying on the Chugwater red beds)	12
	119

A section in the eastern side of the Freezeout Hills near Dyer's ranch, given by W. N. Logan, is as follows:

Section of Sundance formation in Freezeout Hills, Wyo.

		Feet.
15.	Purplish clay with sandy inclusions (has sandy limestone layer near base filled with fossils)	40
14.	Greenish sandstone, thinly laminated	2–5
13.	Purplish fossiliferous clay, with many lime nodules filled with fossils	20
12.	White, sandy clay, dinosaur [marine saurian] remains	4
11.	Sandy clay with brown concretions; green sandstone layer near middle	6
10.	White sandy limestone in thin layers (fossils)	½
9.	Sandy red clay	10
8.	White fissile sandstone	6
7.	Shale, reddish, changing to purple	4
6.	White sandstone, moderately hard	½
2–5.	White sandstone separated by two layers of red clay	1
1.	Red clay of Chugwater formation.	
		94+

East of Laramie Mountains.—The thin margin of the Sundance formation outcrops continuously along the eastern foothills from North Fork of Horse Creek to the southernmost prong of Horse Creek and from the North to the South Fork of Lodgepole Creek. Small exposures appear on North and Middle forks of Crow Creek. The rocks are mostly light-buff sandstones, but some sandy shales appear. The average thickness is 40 feet. * * *

Fossils and equivalency.—The formation contains abundant fossils of Middle to Upper Jurassic age, and it is believed to be equivalent to the Sundance formation of the Black Hills region. The following are the principal fossils: *Belemnites densus*, *Gryphæa calceola* var. *nebrascensis*, *Campectonites* [*Camptonectes?*] *bellistriatus*, *Eumicrotis curta*, *Trigonia elegantissima*, *T. americana*, *T. conradi*, *T. montanensis*, and *Pentacrinus asteriscus*.

In Freezeout Hills the following fossils are reported by W. N. Logan in section given [above]: Bed No. 10, *Pseudomonotis curta;* bed No. 12, remains of Ichthyosaurus and Plesiosaurus; bed No. 13, abundant *Belemnites densus* throughout, and in the concretions *Pinna kingi*, Pinna sp. *Cardioceras cordiforme*, *Avicula beedei*, *Astarte packardi*, *Pentacrinus astericus*, *Tancredia bulbosa*, *T. magna*, *Lima lata*, *Goniomya montanaensis*, *Avicula macronatus*, *Pleuromya subcompressa*, *Cardinia wyomingensis*, *Pseudomonotis curta*, *Belemnites densus*, and *B. curtus*, and also remains of plesiosaurs and ichthyosaurs; bed No. 14, *Camptonectes bellistriatus*, *C. extenuatus*, *Ostrea densa*, and *O. strigilecula;* in a sandy limestone bed in base of bed No. 15, *Pentacrinus astericus*, *Asterias dubium*, *Pseudomonotis curta*, *Avicula macronatus*, and *Ostrea strigilecula.*[a]

The Jurassic of the Black Hills is represented by the Sundance formation and probably by the Unkpapa sandstone (local) and the Morrison formation, although the latter two may prove to be of Cretaceous age. (See Chapter XIV, pp. 606–608.) Darton[237d] says:

This name [Sundance formation] has been given to the marine Jurassic sediments of the Black Hills region, from the town in the northern portion of the uplift. The rocks are shales and sandstones in a series, some members of which vary locally. Over a wide area the succession consists of a lower member of dark-gray shales, averaging 50 feet thick; a prominent ledge of fine-grained sandstones of pale-buff tint; an intermediate member of sandy shales and sandstones of reddish color, and at the top about 150 feet of dark-green shale, including thin layers of very fossiliferous limestone. * * * Fossils occur also in the sandstone and all are of later Jurassic age. At the base of the formation there is often a massive red or buff sandstone occurring in extended lenses, and frequently attaining a thickness of 25 feet, lying unconformably. * * *

This formation extends along the slope of the Laramie Range, presenting its usual characteristics to the northward but thinning rapidly to the southward. In extensive exposures at the east end of Casper Mountain it has a thickness of about 350 feet. At the base overlying the

[a] The spellings of fossil names in this list have been made to agree with those given by Logan in the article cited by Darton (Kansas Univ. Quarterly, vol. 9, 1900, pp. 112–113).—B. W.

limestone, which is supposed to represent the top of the Chugwater red beds, there are 20 feet or more of white to red sandstones, then a few feet of buff sandstones and shales with an 8-foot bed of gypsum, and finally an upper series of dark shales with limestone layers and concretions filled with characteristic fossils, including many *Belemnites densus.*

Along the North Platte River, in its big bend south of Douglas and to the west on Wagonhound Creek, the succession is as follows, from the bottom up: 30 feet or more of massive gray sandstone; 30 feet of pale-greenish sandy shales; 5 feet of soft greenish massive sandstone; 40 feet of bright-reddish sandy beds; 15 feet of massive buff sandstone; and at the top about 200 feet of green shales with a few thin beds of sandstone and limestone containing many upper Jurassic fossils.

The formation appears again on Chugwater and Horse creeks, consisting of an upper series of 30 feet of soft slabby sandstones, gray at the base and buff toward the top, with ripple-marked layers and much intercalated shale, and a lower series 50 feet thick, mostly of green and gray shale, with layers of soft thin-bedded greenish-gray sandstones lying on the Chugwater formation. * * *

This formation appears on the banks of North Platte River northwest of Guernsey and for some distance northward. The lower 145 feet are sandstones with a few thin beds of shales, over which there are 60 feet of interbedded slabby sandstones and clays, all containing characteristic marine Jurassic fossils. * * *

The Sundance formation extends only a few miles into Colorado from the northward, finally ending by thinning out. Dr. Hayden found fossils, "*Ostrea* and fragments of *Pentacrinus asteriscus,*" on Box Elder Creek, in yellow sandstones and clays, with scattered layers or nodules of limestone. He suggested that the limestone sometimes found at the base of the Morrison formation may be a representative of the marine Jurassic, a suggestion based on its similarity in character and relations to a limestone on the Laramie plains, which contains Apiocrinites. As similar limestones exist in typical Morrison beds to the northward, where the marine Jurassic is represented, I feel certain that all those in the Front Range are of Morrison age. * * *

The Jurassic appears to exist only in the northwestern portion of the region to which this report relates, apparently owing to nondeposition in other portions of the region. In the Bighorn Mountains and Black Hills it is represented by from 300 to 400 feet of deposits, but these thin gradually to the southward in the Laramie Range and disappear in the northern portion of Colorado. The thinning appears to be general at the outset and the upper beds probably disappear first, but this point has not been definitely determined, and it may be that the upper beds merge into sandy beds and these thin out gradually together with the underlying sandstones.

The formation is evidently of marine origin, as indicated by its numerous molluscan remains, and its age is regarded as late Jurassic. It has not been divided into subordinate members, but in its regular succession it presents a succession of beds and faunas which are constant over a wide area, especially the sandstone near the base and the green shales above containing numerous *Belemnites densus.* It is probable that the Sundance formation does not extend far east of the Black Hills, nor to the southeastward of the locality at which it disappears in surface outcrops in northern Colorado, but there is no direct evidence on this question.

The Unkpapa sandstone, which succeeds the Sundance formation along the eastern side of the Black Hills, is a relatively local feature of unknown age. It appears to represent a local shore deposit in late Jurassic times, prior to the deposition of the Morrison beds. The horizon may possibly be represented in other regions by the almost general occurrence of a yellowish sandy bed at the top of the Sundance formation. If not, it is probable that in the area in which it is absent there is a small unconformity or hiatus at this horizon. There is a very abrupt change from the Sundance to Morrison sediments, but no direct evidence of unconformity has ever been found.

The latest notes on the Jurassic fauna of the Black Hills are given by Whitfield and Hovey.[928] Summary statements concerning the correlation of the faunas are given by Stanton.[782]

L 11. EASTERN OREGON.

In the Blue Mountains of eastern Oregon occurs a red sandstone from which Jurassic fossils were obtained on Beaver Creek, a tributary of Crooked River. The fauna is that of the Hardgrave sandstone of the Taylorsville district, California, and is assigned by Hyatt [468] to the Lias (Lower Jurassic). Hyatt mentions other localities at which there are characteristic occurrences of the same fauna and infers a connection between them extending from Inyo County, Cal., to the Blue Mountains.

L 12. MONTANA AND WYOMING.

The Jurassic of the Philipsburg quadrangle, Montana, is thus described by Calkins:[a]

> The beds immediately overlying the Quadrant formation in the Philipsburg quadrangle in southwestern Montana are correlated with the Ellis formation on lithologic and paleontologic grounds.
>
> The Ellis in this area consists mainly of calcareous shales and sandstones and impure ferruginous limestone; locally it contains, near the middle, some conglomerate whose pebbles are mainly of chert like that in the Madison limestone. These rocks all weather in ocher-yellow colors which are characteristic of the formation as here developed.
>
> The thickness of the formation on Gird Creek about 5 miles southeast of Stone, Mont., is about 400 feet. It is thinner in places and seems locally to be absent in a small area southeast of Twin Peaks. It appears to be structurally conformable with the Quadrant, but the absence of any deposits belonging between the Carboniferous and Jurassic marks a distinct hiatus.
>
> T. W. Stanton has collected characteristic Ellis fossils from the formation on Gird Creek and on the Ovardo road about 6 miles east of Drummond. Those collected on Gird Creek lie from 50 to 100 feet above the Quadrant formation. They comprise the following forms:
>
> Ostrea strigilecula White.
> Camptonectes pertenuistriatus H. and W.
> Eumicrotis curta Hall.
> Trigonia sp.
> Pleuromya subcompressa Meek.
>
> In this section east of Drummond calcareous beds from 200 to 250 feet above the Quadrant have yielded:
>
> Rhynchonella gnathophora Meek.
> Ostrea sp.
> Camptonectes bellistriatus Meek.
> Lima? sp.
> Cucullea haguei Meek.
> Tancredia? sp.
> Pleuromya subcompressa.
>
> A conglomerate near the top of the Ellis formation here contains *Rhynchonella gnathophora* Meek, Ostrea sp., and Gervilia sp.

For an account of the Ellis formation as developed in Yellowstone Park, the Yellowstone folio [392] may be consulted. In that region the formation consists of a lower limestone division and an upper one chiefly of sandstone. The limestones are impure, argillaceous and gray, and associated with shales, and they carry marine fossils at several horizons. The upper sandstone member varies from a coarsely crystalline, fairly pure limestone carrying an abundance of fragmentary fossils to a true sandstone with conglomerate layers.

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[a] Unpublished manuscript.

The latest account of the Ellis formation in Montana is by Fisher,[332] who states that it—

includes a basal limestone of variable thickness, ranging from 15 to 60 feet, which in places merges upward into a coarse conglomerate that passes into a medium-grained sandstone, light brown to gray in color and more or less thin bedded. In other localities, however, the change from limestone to conglomerate is abrupt. The limestone and conglomerate contain marine Jurassic invertebrate fossils. Some of those in the conglomerate are fragmentary, but more are complete, with pebbles of limestone and quartzite several inches in diameter. The component parts of the conglomerate are bound together by a calcareous cement. The total thickness of the formation is about 80 to 120 feet. It rests unconformably upon the shale of the Quadrant formation in certain parts of the field, and upon the Madison limestone in others. * * *

The following sections illustrate the succession of the beds of the formation in different parts of the field:

Section of Ellis formation near Goodman siding, Montana.

	Feet.
Sandstone, massive, light brown to gray, weathering tan, conglomeratic and fossiliferous at base.	66
Limestone, reddish brown, fossiliferous	6
Beds concealed (estimated)	18
	90

Section of Ellis formation at head of Ming Coulee, Montana.

	Feet.
Sandstone, gray, weathering brown, thin bedded	60
Sandstone, gray, conglomeratic, containing marine Jurassic fossils	29
Limestone, dove-colored, massive; basal member brecciated and containing Jurassic fossils	60
	149

Fossil invertebrates, mainly Ostrea and Camptonectes, are present in great abundance in the two lower members of the above section. The numerous specimens of these genera and a few other forms are sufficient to determine that the rocks belong to the Ellis formation, which in the Yellowstone National Park and neighboring areas yields a characteristic upper Jurassic fauna. The sandstone of the Ellis formation throughout the Great Falls region is usually not fossiliferous, but the conglomerate and underlying limestone contain an abundance of Jurassic fossils.

The Morrison formation, which is regarded as probably Jurassic by some geologists, is described with the Lower Cretaceous in Chapter XIV (pp. 606–608).

L-M 10. OLYMPIC PENINSULA.

Arnold [29] refers to supposed pre-Cretaceous rocks in the Olympic Peninsula of Washington, which he mapped as Jurassic and which are so shown on the map of North America, as follows:

The formations involved in the geology of the coastal region of the Olympic Peninsula include serpentine, old diabase or greenstone, metamorphosed sandstone and quartzite, probably of Jurassic age; 6,000 feet of gray sandstone with minor quantities of carbonaceous shales, supposed to represent the lower part of the Puget group and of Cretaceous age; 1,200 feet of basalt and basalt tuffs of Eocene age; 15,000 feet of Oligocene-Miocene conglomerate, sandstone, and shale; 2,260 feet of Pliocene conglomerate, sandstone, and shale; and at least 300 feet of Pleistocene till, clay, and gravel. In addition to this, the Oligocene-Miocene breccia contains large quantities of angular fragments of hard black slate, indicating a probable widespread formation of this type of rock somewhere in the general region. Nothing is known of the age of the slate except that it is pre-Oligocene.

The supposed pre-Cretaceous rocks of the territory examined were confined entirely to the coast south of Cape Flattery, the most important areas occurring at Portage Head, 8 miles south of the cape, Point of the Arches, 3½ miles still farther south, and in the region from Point Greenville south to within a few miles of Grays Harbor. The types of rock composing this old series embrace old diabase or greenstone, serpentine, quartzite, conglomerate, etc.

These rocks are also described by Reagan [664] as follows:

Rocks supposed to be pre-Cretaceous in age are found in the central Olympic region, in the central ridge which extends westward from the Olympics to Cape Flattery, and on the Pacific front at Portage Head, 8 miles south of Cape Flattery, and at the Point of the Arches, 4 miles farther south, and in the region from Point Granville south to within a few miles of Grays Harbor, and a few other smaller exposures along the Pacific shore line. So far no rocks of this age have been found on the north slope of the peninsula. * * *

The series containing the syenite, gneiss, quartzite, protogene, crystalline and chlorite schists is here placed by the writer in the supposed Cretaceous. Its approximate area is not known, neither is its thickness where the central core of the western extension of the Olympics is exposed. Along the east and west axis of the western part of the peninsula, at Beaver Falls, in the East Clallam-La Push wagon-road, [it] is composed of a very hard dark-gray plutonic rock of more than 10,000 feet in thickness. This core, however, is exposed only in patches. Its greatest thickness is in the vicinity of Clallam Peak. Toward Cape Flattery it is capped with sedimentary deposits. Here it is composed of metamorphosed sandstone and quartzite. It may prove to be of Eocene age.

At Portage Head, Point of the Arches, and at Point Granville the type rock of this old series is conglomerate, quartzite, old diabase or greenstone, serpentine, etc.

This old series, wherever found, is much fractured and faulted and cut by quartz veins, which occasionally carry gold and silver in small quantities. The principal veins carrying precious metals are found in the Point of Arches group and in the vicinity of Clallam Peak and Beaver Falls. An odor of benzine is also given off from the serpentine and conglomerate rocks of this group in the Point of the Arches, derived likely from the shales that are found a mile farther south. There are no other shales or oil-producing rocks in the vicinity; the age of these shales is in doubt, but they are Cretaceous or still younger.

M 10. WASHINGTON AND BRITISH COLUMBIA.

A western occurrence of supposed Mesozoic strata is exposed on the northern portion of Nooksak River and is thus described by George Otis Smith: [757]

For some miles below Shuksan the outcrops on the walls of the canyon of the north Nooksak are of sedimentary rocks distinctly less metamorphosed than those assigned to the Paleozoic. They are mainly sandstones, with some cherty layers and conglomerates. Green colors are rather characteristic of all the rocks. At Austin Pass there are greenish sandstones and banded shales which show on the average about the same degree of induration as the similar rocks of the Pasayten formation. On lithologic grounds, then, it appears probable that there may be a belt of Mesozoic rocks trending northwest from Austin Pass.

There is, moreover, some paleontologic evidence bearing on this question. In 1898 there were sent to Mr. J. S. Diller by Mr. W. H. Fuller, of Fairhaven, Wash., some fossils collected on Cowap or Canyon Creek and on the ridge north of it. Mr. T. W. Stanton examined the material and reported on it as follows:

"The * * * fossils * * * are evidently all from one horizon, which I believe to be upper Jurassic, this opinion being based chiefly on the distinctly striated form of Aucella, identified with *A. erringtoni* (Gabb) of the California upper Jurassic Mariposa beds. This species was collected at both localities. The collection from Canyon Creek includes also a fragmentary Pleuromya and the impression of a small belemnite.

"The collection from the divide between Canyon Creek and the waters of Fraser River contains the *Aucella erringtoni*, a fragment of an ammonite apparently belonging to the genus Stephanoceras, a small, slender belemnite like that from the last-mentioned locality, and the phragmacone of a large, robust belemnite."

M 11. SOUTHWESTERN ALBERTA.

The Fernie shale, which was originally included by Dawson in the Cretaceous as part of the Kootenai formation, has been separated and is described by Dowling.[292] In the Cascade coal basin, Alberta, it consists of black shales with gray sandstones and local limestone beds which occupy the same position relatively to the Kootenai of the older rocks beneath as a similar series at Fernie, where there are Jurassic fossils. The thickness is given as approximately 1,600 feet.

The relations of the Jurassic and Lower Cretaceous of British Columbia are discussed in Chapter XIV (pp. 624–630).

M–O 9–10. WESTERN BRITISH COLUMBIA.

Dawson's descriptions of the "Porphyrite group" (Jurassic?) are given in Chapter XIV (p. 627).

O 4–5. ALASKA PENINSULA.

The Alaska Peninsula is composed largely of Mesozoic rocks, which, though known to comprise several terranes, have not yet been separated in mapping but are grouped under the color which indicates Jurassic. Brooks [101h] gives a general account of the history of investigation of these strata. The latest and most complete study of the section as yet made is that of Stanton and Martin, [786b] to whose account reference should be made for detailed sections and a statement of the stratigraphic relations, which they sum up as follows:

The Mesozoic section of southwest Alaska includes representatives of the Upper Trias, Lower, Middle, and Upper Jurassic, Upper Cretaceous, and probably Lower Cretaceous.

The Jurassic shows the greatest development, both stratigraphically and faunally, and is probably unequaled in these respects elsewhere on the American continent. The total thickness can not be much less than 10,000 feet, and the areas covered by the upper half of the Jurassic are large.

The faunal type is essentially Russian—that is, boreal—though it differs in the common occurrence of Phylloceras and Lytoceras at several horizons. The succession of the faunas from the Callovian to the top of the Jurassic is the same as in Russia, but the vertical thickness of beds through which each ranges appears to be very much greater in Alaska.

The Cretaceous and Triassic rocks so far as now known occur only in small scattered areas, and their faunas may be directly correlated with those of formations in California and elsewhere on the Pacific coast.

The general relations of the formations may be epitomized in the following section:

Tertiary.—Kenai formation. Shales, sandstones, and conglomerates with several beds of coal. The entire formation nonmarine and characterized by a large flora. Thickness, ±2,000 feet.

Unconformity.

Upper Cretaceous.—Lithologically similar to the Kenai, but including some marine shales and sandstones with an Upper Cretaceous fauna. Thickness, ±1,000 feet.

Unconformity.

Lower Cretaceous.—(Not seen within the area studied.) Shales and sandstones with *Aucella crassicollis.*

Unconformity(?).

Upper Jurassic.—Naknek formation. Conglomerate, arkose, sandstone, and shale with interstratified andesite flows. Thickness, about 5,000 feet.

Middle Jurassic.—Enochkin formation. Shales and sandstones with some conglomerate beds. Thickness, 1,500 to 2,500 feet.

Unconformity(?). (Possibly conformable on Lower Jurassic when that is present.)

Lower Jurassic.—Tuffs and sandstones. Thickness, ±1,000 feet.

Unconformity.

Upper Triassic.—Thin-bedded cherts, limestones, and shales usually much folded and contorted and with many intrusive masses. Thickness, ±2,000 feet.

Base not seen.

Martin[574] describes the district north of Alaska Peninsula and states the sequence of rocks as follows:

The region described in this report covers an area of about 4,900 square miles, situated in southwestern Alaska, west of the southern half of Cook Inlet and north of the Alaska Peninsula. It comprises the greater part of the drainage basin of Kvichak River, which is the outlet of Iliamna and Clark lakes, and of the streams flowing into Cook Inlet from the west, south of and including Tuxedni Bay. It lies between the parallels of 59° and 60° 30′ north latitude and the meridians of 152° 30′ and 157° west longitude.

Most of the northeastern part of this region lies within the Chigmit Mountains and consists of high, rugged mountain masses with narrow intervening valleys. The general elevation of these mountains is from 4,000 to 6,000 feet, although many peaks near the north end of Clark Lake are 7,000 feet high, and the highest peak of the whole district is Mount Iliamna, between 9,000 and 10,000 feet.

At Iliamna Bay the mountains extend eastward to the waters of Cook Inlet. Both north and south of this point a belt of foothills and lowlands from 2 to 10 miles in width reaches from the edge of the high mountains to the shore of the inlet. Much of the coast is deeply embayed, Tuxedni Bay, Iniskin Bay, and Iliamna Bay extending into the high mountains, while the other bays have their heads in the foothill belt. * * *

The following table shows what is now believed to be the probable geologic sequence:

General section of rocks in the Iliamna and Clark lakes region.

Age.	Lithologic character.	Areal distribution.
Quaternary.	Beach and flood-plain deposits, terrace gravels, and glacial till.	Entire region.
Tertiary.	Basaltic flows and tuffs with some interbedded sandstone.	Iliamna Lake.
	Shale, sandstone, and conglomerate.	Cook Inlet.
Upper Jurassic	Shale, sandstone, conglomerate, arkose, and tuff, with interbedded andesitic flows.	Cook Inlet.
Middle Jurassic.	Sandstone, shale, and conglomerate.	Cook Inlet.
Middle or Lower Jurassic.	Granite, quartz, diorite, etc.	Chigmit Mountains.
Lower Jurassic or older.	Rhyolitic and andesitic porphyries and tuffs.	Cook Inlet, Iliamna Lake, Clark Lake, east of Clark Lake.
Upper Triassic.	Chert, shale, and limestone.	Cook Inlet.
Triassic or older.	Tuffaceous greenstones.	Iliamna Bay, Pile Bay, Kakhonak Bay, Clark Lake.
	Limestone.	Iliamna Lake, Iliamna Bay, south of Iliamna village (?).
Late Paleozoic.	Slate and chert.	Iliamna Bay, Clark Lake, east of Clark Lake.
Paleozoic.	Limestone and calcareous schist.	Clark Lake, south of Iliamna village (?).
	Gneiss, mica schist, and quartzite, with some crystalline marble.	West of Iliamna Bay, south of Iliamna village, Clark Lake.

O 8. ATLIN LAKE, BRITISH COLUMBIA.

Gwillim,[389] in reporting on the Atlin Lake gold district, describes an extensive area of sandstone and conglomerate about the southern end of Taku and Atlin lakes. The rocks are classed as Mesozoic but were not seen in contact with Paleozoic formations. "Their origin is chiefly igneous and they often pass imperceptiby from a sedimentary and stratified form into the mountain masses of porphyrite and andesite. The few fossils found in some of the bedded sandstones appear to belong to the Jurassic period." This general statement is followed by a more detailed description, as follows:

The prevailing variety of this sandstone series is of a greenish-gray color. It is usually in heavy beds. There are occasional bands of a darker and more argillaceous-looking material, also some thick deposits of thinly bedded fine-grained black and gray material. Conglomerates occur somewhat rarely. Such beds usually contain very coarse bowlders, as large as 3 feet in diameter. These bowlders are principally granite, with sometimes a considerable number consisting of crystalline limestone and porphyrite.

A very good section of this sandstone formation is found on the west side of Tory Inlet on Atlin Lake. An anticline occurs at this point. The northern slope of the beds forms the abrupt eastern face of Section Mountain. This section shows over 5,000 feet of thickly bedded sandstone of the greenish-gray false-bedded variety interbanded with some finer-grained beds of darker material. The upper portion of these beds is without conglomerate. The lower beds contain some narrow bands of which the bowlders are usually small and consist principally of granite and porphyrites (hornblende and andesite porphyrite).

From microscopic examination of several specimens of this series, they appear to be of pyroclastic origin.

* * * * * * * * *

A few fossil forms were found in some of the darker fine-grained beds of this series of rocks. * * * From field conditions and lithological resemblance, this series of rocks was at first believed to be Cretaceous in age. The examination of the few fossil forms appears to place them in the Jurassic. * * * The following is a note on the specimens of fossils collected on Atlin Lake during the season of 1900 and submitted to Dr. H. M. Ami, for examination:

"The fossils are preserved for the most part in a rather imperfect manner in a dark, at times streaky, gray fine-grained calcareous rock, which, when examined in thin sections under the microscope, reveals the structure of a porphyrite or andesite tuff. * * * The fossils are for the most part fragmentary * * * but they represent several small collections * * * and possibly different horizons in the Mesozoic. It is very difficult to state precisely what is the age of the strata, * * * both on account of the condition in which the fossils are themselves preserved and on account of the fact that the fauna represented is practically a new and hitherto unrecognized one in that portion of North America. * * * The presence of a few ammonites, which had the general outward appearance of Arniotites not unlike *A. vancouverensis* seemed to indicate a similar horizon to that of the Triassic system of the Cordilleran belt, but as none of these ammonites show any of the sutures, it is impossible to state precisely in what section or division to place them."

Some of the most typical of these fossils were sent to Dr. T. W. Stanton, of Washington. He found it difficult to determine the ammonites even generically, since they showed no sutures. He says:

"These may possibly be Triassic, but I think it more probable that they are early Jurassic. They are certainly not as late as the Cretaceous."

P 8. LEWES RIVER, YUKON PROVINCE.

For a description of the conglomerate and sandstones near Lake Labarge, which Stanton considers probably Jurassic, see Chapter XV (p. 701).

R 3. NORTHWESTERN ALASKA.

The coast northeast of Cape Lisburne exhibits a section of strata constituting two formations, the lower one coal bearing and according to its fossil plants of Jurassic age, the upper one unfossiliferous. Collier [164a,165b] has described these formations as follows:

Mesozoic rocks occur on the coast about 3 miles east of Cape Lisburne and extend beyond the limits of the area covered by this investigation. They consist of two members, of which the older is coal bearing while the younger is not only destitute of coal but also of fossils.

The coal-bearing member, which has been called the Corwin formation, begins on the coast line about 26 miles east of Cape Lisburne and about 2 miles west of Corwin Bluff. From this point it extends eastward to and beyond Cape Beaufort, the eastern limit of the area comprised in this investigation. This formation consists of rather thin bedded shales, sandstones, and conglomerates. The shales which form the greater part of the section, vary from greenish-brown calcareous to black carbonaceous beds, and in texture from mudstones to fine-grained sandy shales.

The sandstones occur at infrequent intervals through the formation, in beds usually less than 10 feet in thickness. Their outcrops form low ridges, which are easily traceable over eroded areas. The conglomerates are made up mainly of quartz and chert pebbles, ranging in diameter from one-half to 4 inches. A conglomerate bed about 15 feet thick, which reaches the coast at Corwin Bluff, makes a distinct ridge from 100 to 200 feet high, which has been traced southeastward for about 15 miles, giving a definite key to the stratigraphy of a portion of the field.

The thickness of the Corwin formation exposed along the coast near Corwin Bluff is not less than 15,000 feet. The base of the formation has not been observed, but it probably rests unconformably on the Paleozoic rocks.

Fossil plants collected from it indicate that the age is Jurassic.

The structure consists of several broad synclines and anticlines, the dips of the beds varying from 0° to 60°. There is no evidence of faulting other than minor shearing movements parallel with the bedding planes.

The Corwin formation is conformably overlain by a more arenaceous series of sandstones and shales in which neither coal beds nor fossils have been found. The contact of these rocks with the Corwin rocks may be seen about 2 miles west of Corwin Bluff, whence it extends southeastward for several miles to the limit of the area investigated. The western limit of the formation is a well-defined fault line extending southeastward from a point on the coast 3 miles east of Cape Lisburne, where the formation is in contact with the Paleozoic, which is overthrust. The structure of this formation increases in complexity from its base at the top of the Corwin formation as this fault is approached; there are intense crumpling and numerous minor thrust faults. For this reason it is impossible to estimate the thickness of the formation, but the evidence obtained indicates that its minimum thickness is not less than 5,000 feet.

R–S 27. NORTHEAST COAST OF GREENLAND.

Nathorst [609a] gives the following description of the Jurassic strata on the northeast coast of Greenland:

Jurassic strata occur at two localities on Kuhn Island, on the south side and on the east side. At the first-mentioned place they consist of brownish fine-grained sandstones, with an inclusion of coal strata. There are in the sandstones fossils which, according to Youla, indicate the Middle Dogger. Of quite a different age are the sandstone and marl beds that are found about the easternmost point of the island; they are distinguished by a great richness in forms from the family Aucella, and further of *Perisphinctes payeri*, *Belemnites panderianus*, besides others, and are therefore referable to the youngest Jurassic, the Aucella beds. The Jurassic at both localities is given as resting directly on the Archean. * * *

Above the Rhætic beds come others with marine fossils described by Lundgren. Aucella are completely absent, and Lundgren thinks that these beds should be referred to the Kelloway stage of the Jurassic system, and that they are very likely closely allied to the fossiliferous beds on the south side of Kuhn Island. Identifiable ammonites and belemnites were not found in the samples that were brought home, and most of the specimens are lamellibranchs belonging to the families Ostrea, Pecten, Avicula, Modiola, Astarte, Panopæa, Pholadomya, Lyonsia, and others. The fossils occur in an impure limestone that in places becomes conglomeratic or even changes into shell breccia. The fossil-carrying bed is 2.2 meters thick and is overlain by gray sandy slates, yellowish sandstones, etc., without fossils. A basalt bed 3 meters thick is interbedded with the nonfossiliferous layers. The beds dip about 6° S. 50° W. and rise therefore toward the inner part of Jurry Inlet.

Chapter XIV.

LOWER CRETACEOUS.

Color, Medium green.

Symbol, 8.

Distribution: Atlantic, Gulf, and Caribbean coasts; New Jersey to South America; Pacific coast, Alaska to South America. In Mexico areas mapped include Upper Cretaceous.

Content: Potomac group of the Atlantic slope, Georgia, and eastern Alabama; Comanche series (comprising Trinity, Fredericksburg, and Washita groups) of Texas, Oklahoma, and Mexico; Shasta series (Knoxville and Horsetown formations) of California and Oregon; Queen Charlotte group of British Columbia; Kootenai formation of the Rocky Mountains, Montana northward to fifty-second parallel and beyond; Lower Cretaceous, Alaska.

Lower Cretaceous areas.

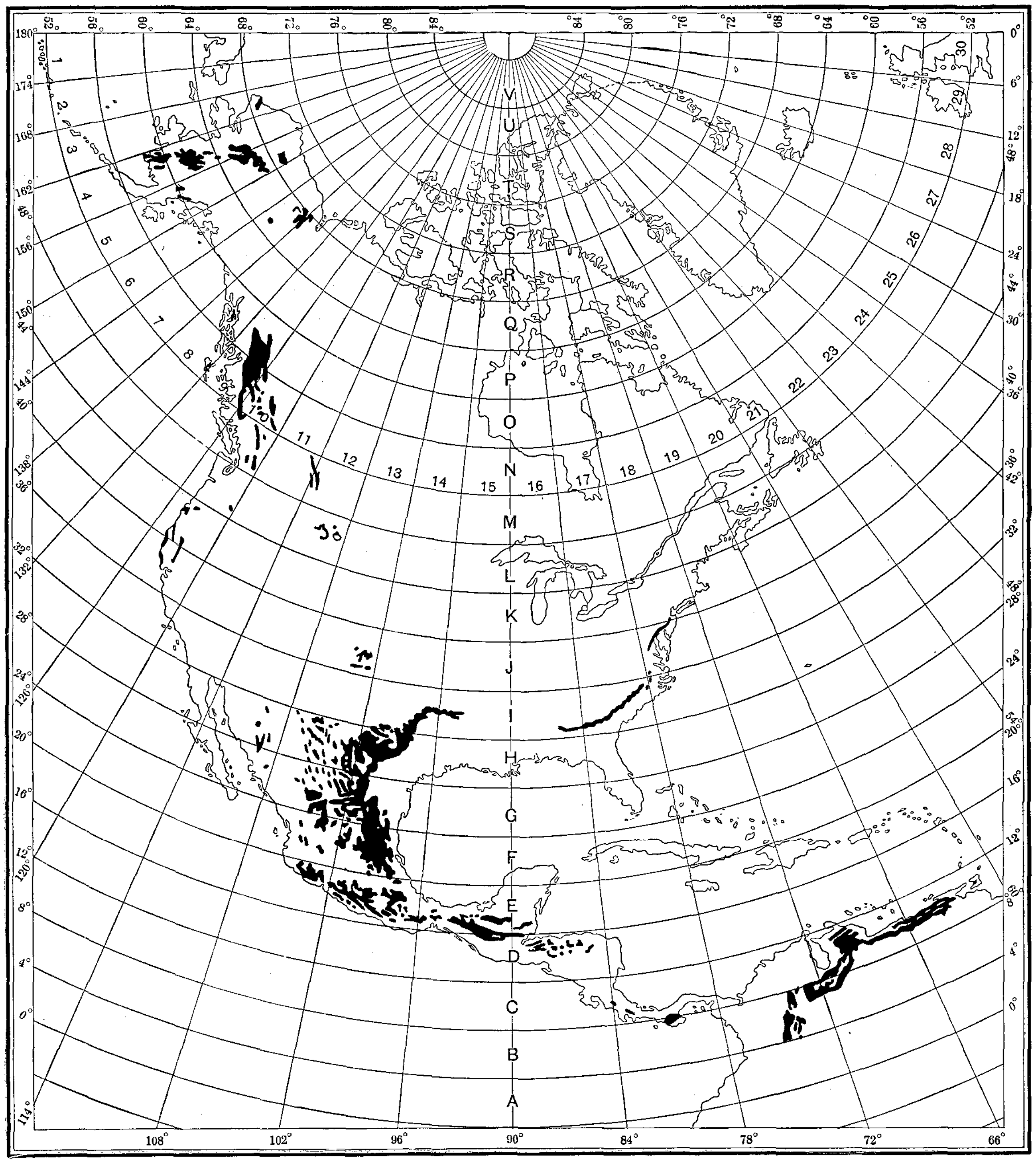

FIGURE 16—Sketch map showing the distribution of Lower Cretaceous rocks represented on the geologic map of North America and the key to references in the text.

B–C 18. COLOMBIA.

We are indebted chiefly to Hermann Karsten,[473a] a physician and botanist, for our knowledge of Colombia, and for the portion of that country shown on the map of North America we have followed his text. He distinguishes five terranes, of which the oldest is the Jurassic, recognized at but one locality in New Grenada. The next, the Lower Cretaceous, outcrops extensively throughout the mountains and is distinguished by a great variety of cephalopods. Karsten suggests that the terrane may probably be divided into two formations owing to the presence of belemnites, Ptychoceras, Humboldtianus Krst., *Ammonites noeggeratii* Krst., *Am. rothii* Krst., *Am. santafecinus* d'Orb., *Am. boussingaultii* d'Orb., and *Hamites arboledæ* Krst., in the lower beds, which are principally marls. The third series, that of the Upper [?] Cretaceous, consists of thick deposits of limestones, sandstones, and siliceous shales and is identified paleontologically by a great number of Rudistes which appear in the eastern portion, and of Polythalamies [Foraminifera], which occur very extensively in the central and western districts.

Succeeding these Cretaceous formations are Tertiary and Quaternary deposits concerning which Karsten is quoted in Chapter XVII (p. 796). In introducing his description of the Cretaceous, Karsten refers to the absence of any trace of Paleozoic rocks, and mentions specifically the discovery of Jurassic beds on the upper Magdalena in New Grenada. As these beds appear to belong to the Lower Jurassic (Liassic), it is possible that the Upper Jurassic is represented in the higher strata which underlie the Cretaceous. Karsten states:

The oldest of the sedimentary formations is a sandy marl of a clear brown or yellowish-red color and distinct stratification. It frequently is of great thickness and sometimes contains in the upper portion beds of blue or dark limestone which completely replace the marl in the higher sequence. Sometimes a reddish-brown marl which closely resembles the preceding contains flakes of mica or fragments of mica schist, as, for example, at Guaduas and at Bucaramanga. The latter marl is, however, probably of more recent date than that which appears in contact with the plutonic rocks and which is very poor in fossils, is without mica, firmer, etc. This nonmicaceous marl occurring in the lower beds is found in all the eastern chain as well as at several places in the central and western chains. It contains the following fossils: *Ammonites santafecinus* d'Orb., *Am. noeggeratii* Krst., *Am. boussingaultii* d'Orb., *Ptychoceras humboldtianus* Krst., *Crioceras duvalii* Lev. var. *undulata* Krst., and may therefore be regarded as the equivalent of the Neocomien of Europe. At Cumanacoa remains of belemnites occur in a yellowish-red marl and in a black calcareous shale which lies upon it. * * * This marl has at Zapatoca a thickness of about 300 meters and is overlain by another bed which is also very thick, of reddish-yellow quartzose sand, that in turn is followed by clay shales and limestones of the horizon of the Gault, rich in fossil remains. The last-named lies upon beds of pebbles and conglomerates derived from these same strata.

Karsten describes several localities at which these strata appear and continues:

Although at the base of the Lower Cretaceous marls and shales predominate, the middle portion of the series consists chiefly of limestones and the upper part of sandstones. These sandstones here and there alternate with thick beds of siliceous shale and include also thin strata of clay shale which are generally white, light, or yellowish in color, and of fine grain. * * * In physical characters the beds resemble the Lower Cretaceous that immediately underlies them, but they may usually be distinguished by the organic remains, especially characterized by Inoceramus. The Upper is distinguished by an abundance of Polythalamies, Orbitolina, Robulina, Nodosaria, and similar species. In the accompanying limestones one also finds the shells of Rudistes and bivalves: Lucina, Cardium, Pecten, Ostrea, *Exogyra boussingaulti* d'Orb.; of echinoderms: *Ananchytes ovata* Lam., *Micraster cor-anguinum* Goldf., *Discoidea excentrica* d'Orb., *Echinus bolivarii* d'Orb., *Enallaster karsteni* de Loriol, Galerites sp., etc. This group of siliceous rocks, whose thickness may be estimated roughly at 1,000 meters, usually forms the summits of the eastern chain. The Paramo de Chita, which has an altitude of about 6,000 meters and is covered with eternal snow, [and other summits] are formed of these sandstones and siliceous shales. The beds which carry Polythalamies are unconformably overlain by micaceous sandstone which is either white or yellow and more or less coarse, or by sandstones and variegated marls containing beds of lignite.

This last group is assigned by Karsten to the Tertiary and further description of it is given in Chapter XVII (p. 796).

The geologic constitution of the Cordillera of Bogota was described in 1892 by Hettner,[437] who distinguished several divisions of the Cretaceous as follows:

Although various explorers have from time to time collected fossils, we are indebted particularly to Karsten for an attempt to distinguish the sedimentary rocks of Colombia. He separated Lower Cretaceous or Neocomien, Middle Cretaceous or Gault, which appears with two definite variations, Upper Cretaceous, and Tertiary. The classification which I have adopted during my journeys agrees in general with Karsten, and Sievers has adopted approximately the same classification for the Cordillera of Merida in Venezuela.

The characteristic rock of the Neocomien is, according to Karsten, a sandy light-brown or red-yellow, imperfectly stratified marl with interbedded strata of blue or dark-colored limestone which predominates in the upper portions. Karsten found fossils in one locality only, near Caqueza. I must admit that I have not discovered any and that I therefore must classify this formation with the following one, the Gault, inasmuch as they are not particularly different in lithologic character. The Lower Cretaceous (Neocomien and Gault) is therefore in general a thick series of clay slates, shales, and bright-colored shaly clays, which are interbedded with thick strata of blue or more rarely black or white limestone, white quartzite, and white, sometimes reddish and greenish sandstones, as well as some other subordinate strata. Where they possess the typical character I propose to call them the Villetas formation, and the greater part of the limestones of the Middle Cretaceous which Sievers has distinguished in his profile sections probably. The principal part of the Villetas formation has been determined by Steinmann as Urgo-Aptien on the basis of its fossils; whereas the upper strata belong to the true Gault.

In the vicinity of Jiron and Zapatoca and elsewhere there occurs, in the neighborhood of the granite gneiss and porphyry, clay, reddish or white, and in part greenish sandstone which, together with violet-brown shales and reddish sandstones may be named the Jiron formation. This is the reddish-yellow sandstone which Karsten regarded as a special development of the Neocomien, and although there are fossils I would also class it as a portion of the basal Cretaceous that is peculiarly characterized through proximity to the crystalline rocks. Sievers also regarded this formation, which occurs apparently quite frequently in the Cordillera, as the lowest member of the Cretaceous. Elsewhere, especially in the snow-covered mountains of Cocui, a white quartzite which usually occurs only in thin beds in the slates and clays becomes so thick that it replaces all other rocks. This Cocui quartzite probably corresponds to the Uribante sandstone of Sievers. The blue limestone may, however, become the predominant member and entirely replace the slates and clays, as is the case in the neighborhood of Velez.

Toward the top the Villetas formation appears to pass by gradation into the next division, the Guadalupe (Karsten's Upper Cretaceous). The slates and shales become less frequent and occur only as thin interbedded layers. The greater part of this division is siliceous sandstone or a thin-bedded silicified clay rock, together with a heavy-bedded white quartz sandstone which in general overlies the other strata. Fossils are very rarely found and are not such as may be definitely determined. It is therefore doubtful whether the Guadalupe formation belongs to the Gault or to the Upper Cretaceous.

B-C 19-20. VENEZUELA.

As regards the Lower Cretaceous, Sievers[741a] in describing the Cretaceous rocks of Venezuela distinguishes conglomerate and breccia at the base, followed by red sandstone, yellow and white quartzose sandstone, and limestone. From the descriptions of these several formations, which consist chiefly of details of local occurrences, the following notes may be taken:

The clay slates which are assigned by Sievers to the Archean and which for the sake of distinction have been placed by the present compiler in the metamorphic Paleozoic are unconformably overlain in many places in the Cordillera by massive deposits of conglomerate and breccia which Sievers calls the Lagunillas conglomerates. They consist of fragments of the "Archean" rocks embedded in a clay and sandy cement. Their horizontal extent is in places considerable; the thickness in the vicinity of Lagunillas is stated at 700 meters. Sievers leaves one in doubt as to whether the conglomerates should be assigned to the Cretaceous or not, saying:

These conglomerates appear widely distributed throughout the Cordillera and always occur between the Archean rocks and the succeeding red and yellow sandstones which we may well regard as Lower Cretaceous. Sometimes they rest upon gneiss, as at Lagunillas, sometimes on clay slate, but they always constitute an intermediate member between the Archean and the Cretaceous. One is obliged to regard them as a coastal formation developed around islands of the older gneiss and clay slate which now constitute the core of the Cordillera. The time at which these conglomerates were formed can not be determined with certainty, but they must be older than the red and yellow sandstone which we regard as the lowest member of the Cretaceous. It is therefore probable that they introduced this period.

After citing the localities at which the Lagunillas conglomerate occurs, Sievers continues:

The conglomerate and breccia are followed by the Cretaceous series, to which most of the sedimentary deposits of the Cordillera belong and which occupies a much greater area than that of the Archean formations. The determination of the age of these formations depends essentially on a few fossils from the blue limestone of Tachira and Barbacoas, which are mostly ammonites and may be correlated with the Upper Albien of the Middle Cretaceous as determined by Prof. Steinmann. The strata which underlie these limestones are therefore older Albien. There are red and yellow standstones as well as the white sandstone. Unfortunately they are as a whole very poor in fossils, but they may be considered as Cretaceous, as in lithologic character they are very similar to the corresponding Cretaceous deposits of Europe. * * *

The red sandstone follows directly upon the deposits of the Lagunillas conglomerate. It is mostly coarse and rich in mica, though also sometimes fine grained, usually according to its relation to the conglomerate, whether directly deposited upon that formation or farther away from it. * * *

At many points in the Cordillera de Merida we observed a white to yellow coarse-grained saccharoidal quartz sandstone which in many respects strongly reminds one of the Quader sandstone of Saxony. * * * Although this sandstone resembles the Pläner (of Germany) and accordingly should be placed among the upper formations of the Cretaceous, it can not be denied that it occurs in the Cordillera under the limestone which is determined as equivalent to the Albien and outcrops together with the red sandstone. * * * The yellow sandstone frequently grades into the red but in general is much more widely distributed than the red sandstone. Where the red is entirely wanting —that is to say, throughout the eastern portion of the range—the white sandstone seems to replace it.

In describing the Cretaceous limestone Sievers refers to classifications by Wall and Steinmann. He cites three divisions of the Older Parian group, so named by Wall in his "Geology of the Island of Trinidad," and finds a parallel with divisions recognized by him in the Cordillera de Merida.

Referring to a report contributed by Prof. Steinmann on the fossils which Sievers had collected Sievers says:

Steinmann infers that there are three limestone formations which may be distinguished—(*a*) the dark bituminous limestones of San Cristobal, with Exogyra; (*b*) the succeeding Barbacoas formation, with many ammonites; and (*c*), still higher, the broad crystalline limestone with many poorly preserved fossils of Exogyra, Trigonia, Cardita, and Astarte, which occur extensively in northern South America. Of these formations the age of the Barbacoas alone can be determined accurately. It belongs to the Upper Albien, on the boundary between the Lower and the Upper Cretaceous, and is distinguished by the following fossils:

Schlœnbachia inflata Sow.
S. varicosa Sow.
S. belknapi Marcou.
Hoplites tocuyensis.
Mojsisovicsia durfeldi Steinmann.
Cardium peregrinorsum d'Orb.
Inoceramus plicatus d'Orb.

C 20. TRINIDAD.

Wall and Sawkins [863a] described the Older Parian group of the Island of Trinidad as Lower Cretaceous.

The Older Parian group consists of a great variety of sandstones, fine or coarse grained and usually highly indurated, which properly seems referable to the extensive diffusion of siliceous cementing material; of shales of a dark color, characterized by flakes of silvery white mica; and of strata composed of an argillaceous base, with small equivalents of carbonate of lime and free silica. * * *

Limestones are rare, do not exceed 10 to 20 feet in thickness, are extremely compact, and their fossils usually partially or entirely transformed into highly crystalline spar. * * *

Very few fossils were collected in this formation, and those obtained were from a single limestone at Point a Pierre, but none of them offering any characters sufficiently precise for defining the geological position. Some fossil remains procured from the same series at Cumana, in Venezuela, fortunately present a more positive aspect and are referable to the later secondary period. It is highly probable that these strata are of similar age to the upper secondary deposits of New Grenada, which are attributed by Von Buch and D'Orbigny to the Neocomian or Lower Cretaceous horizon.

Disturbances are everywhere characteristic, the angle of dip is almost invariably high, and the strata are often vertical; but buried as the formation usually is in the center of the densest forests, it is extremely difficult to obtain sections adapted for resolving the details of position. These disturbances are by no means referable to a single series, since the consolidation, perhaps rapid, and the first elevation must have transpired before the newer Parian deposits were formed, and consequently anterior to the Miocene epoch. Ulterior movements, possibly repeated at intervals, affected both groups nearly equally, since in Naparima and the southern districts the Tertiary members are found at high angles reposing apparently conformably on the subjacent Older Parian.

E. H. Cunningham-Craig,[200] Government geologist of Trinidad, made fourteen brief reports to the legislative council between 1904 and 1907 inclusive and described local details, especially of the oil fields in Tertiary strata.

C 17, D 16. HONDURAS AND COSTA RICA.

Sapper [696a] describes certain strata of southern Central America as the Metapan terrane, and says:

Under this name I included in describing the geologic formations of Guatemala a system of clays, marls, sandstones, and conglomerates with included limestone beds which conformably underlie the Cretaceous limestone. In Honduras the same formations occur with the same lithologic character and they have great extent in all the northern and middle districts; that they belong to the lower Cretaceous is shown by many fossils which have courteously been described by Dr. Joh. Böhm of Berlin.

In a footnote Sapper gives the following list of fossils as having been determined by Böhm:

From Carizal:
- Glauconia cfr. picteti Coqu.

Between Charizal and Cuevas:
- Protocardia cuevasensis n. sp.
- P. ventrosa n. sp.
- Lima wacoensis F. Roem.

From Cuevas:
- Lima wacoensis F. Roem.
- Arca elongatior n. sp.
- Protocardia cuevasensis n. sp.

The most important places at which fossils have been found occur in the interbedded limestone strata near Selila, near Neambar, between Comayagua and Potrero, as well as between Espinas and Esquias. The fossils are, however, not sufficiently numerous and not sufficiently widely distributed to give definite data as to the age of individual beds, and as the petrographic character of the Metapan terrane is often extraordinarily similar to that of the Upper Triassic Tegucigalpa formation, I have not been able to determine with certainty in regard to the occurrence in the departments of Tegucigalpa and Olancho whether we have to deal with the Metapan or the Tegucigalpa terrane.

The Metapan terrane is conformably overlain by a moderate thickness of Upper Cretaceous ["Meso-Cretaceous," Comanche] limestones, which in Honduras often form the mountain summits. * * * The limestones near the western boundary of the Republic of Honduras near Copan, are characterized by well-preserved Rudistes, and thus belong to the Upper Cretaceous ["Meso-Cretaceous," Comanche]. The correlation of the limestones which occur in the departments of Santa Barbara, Comayagua, Yoro, and Olancho and have a thickness of several hundred meters with the Upper Cretaceous depends simply on the fact that they lie conformably upon the Metapan terrane.

Cretaceous limestones have not been certainly identified in the Republic of Nicaragua, but it seems to me quite possible that the limestones of the middle course of the Rio Coco may be so correlated.

Sapper then goes on to mention occurrences in Costa Rica and, quoting R. T. Hill, describes a dark-blue massive limestone which outcrops in steeply dipping beds and is in large part composed of Rudistes and Inoceramus. He mentions several other localities in Costa Rica at which rocks of probable Cretaceous age occur.

D-E 15-16. GUATEMALA AND CHIAPAS.

The Mesozoic formations of Guatemala are described by Sapper,[695a] who says:

The Mesozoic formations occupy very extensive areas in Alta Verapaz (Guatemala), but the strata are nevertheless very monotonous and consist everywhere of limestones and dolomites, together with conglomerates and breccias of the same rocks, so that it is impossible to distinguish different horizons by lithologic differences.

It is true that in the south the limestones and dolomites are in general of darker-gray to black tones and are thus distinguished from those of the north, which exhibit clear, mostly yellowish color values. The conglomerates often contain interbedded layers which are colored red by iron oxide. The predominance of brighter colors in the limestones of the north does not, however, prevent the frequent occurrence of limestones and especially of dolomites of dark-gray tones in that region; but it has not been possible to show that there was any difference in age between the lighter and darker limestones.

The paleontological evidences also fail to bring complete satisfaction, for only the light-colored limestones contain fossils, such as the remarkable Barettia, and in other localities Sphærulites or remains of Radiolites, which have not yet been accurately determined. In many places there are organic breccias of mussels and snail shells, which, however, are not accurately determinable. Yet as they occur with well-recognizable traces of Rudistes they evidently belong to the Upper [?] Cretaceous.[a] I find remains of Rudistes as far south as the crest of the Chicoj Range, but thence southward the limestones and dolomites of the Coban terrane have failed to yield a trace of fossils. They seem to be older than the Upper Cretaceous limestone of the north. The boundaries of the Coban limestone with the Carboniferous limestones and dolomites on the south are as difficult to fix as are those of the Cretaceous in the north, and for that reason they are shown upon the map only by dotted lines.

Sapper estimates the thickness of the Cretaceous at about 800 meters.

Böse [88] in 1905 described at some length the Lower Cretaceous (Eo- and Meso-Cretaceous as he described the beds) of Chiapas and expressed the opinion that the Neo-Cretaceous (Upper Cretaceous) was lacking in that province. He says:

The Eo-Cretaceous of Chiapas is composed of argillaceous, sandy, slate-colored strata, red beds, slate-colored limestones, and sandstones in thick beds. These strata occur beneath the limestones with Rudistes and in the south in contact with the Todos Santos terrane. The limit between the basal Cretaceous and the Todos Santos has not been carefully studied. The Lower Cretaceous in the south is everywhere followed by Cretaceous limestones with Rudistes. Moreover, it occurs in the basin of Chiapas, where it is laid bare by erosion. The thickness of this formation is about 300 or 400 meters. It is followed conformably by Cretaceous with Rudistes, as may be seen to the south and west of Tuxtla, Gutierrez, and Chiapa. Sapper classed these beds as Upper Cretaceous and said that they rest upon the limestone with Rudistes. This is not certain. * * * The few fossils which I have been able to examine indicate rather an Eo-Cretaceous than a Neo-Cretaceous age. It should be stated that the greater part of the species which Sapper cites are contained in the private collection of the former director of the Instituto Geológico, which was not accessible to me. I have from those beds only an Isastræa sp. nov. very like an Isastræa of the Eo-Cretaceous of San Juan Raya, two examples of *Nerineopsis goyzuetæ* Aguilera, n. gen., n. sp., and some poorly preserved corals. It is possible that to this division belong also certain gray and brown strata with masses of limestone which occur near Cancuc, at the northern base of the Mesa Central. * * * It is quite probable that these strata correspond to the upper part of the Metapan terrane, which is found in the southern part of Guatemala, in western Honduras, and in the northwest of San Salvador and which consists also of marls, sandstones, and argillaceous rocks and conformably underlies the limestones with Rudistes.

Böse then goes on to describe the Cretaceous limestones with Rudistes ("Meso-Cretaceous") and says:

This division is much the most important in Chiapas. * * * It consists of limestones and dolomites which generally occur in quite thick beds and only occasionally as intercalated

[a] Probably Meso-Cretaceous of the Mexican Survey or Comanche series of the United States Geological Survey.—T. W. Stanton, comment on manuscript. See also citations from Böse and Aguilera, beyond.

lenses. Occasionally beds of limestone of brecciated structure are found. In the lower part there sometimes occur beds of limestone with chert concretions, but the upper part consists generally only of gray limestone with interbedded dolomite. It may be said that these strata everywhere contain Rudistes, especially radiolites.

Böse then cites a number of localities. In regard to the Neo-Cretaceous (Upper Cretaceous), he says that the strata of Tuxtla, Gutierrez, and Chiapa, which Sapper took for Neo-Cretaceous, in reality belong to the Eo-Cretaceous; that he himself has never observed strata which might with certainty be assigned to the Neo-Cretaceous; but that possibly the dolomites and limestones in the extreme north of Chiapas represent a horizon of Upper Cretaceous.

E 14. STATE OF VERA CRUZ, EASTERN SLOPE OF THE MEXICAN PLATEAU.

In the vicinity of Orizaba Böse [87] made a special study of a Cretaceous section which he divided into three parts, to each of which he gave a locality name. His account may be summarized as follows:

In the region which we are to describe and which includes the environs of the Rio Metlac and Boca del Monte branch of the Veracruz-Mexico Railway the only sedimentary formations that occur belong to the Cretaceous system. They have been divided into three parts, which may be distinguished partly by paleontologic criteria and partly by lithologic differences. The formations are, in succession from above downward: (1) Escamela limestones; (2) Maltrata limestones; (3) Necoxtla slates. * * *

The greater part of this division [the Necoxtla slates] consists of argillaceous slates which are yellowish, gray, and reddish, with the luster of silk, and which include not infrequently segregations of pyrite crystals. The slates also contain in some places small amounts of mica. They are very fissile. In the upper part of the slates one may observe an enrichment in lime and the slates are often arenaceous and sometimes merge into a greenish sandstone which contains a large proportion of lime and in some places is almost entirely composed of calcareous fragments.

The Maltrata limestones constitute an important division, which is often of great thickness. The greater part is composed of limestones in thin beds, is without fossils, and of a clear dark-gray or black color. The limestones contain numerous segregations of flint in the form of lenses. In the upper portion the flint occurs in the form of nodules and irregular bodies. In the lower part of the limestones there occur in many places intercalated argillaceous slates which are yellowish and lustrous like silk, but these never form heavy beds. In the upper part toward the boundary with the Escamela limestones, there occur gray limestones and dolomites in heavy beds in which the stratification is scarcely recognizable. Above these follow dark compact limestones which represent the passage to the Escamela limestones and which may better be considered a part of the latter. In some places there occur above the dolomites flinty limestones, and in that case the line between them and the Escamela limestones is sufficiently well marked.

The Escamela limestones are composed of a clear gray to a dark-gray limestone, in some places but slightly stratified and elsewhere in clearly distinct beds. Cherts occur only in the lower portion. There are no intercalations of slates or marls. The limestones resemble in their characters very often the Cretaceous limestones of southern Italy. They are petrographically very uniform and may be recognized with ease.

Böse's description includes lists of fossils and a study of the relations of the Cretaceous of Orizaba with that of Texas and northern Mexico and that of Europe. His correlation table is translated as follows:

<table>
<tr><th colspan="2">District of Orizaba and Tehuacan; formations of southern Mexico.</th><th colspan="2">Texas and northern Mexico.</th><th>Stages.</th></tr>
<tr><td rowspan="2">Orizaba limestones.</td><td>Escamela limestones, 600 meters.</td><td rowspan="2">Comanche series.</td><td>Washita division</td><td>Turonian.</td></tr>
<tr><td>Maltrata limestones, 500–600 meters.</td><td>Fredericksburg division
(?)</td><td>Cenomanian.</td></tr>
<tr><td rowspan="2">Tehuacan slates.</td><td>Necoxtla slates, thickness not determined.</td><td colspan="2">Trinity division.</td><td>Aptien-Urgonian.</td></tr>
<tr><td>Zapotitlan slates and sandstones.</td><td colspan="2">(?)</td><td>Upper Neocomian.</td></tr>
<tr><td colspan="2">Black calcareous slates.</td><td colspan="2"></td><td>Middle and lower Neocomian.</td></tr>
<tr><td colspan="2">Upper Jurassic and older formations.</td><td colspan="2"></td><td>Upper Jurassic.</td></tr>
</table>

Böse's paper has been reviewed by Stanton,[780] who has also contributed the following notes in regard to the relations of the limestones in the vicinity of Orizaba:

The faunas of the two limestones indicate correlation with the Comanche series, and the underlying slates, though unfossiliferous, are correlated by lithology and stratigraphic position with the Lower Cretaceous of Zapotitlan, in Puebla.

The section at Zapotitlan and San Juan Raya has been described by Aguilera (Guide géologique au Mexique), who states that the Escamela and Maltrata limestones, which he refers to the Cenomanian, are represented here by a single unfossiliferous limestone called the Cipiapa division. The underlying Eo-Cretaceous includes the San Juan Raya and Zapotitlan divisions, which together are correlated by their faunas with the European Lower Cretaceous horizon from the upper Barremian to the Aptien, inclusive.

E 15. ISTHMUS OF TEHUANTEPEC.

Böse published for the Tenth International Congress an account of the geology of the Isthmus of Tehuantepec. He said in part: [90a]

Before commencing the description of the excursion in the isthmus, we will summarily describe the geology of the terranes which extend from east to west in this region. West of the isthmus there is the mountain chain of Mexico, and on the left the chain of Central America. The former consists of the following formations: At the base there is a series of gneisses and mica schists, with ancient diorites and granites. Upon these rocks there rests in general the Cretaceous, but there are also islands of Rhætic, Liassic, and Upper Jurassic. The series is rarely complete, and the Paleozoic is always absent. The Cretaceous is composed of the lower and middle Cretaceous and covers probably the larger part of the country. In the north [of Mexico as a whole] these are supplemented by the upper Cretaceous.

From this distribution of the Cretaceous Böse infers an early elevation of southern Mexico, to which he attributes the absence of marine Tertiary in the high plateaus, and he says further:

In the plateaus we encountered deposits from extensive lakes which belong in part to the Eocene and Miocene, the Pliocene, or Quaternary. Their age has been determined in many cases by means of fossils, both plant remains and vertebrates; in other cases it has been necessary to base an opinion upon the presence or absence of modern eruptive rocks in the conglomerate.

E-H 12-15. MEXICO IN GENERAL.

Cretaceous rocks, chiefly limestones, have great thickness and wide distribution in Mexico and Central America. Two classifications have been applied to them. One is that of Hill, who recognized the Comanche series in its characteristic development and also the Upper Cretaceous. The Mexican Survey, on the other hand, divides all the strata of the Cretaceous system into three series, which it designates as Eo-, Meso-, and Neo-Cretaceous and which are correlated on paleontologic evidence with European divisions. The Eo- and Meso-Cretaceous of this classification correspond with the Comanche of Hill's classification, and the Neo-Cretaceous is Upper Cretaceous, later than Dakota. Aguilera[9b] refers to the synopsis of the geology of Mexico[7] and says:

> We divided the Cretaceous into Lower, Middle, and Upper divisions, which, according to the resolutions adopted at the International Geological Congress, should be called respectively Eo-Cretaceous, Meso-Cretaceous, and Neo-Cretaceous. In practice this arrangement has proved advantageous, although it has been abandoned elsewhere, as it is here very useful from the double point of view of lithology and paleontology. The limit between the Eo-Cretaceous and Meso-Cretaceous series should correspond to the bottom of the compact limestones which form the mountains of Mexico, where it is impossible for us to separate the Albien from the Cenomanien, as the former has not yet been identified by its fossils in Mexico; and the Eo-Cretaceous series thus ends with the Aptien. The Meso-Cretaceous extends from the Albien to the Cenomanien inclusive, and the Neo-Cretaceous is composed of the Turonien, Emscherien, Aturien, and Danien.
>
> The Meso-Cretaceous series is very extensively developed throughout the country and forms almost all of the limestone mountains of Mexico. It is found from Sonora, Chihuahua, and Tamaulipas in the north to Chiapas and Tabasco in the south, and from the Gulf of Mexico to the Pacific Ocean. The predominant facies of the Meso-Cretaceous are those of the Rudistes and Caprinides. Up to the present time we have not succeeded in clearly separating the Albien from the Cenomanien. To the north the series is composed of marly rocks and in certain places carries a sufficiently rich fauna.

The following notes on the stratigraphy and distribution are condensed from Aguilera's descriptions, and arranged from south to north. For fossils and European equivalents, the original should be consulted.

Eo-Cretaceous strata occur as follows:

In the State of Oaxaca, at Tlaxiaco, the Eo-Cretaceous is represented by calcareous to gray calcareous argillaceous shales and by compact limestones of gray and grayish-black colors.

Near Cualac, in the State of Guerrero, are quartzose sandstones, gray to red in color, with grayish and yellowish argillaceous and marly shales. At the base are gray sandstones with impressions of plants. Red and yellowish quartzose sandstones and argillaceous schists occur near Tomixlahuaca.

In the State of Michoacan argillaceous shales of black and grayish colors alternating with yellowish fossiliferous sandstones are found at Cochixtla, and argillaceous marly shales alternating with calcareous fossiliferous shales at Parota, in the district of Coalcoman.

In the State of Puebla, at Zapotitlan and San Juan Raya, the terrane consists of gray argillaceous rocks, marly gypsiferous yellow shales, calcareous green sandstones, marly green sandstones, and varicolored shales.

In the State of Vera Cruz, at Necoxtla, occur argillaceous micaceous reddish gray or black shales, with beds of limestone in the upper part but without fossils.

In San Luis Potosi, at Catorce, there are in the upper part shales and marly sandstones and compact limestones.

In the State of Tamaulipas, at Miquihuana, there are beds of sandy shales and limestones which rest upon sand with pebbles of quartz but which are unconformable upon the older Mesozoic strata. According to Hill they closely resemble the beds of the Trinity group of Texas but have a different fauna. Felix and Lenk believe that these beds represent the littoral facies of their Monopleura beds of Tehuacan.

In the northern part of the State of Zacatecas (at Mazapil, Santa Rosa, Concepcion del Oro, and Canutillo) the Eo-Cretaceous begins with marl and limestone. Above these come bluish limestones and other limestones with large concretions of chert, having a thickness of 400 or 500 meters but poor in fossils, and yellowish marls containing many forms. These last-named beds may serve as the plane of separation between the Eo-Cretaceous and the "Meso-Cretaceous."

Occurrences of "Meso-Cretaceous" strata are specifically listed by Aguilera from the following localities in several States:

In Chiapas and Guatemala there are limestones and dolomites, in general in thick beds but in some places occurring in thin beds. Some of the layers present a brecciated structure. In the lower part the limestones include concretions and nodules of chert; in the upper part they inclose intercalations of dolomite. These limestones form an extensive belt which runs through the center of the State of Chiapas, passes on to Guatemala, and ends in the Gulf of Honduras.

In the State of Michoacan, at Coalcoman, are compact black and gray limestones. At Aguililla occur compact gray and blackish limestones with chert, but without fossils. At Huetamo are compact limestones and calcareous shales.

In the State of Mexico, at Zumpahuacan, in the Sierra de San Gaspar, are compact gray yellowish-white limestones. In Morelos the horizon is represented at Ayala and Yontepec.

In Jalisco fossils of the "Meso-Cretaceous" have been obtained at Saistra, Sierra de Tapalpa, and at the hacienda of Huilcalapa, Canton de Zapotitlan.

In the State of Vera Cruz the limestones of Orizaba may be divided, from above downward, into the Escamela limestones, which are gray and occur in thick beds with a facies of Rudistes and Chamides, and the Maltrata limestones, with blackish cherts and without fossils.

In the State of Queretaro, at Cadereyta, occur compact gray fetid limestones, limestones with chert, and calcareous and argillaceous shales.

In the State of Hidalgo, at Zimapan, are compact gray fetid limestones with calcareous shales.

In the State of Zacatecas, at Mazapil, Santa Rosa, Concepcion del Oro, Fresnillo, Comacho, and Noria de Angeles, occurs a pelagic facies. It consists of limestones with black chert, having a thickness of 400 to 500 meters or more. In the vicinity of Colima there are limestones and shales. On the eastern slope of the Sierra de Tamaulipas, near Victoria, occur limestones and shales.

In the State of Chihuahua the transition stage to the Cenomanian occurs at several places in the Cerro Muleros, near Ciudad Juarez, with argillaceous sandstones and shales, and at Encantada, near Placeres de Guadalupe, where there are shaly limestones and marly schists. This stage corresponds to the Fredericksburg group, or some portion of it, of the Lower Cretaceous of the United States. At Arivechi, in the State of Sonora, there are calcareous and marly shales.

The Cenomanian is well developed throughout in the States of Chihuahua (Cerro de Muleros) and Coahuila (Hacienda de Vacas, Rancho de San Diego, Santa Eulalia, Javal, etc.), consisting of limestones and gray compact shales with a littoral facies and a rich fauna. Characteristic fossils occur in the limestones and shales of the Sierra Mojada.

For the Neo-Cretaceous (Upper Cretaceous) see Chapter XV (p. 644).

F 14. SAN LUIS POTOSI.

In examining the section along the railway line between San Luis Potosi and Tampico, Böse [89] studied a Cretaceous series which is distinguished by a peculiar facies that is not represented as a whole elsewhere in North America, except perhaps in Jamaica. He has described the fauna and correlation in detail. The following statement regarding the stratigraphy is extracted from his work:

> The strata which contained the fauna described in this work constitute a complete whole to which we give the local name Cardenas division, for the facies is very different from that of any other Cretaceous formation in America. It has a sufficiently great thickness, which may be estimated approximately at 600 meters; this amount is naturally not exact, as the strata have been greatly folded, and it has not been possible to establish with certainty the existence of any younger beds. Lithologically, the Cardenas division is composed of various formations. Above the heavy-bedded limestones which form the canyon of Tamocopo, in the upper portion of which we have not been able to find determinable fossils, there occur in the vicinity of Canoas station arenaceous limestones, which alternate with marls and with clay and marly slates. Above these slates occur heavy beds of limestone, which are in part marly, and still higher there again appear marly and arenaceous slates, which pass gradually into heavy-bedded limestones. These are poor in fossils and are followed at first by yellow clay slates without fossils, upon which rest marly yellow slates with intercalations of sandstones of the same color, which are fossiliferous. The top of the division is composed of marls of a grayish-yellow color, with some beds of limestone. The beds are very strongly folded and their order of succession can not be made out.

Stanton[a] states:

> Near the eastern margin of the Mexican plateau, between San Luis Potosi and Tampico, there is a thick Cretaceous section which evidently includes the equivalent of a large part of the Comanche series as well as some Upper Cretaceous. A part of the latter which shows a faunal and lithologic facies not known elsewhere in North America has been described by Böse under the name Cardenas division and referred to the lower Turonian. Its thickness is estimated at 600 meters. The presence of *Exogyra costata* and *Gryphæa vesicularis* suggests its approximate correlation with the Ripley of the Southern States, but the rest of the fauna is distinct and in its general character more nearly resembles that of Jamaica and of the European Gosan beds.

[a] Personal communication.

G 13-14. SIERRA DE MAZAPIL, ZACATECAS.

Burckhardt[109a] thus describes the Eo-Cretaceous and "Meso-Cretaceous" of the northern part of Zacatecas:

The Cretaceous limestones that overlie the shaly formations which we have just described represent the complete series from the upper limit of the Jurassic to the Upper Cretaceous. Near the middle of their thickness these limestones are divided into two parts by a very fossiliferous bed of marl known as the "Parahoplites bed." Furthermore, there is at the base of the sequence a second marly bed, which is also rich in fossils, the "Holcostephanus bed." By means of these fossiliferous marls, it is possible to establish four subdivisions of the Lower and Middle Cretaceous of Mazapil. The lower marls, which contain Holcostephanus, are rather thin and separated from the Jurassic by thin strata of gray limestone.

These marls are generally yellowish and contain many nodules of iron oxide. They alternate with beds of grayish or brownish limestone. Fossils are very numerous.[a] * * *

Above the marls with Holcostephanus there follow limestones which have a thickness of 400 to 500 meters and which are generally markedly distinguished by intercalations of chert. These cherts, which are usually brownish at the surface and bluish in the interior, are commonly of very irregular forms, and never assume a notably horizontal extent, as is the case with the layers of chert in the Middle Cretaceous. It is very difficult to extract any fossils from the rock, and the only fairly good specimen which I have found is a fragment of Holcodiscus. * * *

Between the limestones which have just been described and those of the Middle Cretaceous, there occurs an argillaceous terrane, which may readily be recognized throughout the Sierra de Santa Rosa. * * * The beds are not thick, but very characteristic—marls and marly limestones of a bright-yellow color, alternating with compact limestones which are grayish, bluish, or slightly brownish. They everywhere contain many fossils.[a] * * *

The Middle Cretaceous is represented by a very thick series of grayish limestones, which are generally well stratified and alternate with layers of black chert. These limestones attain a thickness of 400 to 500 meters and are easy to recognize, as there is no other division of the Jurassic or Cretaceous of Mazapil which offers so great a thickness of well-stratified limestones in alternation with such regular beds and lenses of black chert. The intercalations of chert have almost always great extent. They are strata rather than lenses. The rocks are not poor in fossils. On the contrary, the beds abound in open ammonites, generally rather slender, belonging to the genera Hamites, Crioceras, Ancyloceras, and probably Hamulina. But these remains are not specifically determinable.

Burckhardt's table is given in Chapter XIII (pp. 552–553).

H 12. SOUTHEASTERN ARIZONA AND SONORA.

In the Bisbee district of Arizona Comanche strata overlap on Paleozoic, according to Ransome,[658d] who gives the following section:

Generalized section of the Cretaceous rocks of the Bisbee quadrangle, Arizona.

Bisbee group (Comanche series.)	Cintura formation, 1,800 feet plus unknown thickness, removed by erosion.	Red nodular shales with cross-bedded, buff, tawny, and red sandstones. A few beds of impure limestone near base. Unconformably overlain by fluviatile Quaternary deposits.
	Mural limestone, 650 feet.	Thick-bedded, hard, gray, fossiliferous limestone.
		Thin-bedded, arenaceous fossiliferous limestones.
	Morita formation, 1,800 feet.	Buff, tawny, and red sandstones and dark-red shales, with an occasional thin bed of impure limestone near top.
	Glance conglomerate, 25 to 500 feet. Great unconformity.	Bedded conglomerate with rather angular pebbles, chiefly schist and limestone. Rests on irregular surface produced by erosion.

[a] For list see the work cited.—B. W.

Ransome describes the four formations in detail. Fossils were obtained chiefly from the Mural limestone and Stanton reported on them as follows:

The collection consists of a considerable number of small lots of fossils, with seldom more than three or four species from one locality, and it includes a number of undescribed forms. The known species that are recognized, however, are sufficient to prove that only the fauna of the lower Cretaceous, or Comanche series, is represented in the collection. The identified species all occur in Texas, indicating that the waters in which the Arizona deposits were laid down were directly connected with the Comanche sea of Texas and Mexico, which probably did not extend much farther west than the Bisbee area.

In the Texan region three principal divisions are recognized in the Comanche series—Trinity, Fredericksburg, and Washita. All of the identified species in this collection occur in the Glen Rose beds of the lowest or Trinity division and only one of them (*Lunatia pedernalis*) is known to pass up into the lower members of the Fredericksburg division.

A list of species referable to the Glen Rose limestone of Texas follows.

Dumble[295] cites Aguilera's description of the Cretaceous in Mexico and gives accounts of the strata west of Casita, near Zubiate, Hermosillo, and particularly near Cabullona, northeast of La Morita. He says:

By far the best exposure observed is that near Cabullona, northeast of La Morita. Here appears a great series of Cretaceous rocks, probably including strata belonging to both the Lower and Middle divisions of the Mexican geologists, with other beds of which I find no description at all.

A section made about 2 miles from the Cabullona ranch house gave the following:

1. Interbedded sands and clays of varied colors. The materials are altered in places by metamorphism, some being quartzitic, and some of the clays hardened and greasy. There are some intercalated andesitic beds and dikes of porphyry. The top was not seen, 1,000 feet.

2. Massive limestones; light-colored semimarbles at the top, followed by brown and gray limestone. All the beds are very fossiliferous, but the fossils appear only as cherty protuberances on weathered surfaces and in many cases are so broken as to be scarcely distinguishable. Among the forms certainly recognized were a small Gryphæa and a Trigonia (like *T. emoryi*). The middle beds carry flints in considerable quantities, and the Gryphæa occurs in the basal portion in great numbers, 500 feet.

3. A series of interbedded marls and marly limestones, with large numbers of a very heavy oyster, Trigonia, Cardita, and other forms, 900 feet.

4. Quartzites, sands and interbedded clays or marls; bottom not seen, 400 feet.

Except for their metamorphosed condition, the uppermost beds of this section resemble very closely the "coal series" of the section made at Eagle Pass, Texas, and, like those beds, they are coal-bearing. They cover quite an extensive area in this region but are badly cut up and disturbed by eruptive intrusions. These beds comprise alternations of sands and clays with ferruginous concretions (some of which are of large size), considerable quantities of gypsum, and some petrified wood. The sandstones vary from fine-grained to grit, and the clays from those nearly pure to those with a large admixture of sand. The metamorphism directly or indirectly due to the volcanic extravasations which accompanied and followed the deposition of these beds has produced, in addition to its indurating effects, bright-purple and greenish colors in some places, so that some of the beds closely simulate those of the tuff itself. The beds are somewhat faulted and broken. Our work did not extend far enough to the north to reach the top of the beds, which are certainly more than 1,000 feet in thickness. The only fossils found were specimens of a small square-beaked oyster, which occurred just below the coal.

There are two beds of coal, both highly altered. The lower is quite graphitic, and the upper, while retaining the structure of bituminous coal, is an anthracite in its composition.

The massive limestones underlie these sands and clays, and, as far as could be seen, without any unconformability. These limestones seem to correspond very well with Aguilera's description of the Middle Cretaceous. The Gryphæa which they carry in such abundance resembles very closely the variety found at the base of the Fredericksburg beds, in northern Coahuila.

H 13. QUITMAN MOUNTAINS, TRANS-PECOS TEXAS.

The Quitman Range crosses the thirty-first parallel near longitude 105° 25′ and extends northward to Malone Mountain and southward to the Rio Grande. The development of the Comanche series in the southern portion of the range is thus described by Stanton[177a] in Cragin's report on Malone Mountain:

Cretaceous rocks have a great development in this region and represent the three main divisions of the Comanche series—the Trinity, Fredericksburg, and Washita—as well as a part of the Upper Cretaceous. Lithologically the section differs greatly from that of central Texas, where the Comanche series has been most studied, and there are also considerable differences in the vertical range of some of the common species, so that it is impracticable to recognize many of the minor formations and horizons that have been studied. The general faunal succession is the same in both regions, and it is usually not difficult to classify the beds by means of the fossils as Trinity, Fredericksburg, or Washita, though it was difficult and sometimes impossible to assign each exposure to its exact position in the general section, because many of them are relatively small and isolated and the structure is complicated by folds, faults, and igneous intrusions. The most complete sections are to be found in the Quitman Mountains, especially toward the southern end and in the lower hills farther south on the Rio Grande, in the southern extension of the same line of uplift.

The description of the Quitman Range comprises notes on structure and on igneous intrusions, as well as on stratigraphy, and the more complete section near the Rio Grande is given as follows:

Still farther south, near the Rio Grande, the upper part of the section is much more complete and more simple, furnishing the key to the sections already discussed, which are parallel with it across the same line of uplift. The eastern end of the section is about 1 mile north of the Rio Grande in the first hills west of the broad valley of Quitman Arroyo. Here the beds are sharply folded and a prominent ridge shows an anticline consisting of argillaceous limestone belonging to the Washita division.

The western limb of the anticline dips 70° to 80° W., and the exposure is as follows:

Section in hills just west of Quitman Arroyo, about 1 mile north of the Rio Grande.

	Feet.
1. Argillaceous limestone, weathering in nodular form, with bands of harder limestone	200
2. More massive limestone, much seamed and fissured	30
3. Dark, fissile shale, with occasional bands of impure brown limestone, underlying a valley about 1 mile wide. Dips at first steep to the west, becoming variable and much less toward the middle of the valley and again steep to the west on the west side of the valley. *Inoceramus labiatus* and a few other Upper Cretaceous fossils were found west of the middle of the valley; thickness apparently several thousand feet.	
4. Massive limestone, probably same as No. 2	30
5. Argillaceous limestone with some bands of clay and sandstone; fossils: *Nodosaria texana*, *Enallaster texanus*, *Neithea texana*, *Exogyra arietina*, *E. drakei* var., *Plicatula incongrua*, and other Washita forms	300
6. Heavy-bedded limestone (40 feet) forming a cliff, followed by argillaceous nodular limestone (30 feet), which yielded *Enallaster texanus*, *Gryphæa corrugata*, *Lima wacoensis*, *Neithea texana*, and *Schlœnbachia vespertina*	70
7. Similar limestones with dip not less than 45° westward	300

		Feet.
8.	More argillaceous light-gray limestone, interstratified with dark clay shales; one of the limestone bands yielded *Epiaster whitei*, *Terebratula* (*Kingena*) *wacoensis*, *Gryphæa washitaensis* (?), *Plicatula incongrua*, and *Schlœnbachia vespertina*, and another band farther west yielded *Epiaster whitei*, *Schlœnbachia acutocarinata*, *S. serratescens*, and *Hamites fremonti*....	300
9.	Dark clays with brownish calcareous bands; *Exogyra texana* abundant	50
10.	Covered	100
11.	Limestone, very heavy bedded above, with increasing bands of argillaceous limestone below; Requienia and a small conical Foraminifera abundant; *Exogyra texana* also occurs	300
12.	Shales, limestones, and bands of brown sandstone, not well exposed	250
13.	Argillaceous limestone, with some harder bands containing "Caprina" and Requienia	75
14.	Generally more massive limestone with some bands of brown sandstone. Also contains "Caprina," Ostrea, etc	350
15.	Quartzitic sandstone with thinner bands of clay shale and impure limestone, dipping steeply westward	400
16.	Hard, blue limestone, full of *Orbitolina texana*	60
17.	Sandstone and impure limestone with some clay	40
18.	Sandstones and clays	250
19.	Thin-bedded passing into massive limestone, full of *Orbitolina texana;* at least	300

The steep western surface of No. 19 forms the eastern wall of the canyon of the Rio Grande at this point.

So far there has been no apparent serious break in the section, but the beds now become complexly faulted and folded. A short distance north No. 19 is cut off by a fault, and on the west, across the river, the same bed seems to be repeated in several postures.

It is evident that the eastern portion of the section crosses a syncline, so that in passing from No. 1 to No. 5 the same beds are all crossed twice. In the rest of the section, while there may be some repetition of beds due to small faults, there are no anticlines nor synclines, and the fossils show that in general the beds are successively older toward the west. No. 3 is Upper Cretaceous, of the age of the Fort Benton; Nos. 4 to 8 are Washita; Nos. 9 to 14, and probably 15, are Fredericksburg; and Nos. 16 to 19 belong to the Trinity. As the dips are all steep to the west it follows that all the beds from No. 4 to No. 19, inclusive, are overturned. It will be seen also that the succession of rocks and fossils is similar to that found on the east slope of the mountains near Quitman Canyon, and that there is no place for the great sandstone series of the "Mountain bed" within the Washita division. It must be older than the Orbitolina limestone.

H 13. CHISOS REGION, TEXAS.

For the region lying in the great bend of the Rio Grande in Brewster County, Tex., the report prepared by Udden in 1905 may be consulted. He sums up as follows:[819b]

It was not attempted to make out the succession of separate divisions in the Comanche series, for this would have required much more time than was at our disposal, but it may nevertheless be worth the while to sum up the observations made bearing on this subject.

1. The base of the series consists of sandy or clayey beds containing calcareous material also, weathering rather easily. At Cienega Mountain these strata have a thickness of about 150 feet.

2. At about 150 feet above the base there is a conglomerate or a pebbly sandstone measuring some 20 feet. These two members, and very likely a part of the succeeding beds above, are absent at Altuda, where they probably never were laid down, owing to an overlap.

3. At an unknown distance above this conglomerate there are some dark ledges of very compact limestone interbedded with some shaly seams, and these are followed upward by several hundred feet of heavy-bedded limestones of lighter color. These lowest three divisions are equivalents of the Presidio beds in the Shafter section.

4. Then follow 200 or 300 feet of more thin-bedded and less pure limestones, which weather more easily and contain a fauna resembling that found in the Shafter beds.

5. Above this there are several hundred feet of very massive light limestone, which is clearly the equivalent of the Edwards limestone.

6. The last and highest of the series is a compact limestone only some half a hundred feet thick, which is the equivalent of the Buda. It is separated from the massive beds below by some 20 feet or more easily weathering ledges which are frequently filled with organic fragments and which correspond to the Del Rio clay.

At Terlingua both the Buda and the Del Rio zones are much heavier than to the east of the Chisos. These formations clearly thin out or entirely disappear in this direction.

H 13. TEXAS, NEAR EL PASO, AND CHIHUAHUA, MEXICO.

Near El Paso, Tex., occur strata of Cretaceous age, which represent the Fredericksburg and Washita groups of the Comanche series. They consist of about 700 feet of limestone, shale, and sandstone of which Stanton and Vaughan[787] gave a detailed section. This section is quoted below, with a correction in the relations of divisions 8, 9, and 10. As observed in the field and as described in the published section these beds were inverted.

The following is a description of the section beginning with the highest bed:

Columnar section of Cretaceous near initial monument of Mexican boundary survey, on west side of the Rio Grande from El Paso, Tex.

		Feet.
	8. Hard limestone with the same species of Exogyra in the top	15
	9. Clay shales, with bands of limestone nodules, containing great numbers of a large Exogyra	40
	10. Sandstone, white, yellow, or brownish, with shale beds	200±
	7. Sandstone, white or brown	30+
Washita division.	6. Upper part of the bed, clay shales alternating with brown sandy flags. Brown sandy calcareous layers at base, containing *Gryphæa washitaensis* Hill and *Nodosaria texana* in great abundance. The *G. washitaensis* is confined to base; 30 feet above the base, *Ostrea subovata; Ostrea quadriplicata* Shum. very abundant between 30 and 40 feet; 40 feet above base zone of *Kingena wacoensis*	60
Washita division.	5. Flaggy argillaceous limestone, with shale partings. Layer of sandy flags at base. In the sandy flags, Cyprimeria. In the limestone bands *Schlœnbachia leonensis, Gryphæa washitaensis*, Protocardia, *Trigonia emoryi*. The zone of *G. washitaensis* is at the top	100
Washita division.	4. Clay shales, with indurated calcareous bands. No fossils were found	125
Washita division.	3. Ledges of hard limestone. Fossils not numerous; at the base there is a considerable number of an undetermined species of Gryphæa, *Gryphæa tucumcarii*, Neithea, and Schlœnbachia	25
	2. Alternations of clay and soft argillaceous limestone ledges. Fossils: *Exogyra texana, Gryphæa tucumcarii, Gryphæa forniculata, Schlœnbachia peruviana*, two other species of Schlœnbachia, and a large Neithea	24
Fredericksburg division.	1. Argillaceous limestone, in thick ledges, weathering into nodular limestone, the nodules surrounded by clay. Fossils: *Protocardia texana, Tylostoma pedernalis*, Trochus, Turritella, *Exogyra texana*, an anchuroid genus, two species of echinoids, *Pleuromya knowltoni*, Requienia, etc.; 11 feet from the top *Ostrea subovata* (?)	79
		698±

* * * * * * * * *

Taking the fauna of the section as a whole, its essential identity with that of the noted Tucumcari region in New Mexico and of other localities on the western and northern borders of the Lower Cretaceous area is at once apparent.

The section studied by Stanton and Vaughan at El Paso occurs in the Cerro de Muleros, which extends into Mexico and has been investigated by Böse,[91] who presents a different interpretation of the sequence. He says:

We have elsewhere stated that we differ on several points from the ideas of the authors mentioned. The errors of Stanton and Vaughan resulted from the fact that they did not clearly understand the structure of the locality and consequently counted the same sandstone twice as two beds of different ages. At several points where the series of strata is clearly exposed and but little disturbed we have been able to observe the true succession. In our excursion we followed in part the road which Stanton and Vaughan followed, and we shall see what led to their mistake.

All of the sedimentary rocks with the exception of the recent conglomerate and sands belong to the Cretaceous. Stanton and Vaughan recognized only their lower part, of which they give a list of fossils, but their determinations differ in many cases from ours. With reference to this subject we would refer the reader to our publications.[a] Stanton and Vaughan distinguished in this lower part ten horizons which we are obliged to reduce to eight, but these horizons can not be classed as real stratigraphic horizons. There are in fact in the lower part only two horizons, to which we must also add two higher horizons which may be considered as such. We give a summary of the distribution of fossils in the rocks.

In his monograph on the Cerro de Muleros, which was not published until the summer of 1910, Böse[92] says:

According to my observations the succession of the beds is as follows (from above downward):

No. 11. Brown sandstones alternating with argillaceous slate or shale, frequently containing *Inoceramus labiatus* Schloth.; 110 meters.
No. 10. Whitish to yellowish sandstone, highly quartzose and fine grained, with satiny argillaceous shale at the base, without fossils; 250 meters.
No. 9. White to clear gray limestone with *Exogyra ponderosa:* 10–20 meters.
No. 8. Yellowish marls with *E. ponderosa, Hemisater calvini* Clark, etc.; 10–20 meters.
No. 7. Red, brown, and black sandstone in heavy beds, with *E. ponderosa;* 20–100 meters.
No. 6. Slate-colored brownish marls, sandstones, and limestones, with *Ostrea quadriplicata;* 10–20 meters.
No. 5. Gray marls with marly shales and beds of limestone with *Schlœnbachia trinodosa;* 30–50 meters.
No. 4. Argillaceous shales, marls, and beds of limestone, with *Schlœnbachia nodosa;* 30–50 meters.
No. 3. Gray limestones in thin-bedded calcareous gray sandstones and brown to yellow marls and black argillaceous shales, with *Schlœnbachia* cfr. *belknapi;* 10 meters.
No. 2. Brown marls with beds of limestone and calcareous sandstone with *Schlœnbachia bravoensis;* 10–20 meters.
No. 1. Hard limestones in thick beds and of a gray color, with *Turritella vibrayeana;* 20–25 meters.

Our subdivisions 1 to 7 correspond to the horizons which were numbered 1 to 7 by Stanton and Vaughan, 8 and 9 to the horizons 9 and 8 of those authors, since in fact the limestones with *E. ponderosa* are above the marls which carry the same fossil. That which Stanton and Vaughan regarded as their horizon No. 10 is in reality the same sandstone as their horizon No. 7, and the two American authors did not see our subdivisions 10 and 11. We shall see in the discussion of the structure why they mistook a recumbent synclinal for a normal succession. If they had gone on to the porphyry they probably would not have fallen into this error, since one may there see clearly that the beds or the strata with *Ostrea quadriplicata* rest on the sandstone No. 7 of our classification, which is the horizon No. 10 of Stanton and Vaughan.

Richardson[666a] studied the occurrences of the Cretaceous near El Paso north of the Rio Grande and made some subdivisions. He says:

The Cretaceous system is represented here by the Fredericksburg and Washita groups of the Comanche series. The Trinity group has not been recognized in this area, nor has the Upper Cretaceous been found (with the possible exception that a few small areas of shale in the city of El Paso are of Upper Cretaceous age), though rocks belonging to both of these ages occur not far to the south and west.

The Fredericksburg is separated into three formations—the Campagrande, the Cox, and the Finlay, which are differentiated by their lithologic features. All these contain Fredericks-

[a] Böse, Emil, Monografía geológica y paleontológica del Cerro de Muleros, cerca de Ciudad Juarez, Chih.: Bol. del Inst. Geol. de México, No. 25.

burg fossils, but the faunas of the individual formations have not been collected with sufficient fullness to permit their paleontologic definition. * * *

The lowermost formation of the Fredericksburg group is composed of calcareous rocks that are well exposed in the Finlay Mountains, where, in the central part of the dome, they lie unconformably on the Hueco formation. At the base of the Cretaceous section is a limestone conglomerate about 25 feet thick composed of rounded pebbles of Carboniferous limestone averaging possibly about 2 inches in diameter. Above this are 350 feet of gray limestone, which is generally massive but locally contains nonpersistent, thin-bedded limestone grading into shale. * * *

The Campagrande formation is conformably overlain by the Cox formation.

The Cox formation consists of massive soft brownish sandstone, some intercalated gray limestone, and near the base a red-drab shaly member. The formation averages about 600 feet in thickness and is subject to variation in composition, so that no one section is typical. Sandstone predominates and composes probably nearly 500 feet of the formation. It is usually fine textured, but there are some coarse beds of no great thickness containing quartz pebbles as large as marbles. Locally the sandstone is pitted with rounded iron stains the size of buckshot, which seem to be due to the weathering of pyrite nodules. In places the sandstone is cross-bedded. The intercalated limestone and shale are usually thin bedded and are generally fossiliferous. The shaly member in the Finlay Mountains is about 100 feet thick. * * *

The Cox formation * * * is conformably overlain by the Finlay formation, [which] consists almost entirely of massive gray nonmagnesian limestone, but locally thin beds of brown sandstone are included. There are at least 300 feet of the Finlay formation exposed in this region, but the top has not been found. * * *

Rocks of Washita age are present as outlying masses in several localities. The thickness of the strata is not great and it has not been found practicable definitely to correlate the different exposures. They look much alike, being commonly buff-colored calcareous shale and thin-bedded limestone with occasional subordinate sandstone.

H 14. LLANO-BURNET REGION, TEXAS.

From his studies in 1910, the results of which are published in folio 183 of the Geologic Atlas of the United States, Paige gives the following sections of the Llano-Burnet region of Texas:

In the Llano-Burnet region only the Fredericksburg and Trinity groups of the Lower Cretaceous are represented. Although in the Austin quadrangle [a] to the southeast, the Trinity group was subdivided into the Glen Rose and Travis Peak formations, it was found impractical for the following reason to make this distinction in the Burnet quadrangle. The Travis Peak formation, while a definite lithologic and paleontologic unit in the southeast corner of the Burnet quadrangle, loses these characteristics toward the north. This change is due to changes in the conditions of sedimentation along a slowly subsiding coast line. Owing to the gradual transgression of the sea over the land and the concomitant lowering of the surface which supplied débris for sedimentation, the sediments grew finer and more calcareous, the basal beds thinner and less conglomeratic, until a condition existed where only nearly pure limestones were being deposited along low, gently sloping shores. The following formations have been mapped in the Llano-Burnet area: The Edwards limestone; the Comanche Peak limestone, including the Walnut clay; and the Trinity formation, including the undifferentiated Travis Peak and Glen Rose. The following sections afford examples of the several formations.

[a] Hill, R. T., and Vaughan, T. W., Austin folio (No. 76), Geol. Atlas U. S., U. S. Geol. Survey, 1902.

Hickory Creek section of the Travis Peak formation, beginning at the top of the divide between Hickory and Cow creeks and continuing to the Colorado River level at the mouth of Hickory Creek, Burnet County.[a]

	Feet.
12. Bands of conglomerate and calcareous sandstone, alternating with beds of arenaceous limestone, the arenaceous limestone predominating	40
11. Marly magnesian limestone	40
10. Calcareous sand at base, grading upward to a siliceous limestone at the top, barren of fossils	55
9. Yellow calcareous sand, stratified	15
8. Conglomerate similar in character to No. 2, with the exception that the pebbles are smaller and more worn, grading into sand below and into calcareous sand above	25
7. Red sand, unconsolidated	3
6. Friable yellow sand	5
5. Cross-bedded shell breccia, containing many small rounded grains and pebbles of quartz flint and granite sand. Fossils: Trigonia and small bivalves, and *Ammonites justinæ*	7
4. Ostrea beds, magnesian lime cement, fossils en masse	3
3. Brecciated grit, composed of worn fragments of oyster shells and shells of other Mollusca, with sand and fine pebbles, stratified in false beds	5
2. Bands of friable bluish shale and calcareous sand, stratified. Fragments of oyster shells are common in the calcareous sandstone	15
1. Basal conglomerate of pebbles of limestone, quartz, chert, granite, and schist, well rounded in a cement of ferruginous yellow and red gritty sand. Some of the pebbles at the base are from 5 to 6 inches in diameter. They decrease in size, however, upward from the base, until a false-bedded calcareous shell grit appears at the top	50
Total thickness of Travis Peak beds	263
Carboniferous:	
Laminated, flaggy Carboniferous sandstones and friable light-blue clay of Carboniferous (Coal Measures) age from the Colorado River level upward to the base of the Trinity conglomerate, the laminated sandstone containing prints of ferns, nearly	100
[Total thickness of section]	363

Section at Post Mountain, 1 mile west of Burnet.[b]

	Feet.
Fredericksburg division:	
5. Barren Edwards limestone and Comanche Peak limestone	95
4. Walnut clay	10
	105
Trinity division:	
3. Impure arenaceous limestone and marl with aragonite crystals	25
2. Limestone agglomerate of shells with asphaltum	25
1. Reddish sandy clays and conglomerate	20
	70
Paleozoic.	
	175

Section of Trinity formation.

From divide west of Cow Creek on road southwest to bench mark 842.

	Feet.
Chalky white limestone, weathering porous or honeycombed; fossils	15
Similar but not honeycombed; weathers knotty	20
Covered slope	40
Wagon road.	
Buff-weathering limestone; no fossils	12½

[a] Section by J. A. Taff (Hill, R. T., Geography and geology of the Black and Grand prairies, Texas: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1901, p. 140).

[b] Hill, R. T., op. cit., p. 136.

	Feet.
Porous honeycombed limestone; no fossils	2
Buff limestone, massive, weathering somewhat nodular; 2 feet at base somewhat shaly	7½
Fine-grained sandy limestone	10
Fine-grained sandy limestone, shaly	1
Yellowish limestone, more massive and less sandy	4
White clay	1
Coarse buff limestone	4
Oyster shells in sandy layer	2
Massive limestone, weathering yellow	4
Shaly yellow limestone, nodular and full of oysters	8
Shaly, with thin limestone layers	6
Hard, porous, dense, buff-weathering limestone	1½
Oyster-shell breccia	3
Clay or sand containing chalky nodules	5
Chalky layer	½
Clay or sand containing chalky nodules	3
Hard, dense buff limestone, shaly at bottom	5
Nodular limestone, weathering into nodular clay	8
Siliceous limestone	3
Oolitic fossiliferous shaly-weathering limestone	10
Coarse reddish limestone	5
White clayey limestone with shaly weathering	3
White sandy honeycombed limestone	2
Sandy and nodular-weathering limestone	6
Dense dull-white limestone	1
Nodular-weathering limestone	10
Dense brown limestone	1
Clayey limestone, weathering nodular	4
Dense buff limestone, weathering nodular, with calcite films and sand grains	10
Nodular-weathering limestone, possibly conglomerate	7
Like above, but containing coarser grains of quartz	16
Stream at bottom of slope.	
Clays, yellow, honeycombed at base	10
Light-colored limestone, somewhat gritty; makes small bench	5
Soft layers, covered	5
Hard limestone	2
Alternating hard and soft beds, clay and marly limestone, not very fossiliferous; makes small terraced slopes	30
From top of slope northeast of bench mark 842.	
Sandy limestone; few fossils	5
Sandy limestone with many shells	15
Covered	5
Fine sandy limestone with fossils	5
Fine sandy limestone; not many fossils	8
Fine-grained conglomerate, in places shaly	5
Covered	5
Conglomerate, weathering nodular	5
Covered	18
From bench mark 842 downstream.	
Sandy conglomerate	10
Oyster shells	1
Sandy conglomerate	1
Sand and sandy conglomerate	9½
Conglomerate and oyster shells	4
Covered	20
	409½

Section of portion of Trinity formation, 2½ miles west of southeast corner of Burnet quadrangle, at south edge of quadrangle, from top of hill down to Cow Creek.

	Feet.
Soft sandy marl containing lamellibranchs	5
Covered terrace	5
Buff-weathering, massive, slightly honeycombed limestone containing fragments of shells	2½
Sloping terrace of softer marly limestone	7½
Steeply sloping surface underlain by nodular gray limestone with 2-inch layer of slightly gritty material	9
Buff-weathering sandy limestone	6
Light-buff calcareous shale, weathering nodular, containing some fossils	10
Sandy calcareous limestone containing numerous fossils	5
Sandy limestone	10
Covered slope, probably underlain by soft bedded limestone	14
Sandy limestone	1
Soft, knotty, marly buff limestone	5
Covered gentle slope	5
Cream-colored limestone, slightly sandy	1
Clayey marl; top 1 foot very fossiliferous; 5-inch band of buff limestone 2 feet from top	19
Marly beds with hard layers containing some fossils	8½
Yellow porous limestone containing shells	5½
Similar, but more massive	6
Similar, but thin bedded	5
Similar, but shaly	14
Solid yellow limestone	6
Thin-bedded fossiliferous limestone	9
Massive chalky limestone, with fossils	6
Massive chalky limestone	15
Shaly limestone, transition from above	8
Fine-grained massive yellow limestone	7
Calcareous shale	10
Fine-grained gray sandstone, calcareous	5
Covered slope	10
Conglomerate with many pebbles	27½
Total in cliff and side of hill	247

H-I 14. CENTRAL TEXAS.

From Hill's detailed monographic discussion of the Cretaceous of Texas[445] are taken the following extracts:

The strata of the Lower Cretaceous, or Comanche series [in central Texas] * * * belong to three divisions, as follows, beginning with the lowest: Trinity, Fredericksburg, and Washita. The general characteristics of these divisions are as follows:

The Trinity division is especially marked by strata of friable white packsands, which do not occur in the other divisions and which in places constitute nearly the entire rocks of the division. In some places, especially south of the Brazos, these sands alternate with marly clays and chalky and clastic limestones, the latter being composed of minute shells or fragmental particles of shells and sands having a lithologic and paleontologic individuality by which they can usually be readily distinguished. All the calcareous strata are white or yellowish and occur in numerous persistent alterations of hard and soft strata of various thicknesses.

The rocks of the Fredericksburg division in the typical area of occurrence are almost entirely chalky limestone, initiated by beds of marly clay, which grade into the limestone.

The rocks of the Washita division include the beds between the top of the Edwards limestone of the Fredericksburg division and the coarse sands of the Woodbine (Dakota).

The sediments of the Washita division, while generally light in color in their lower half, show darker tones and greater ferrugination of rocks toward the top. They are composed largely of alternations of marly clays and firmer layers of limestone. The limestones of this division, while slightly resembling others in the series, have a sufficient proportion of grit, and sometimes of iron, to make them relatively impure. The beds are successively shallower in origin in ascending series.

In general, rocks of the Trinity division were laid down upon a subsiding bottom of a former land surface; rocks of the Fredericksburg division (in this portion of Texas) upon a stationary offshore bottom of Trinity sediments; and rocks of the Washita division upon a shallowing bottom of Fredericksburg sediments.

TRINITY DIVISION.

This division includes the lower or initiatory beds of the Cretaceous formations of the Texas region, embracing all the rocks lying below the Walnut beds of the Fredericksburg division. * * * In general these strata consist of sands, clays, marls, and massive limestones (including in the latter shell breccias, agglomerates, and chalks), all of which grade imperceptibly into one another, both vertically and horizontally, according to their proximity to the shore line against which they were deposited. * * *

Studies of these three areas, the western border, the incised sections of the Grand Prairie, and the embed beneath the Black Prairie, show great differences in thickness and composition of the rocks of the Trinity division, indicating that they are thinner and more arenaceous along the western border region, where they are best exposed, and that they thicken and become calcareous to the east, being buried in the region of their greatest development beneath the Black and Grand prairies, where a knowledge of their nature can be obtained only by careful interpretation of the artesian drillings. * * * As a result of these variations of thickness and composition the rocks of the Trinity division along the eastern portion of the general area of exposure within the incised valleys of the Edwards Cut Plain present the aspect of several well-defined and mappable lithologic units of various kinds of rock, which so coalesce along the western border exposures into a general basement formation of sands that they are there usually inseparable.

As a whole these strata of the Trinity division may be subdivided into the following conspicuous formations and beds:

Paluxy formation	Upper sands. Thin limestones. Lower sands.
Glen Rose formation.	
Travis Peak formation	Hensell sands. Cow Creek bed. Sycamore sands.

The term Basement sands will be used as the equivalent of any of the above formations where they rest upon the underlying Paleozoic floor. The name Antlers sands will be applied to the equivalents of all these formations as they coalesce along the western border region north of Parker County.

FREDERICKSBURG DIVISION.

During the Fredericksburg subepoch the Cretaceous shore reached west and north approximately to a line extending from El Paso north into southwestern Kansas. The area lying south and east of this line, as far at least as the eastern border of the Black Prairie, as shown by the extent of the Edwards limestone, was a great arm of the sea, the bottom of which was covered with calcareous organisms as certain banks of the present West Indian seas are now covered. Over the entire area thus covered by the oceanic waters the sea deposited a mantle of arenaceous, argillaceous, and chalky sediments which now make the rocks of the Fredericksburg division. * * *

As a whole, these sediments thicken and become more calcareous seaward, away from the position of the old peripheral shore line at the close of the Fredericksburg epoch. * * * This thickening took place by the accretion of calcareous layers offshore and horizontally away from the diagonal basement beds. * * * These changes in thickness were very gradual and can only be noted by comparing widely separated local sections. Hence the rocks of this division, as a whole, notwithstanding the variations to be noted, may be considered as presenting a remarkable example of uniformity of thickness and composition. In its entirety this division is composed of more calcareous rocks than the other divisions of the Comanche series. Although its interior margins ultimately pass into the Basement sands, this change mostly takes place beyond the borders of the east-central province, within which it is practically a great limestone formation (Edwards limestone), initiated by beds of clay (Walnut formation) at its base.

* * * The limestones of the Fredericksburg division thin toward the Rocky Mountains and the Ouachita uplifts to the north, and thicken southward or toward the Rio Grande, being in the neighborhood of 700 feet in the latter region and less than 30 along the southern foot of the Ouachita Mountains of Indian Territory. They ultimately pass into clays and sands around the western ends of the Ouachitas in southern Kansas and west of Texas in eastern New Mexico. * * *

In the area of its most typical if not greatest development, in the Grand Prairie region between the Brazos and the Colorado, as will be more fully set forth later, the limestone is further differentiable into two well-marked mappable subdivisions. In this region all sections of the Fredericksburg division present the following sequence:

1. At the base there are a few feet of calcareous clays intercalated with brecciated limestones, passing up into chalky layers, which become more numerous toward the top. These are the Walnut beds.

2. The chalky bands which begin to appear in the top of the Walnut clays are the beginning of a succeeding limestone formation (Comanche Peak limestone), which in this region is separated into two well-defined stratigraphic units. (*a*) The lowest of these is the Comanche Peak formation. This formation is composed of compact white rocks which on weathering shatter into numerous angular or conchoidal flakes, seldom weathering into ledges, and contain great numbers of casts of mollusks and echinoids. (*b*) Without break or apparent change in composition the rocks above the Comanche Peak begin to become harder, weathering into ledges often semicrystalline in character, and containing flint nodules and peculiar fossils of the types known as Requienia and Rudistes. These rocks form the Edwards limestone. The Comanche Peak beds are chiefly distinguishable from the succeeding Edwards limestone by the absence of flints and certain very peculiar fossils of the overlying beds, and by the fact that they weather into slopes instead of bluffs.

Stratigraphically there is no break between the various formations, and they pass upward or downward into one another by gradual transition. The marly lime of the upper portions of the Walnut formation grades into the chalky limestones at the base of the Edwards formation without demarcation.

The combined Comanche Peak and Edwards limestone thins out north of the Brazos, where it is no longer separable into individual beds [and is called the Goodland limestone]. On the other hand, it thickens south of the Colorado, where several distinct subdivisions could be made.

* * * * * * * * *

WASHITA DIVISION.

The Washita division has been defined as the uppermost of the three stratigraphic groups of the Comanche series. It is composed essentially of sediments laid down in a shallowing sea accompanying a regional uplift which followed the subsidence of earlier Comanche time. The Fredericksburg division ceases everywhere throughout its extent with the purer limestones of the Edwards formation. These limestones represent the deposition of the deepest waters of the Comanche epoch and the culmination of the subsidence which had been progressing since the beginning of Cretaceous time. The succeeding sediments of the Washita division within the east-central province are all of a less purely calcareous, [more] argillaceous, or arenaceous nature.

* * * * * * * * *

The beds of the Washita division in general are more varied in composition, of greater thickness, and more closely resemble shallow-water deposits toward the northern border region, extensive formations of ferruginous sands and bituminous clays occurring in that direction, which cease to the south. In general the strata of the Washita division, as a whole, become more calcareous to the south, but even this rule has its exceptions.

As a whole, the group decreases from about 400 feet in the Denison section on Red River to less than 175 feet in the Austin section, on the Colorado. This loss in thickness of the Washita division to the south is compensated for by a corresponding gain in that direction in the thickness of the Edwards limestone of the Fredericksburg division, so that the thickness of the Comanche series in its entirety is not impaired thereby.

The individual indurated beds of the Washita division seldom exceed a foot or two in thickness. The strata rarely extend through a hundred vertical feet without conspicuous lithologic or faunal changes. These individual beds are remarkably persistent in horizontal extension, especially when they are studied in large local areas, preserving their lithologic and paleontologic characters without any perceptible change for great distances. When the beds are traced through long distances, such as Texas provides, gradual important changes may be noted which can be appreciated only by comparison of widely separated minute local sections. What is a conspicuous clay formation in the Red River section may become a limestone when traced 300 miles south to the Colorado, or a formation which is a limestone upon Red River may be a clay on the Colorado.

Owing to these gradual changes in the character of the rocks the sections of the Washita division at the extreme ends of the area treated in this paper, as exemplified in the Denison and Austin sections, present entirely different lithological aspects and sequences, the relations of which would not be traceable were it not for the existence of certain well-determined paleontologic zones which persist regardless of the lithologic changes.

* * * * * * * * *

The Washita division presents several well-defined mappable units—eight, for instance, along Red River, and only three at Austin, on the Colorado.

In the region of its typical development as seen in the Red River section there are eight broad subdivisions: (1) Basement beds of bituminous clays rather abruptly succeeding the Edwards limestone; (2) beds of white, arenaceous, chalky limestone alternating with marls, which terminate with (3) a conspicuous limestone formation; (4) a group of beds of marls and shell conglomerates; (5 and 6) two groups of clays and sands separated by limestone; (7) an upper limestone; and (8) an uppermost lime marl.

These subdivisions, which are locally still further subdivided into conspicuous beds, may be named the Kiamitia, Duck Creek, Fort Worth, Denton, Weno, Pawpaw, Main Street, and Grayson beds. To the south, in the Colorado sections, only three lithologic members are recognizable—the Georgetown limestone, Del Rio clays, and Buda limestones. Each of these formations, although possessing very marked and important features in particular localities, loses its identity when traced through long distances, by coalescing with other formations.

I 14–15. NORTHERN TEXAS, SOUTHERN OKLAHOMA AND ARKANSAS, AND NORTHERN LOUISIANA.

Of the Lower Cretaceous of this region Veatch[838b] writes as follows:

The lowest Cretaceous beds represent the near-shore deposits of the sea advancing over the old Jurassic peneplain and are, therefore, sandy and contain vegetable remains, as well as brackish-water shells. These are succeeded by limestone and marls, indicating deeper water, and these in turn are limited above by the great sand beds that represent the extreme shallow-water conditions which marked the beginning of the upper Cretaceous.

In Arkansas only the lowest of the series, the Trinity sand, is well developed, although near the Indian Territory line are good outcrops of the Goodland limestone, overlain by a series of marl and limestone beds, which, with the Goodland limestone, represent the other two grand divisions of the Comanche series, the Fredericksburg and the Washita.

The Trinity sand, the oldest and lowest formation of the Coastal Plain series in this region, outcrops in a narrow band 6 to 12 miles wide, which extends westward along the base of the Ouachita and Arbuckle mountains from Wolf Creek in Pike County, Ark., into Indian Territory to a point somewhat west of Ardmore, where it turns south toward Austin. Because of its extensive development about the headquarters of Trinity River in Wise, Tarrant, and Parker counties, Tex., it has been called the Trinity sand or Trinity formation.

South of Tishomingo and Atoka, in the Choctaw Nation, this formation consists of a fine yellowish pack sand, with irregular conglomerate beds at the base, and contains occasional lenticular masses of clays, the whole having an aggregate thickness of 200 to 400 feet.[a] In this region it contains no fossils except occasional tree trunks, thought by Taff to be driftwood. Eastward these beds become more clayey in character and in southern Arkansas contain frequent thin layers of yellowish limestone, composed largely of the small oyster *Ostrea franklini* Coquand, together with other near-shore or brackish-water forms. Occasional thin beds of gypsum, like that at the Plaster or Gypsum Bluff on Little Missouri River near Murfreesboro occur. * * *

Above the Trinity formation is a thin bed of chalky limestone 15 to 25 feet thick, which, because of its whiteness and firmness, contrasts sharply both with the Trinity sand and with the series of marls with thin limestone layers that overlie it. Because of these features it is easily traced from its type locality, 2 miles north of Goodland, on the St. Louis & San Francisco Railroad, in the Choctaw Nation, Indian Territory, both eastward to Cerro Gordo, on Little River, in Arkansas, and westward past Oakland and Marietta, in the Chickasaw Nation. It is everywhere in this region characterized by peculiar fossils. South of Red River in Texas it increases gradually in thickness until it reaches a total of 700 feet on the Rio Grande,[b] where it is composed of two members which are called the Comanche Peak and Edwards formations. * * *

Above the Goodland limestone, near Cerro Gordo, Ark., is a series of calcareous clays, containing thin beds of limestone and having a total thickness of over 250 feet.[c] These beds have not yet been carefully studied, but Hill's reconnaissance in 1888 has shown that they may be regarded as the representatives of the Preston, Fort Worth, and Denison formations of the Texas section and of their equivalents in Indian Territory—the Kiamichi, Caddo, Bokchito, and Bennington formations of Taff [Washita group]. * * *

At the close of the lower Cretaceous there was evidently a considerable change in the depth of the ocean waters in the Texas and Arkansas areas, since overlying the marine deposits of the Washita series are sands and clays containing lignite and other remains of land plants of species very similar indeed to those of to-day, whose ancesters they probably were. In many places there is some evidence of slight erosion of the lower beds before these littoral deposits were laid down, and some portions of this area may have been dry land for a limited time.

I 16-17. ALABAMA, GEORGIA, AND SOUTH CAROLINA.

L. W. Stephenson has contributed the following notes:

The basal portion of the Cretaceous deposits in the region included between the Roanoke Valley in North Carolina and the Alabama Valley in Alabama is composed of highly cross-bedded arkosic sands, in general of coarse texture, with subordinate interbedded layers and lenses of light-colored clays of greater or lesser purity, reaching an estimated maximum thickness of 500 or 600 feet. These have been designated the "Cape Fear" formation in North Carolina by the writer[d] and the "Hamburg beds" in South Carolina by Earle Sloan[e] and have

[a] Taff, J. A., Atoka folio (No. 79), 1902, and Tishomingo folio (No. 98), 1903, Geol. Atlas U. S., U. S. Geol. Survey.

[b] Hill, R. T., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1901, p. 214.

[c] Ann. Rept. Geol. Survey Arkansas for 1888, vol. 2, 1888, pp. 110–111.

[d] Some facts relating to the Mesozoic deposits of the Coastal Plain of North Carolina: Johns Hopkins Univ. Circ., new ser., No. 7, July, 1907, pp. 93–99.

[e] Clays of South Carolina: Bull. South Carolina Geol. Survey, 4th ser., No. 1, 1904, pp. 72–75; Handbook of South Carolina, State Dept. Agr., Commerce, and Immigration, Columbia, S. C., 1907, pp. 85–88.

been regarded as the eastward continuation of the Tuscaloosa formation (Upper Cretaceous), by the Georgia and Alabama geologists.[a]

In the Carolinas these beds are separated from the overlying Black Creek formation by an unconformity. Likewise an unconformity separates them from the overlying Eutaw formation in the Chattahoochee and Alabama river regions in Georgia and Alabama. Geographically the belt in which the deposits occur is separated from the Cretaceous occurrences to the northward in Virginia by an overlap of Miocene beds. However, in all their physical characters they bear a close resemblance to the Patuxent formation, which forms the basal division of the Potomac group in Virginia and Maryland. On account of this physical similarity and because of their supposed buried connection with the Virginia Patuxent, the application of the name Patuxent has been extended to include these North Carolina arkosic beds. The apparent continuity of the North Carolina beds with the similar deposits to the south would, in the absence of known unconformities, seem to necessitate the adoption of the name Patuxent for all the beds in question in South Carolina, Georgia, and Alabama, unless biologic evidence indicating the incorrectness of this interpretation is forthcoming. With one exception no organic remains have been found in these arkosic beds south of the Virginia line. A few poorly preserved plant remains have been collected recently from an exposure in a bluff of Tallapoosa River at Old Fort Decatur, in Macon County, Ala. These were submitted to E. W. Berry, who expressed the opinion that the beds containing them are of Lower Cretaceous age. The meager paleontologic evidence thus afforded tends to confirm conclusions which Mr. Berry and the writer had previously reached, based on physical criteria alone. Unfortunately the poorly preserved condition of the leaves renders it difficult to determine satisfactorily the relation of the formation to the Patuxent formation of Virginia and Maryland. However, in Mr. Berry's opinion, the presence of large numbers of leaves, apparently dicotyledons, most of which are too poorly preserved to permit their specific or even generic determination, seems to justify doubt as to their being as old as the Patuxent formation, in which similar questionably identified dicotyledons are very sparingly represented.

I-J 13-14. EASTERN NEW MEXICO, OKLAHOMA, AND SOUTHERN KANSAS.

Portions of the Comanche series appear along the canyons which descend from the Tertiary of the High Plains to the "Red Beds." There are unconformities both above and below these incomplete sections, which constitute the northwestern occurrences of the Comanche series. Hill [441] describes in detail sections observed in Kansas, Oklahoma, and New Mexico, with comparative faunal lists, and under the title "Plains section" he summarizes the strata as follows:

Plains Tertiary.
"Dakota" sandstone.
Belvidere beds:
- (*b*) Blue and black shale with fossils [the Kiowa shale of Cragin [172,174]].
- (*a*) Cheyenne sandstone grading upward into *b*.

"Red beds."

The fauna consists largely of typical Washita species with a few that range down into the Fredericksburg.

I-K 13. NEW MEXICO, COLORADO, AND WYOMING.

The Morrison formation of Wyoming and Colorado was formerly referred without question to the Jurassic on the evidence of its large vertebrate fauna. More recent studies of this fauna by Scott, Williston, and others favor its reference to the Lower Cretaceous, but this assignment of age is not yet unanimously accepted, and

[a] Langdon, D. W., Variations in Cretaceous and Tertiary strata of Alabama: Bull. Geol. Soc. America, vol. 2, 1890, pp. 587-606. Veatch, Otto, Second report on the clays of Georgia: Bull. Geol. Survey Georgia, No. 18, 1909, pp. 82-106.

the formation is called Jurassic (?) in recent publications of the United States Geological Survey. Its relations to the Comanche series were traced by Stanton,[781] with W. T. Lee and C. W. Gilmore, and are expressed in the following comments and sections:

The beds now generally designated on United States Geological Survey maps as the Morrison formation have been a subject of interest and discussion since 1877, when abundant remains of dinosaurs were found in them. The first extensive collections of the vertebrate fauna were obtained in the neighborhood of Morrison near Denver, in Garden Park, near Canon City, Colo., and at Como or Aurora, Wyo. Since then the formation has been recognized by means of its fossils, its lithologic features, and its stratigraphic relations in the Black Hills, on the Laramie Plains, and elsewhere in Wyoming, in Montana, in western Colorado, in southeastern Colorado, and in adjacent parts of Oklahoma and New Mexico. * * *

The formation is nonmarine throughout, so far as known, and consists of variegated marls and shales with irregular beds of sandstone and sometimes thinner layers and lenses of siliceous limestone. The colors of the shales and marls are greenish gray, purplish, maroon, and red, very irregularly distributed, while the sandstones are usually gray, sometimes weathering brown or with small brown spots. The limestones are gray, in some cases weathering with a reddish tinge. The general appearance of the formation is remarkably uniform over large areas, and yet the individual elements are so variable that no two detailed sections are exact duplicates of each other. The total thickness is seldom more than 200 feet, though it is possibly more than 400 feet at Canon City.

Several geologists, particularly Hill and Lee, having suggested that the Morrison was a representative of some part of the Comanche series, Stanton examined its relations, as stated above, and found:

Section on Purgatoire River about 20 miles south of La Junta, Colo.

	Feet.
1. Benton shales, thickness probably not more than	200
2. Dakota sandstone	100
3. Dark shales and shaly limestones with Comanche fauna	50–100
4. Coarse gray cross-bedded sandstone	15–60
5. Variegated shales, marls, sandstones, and limestones of the Morrison formation, with Brontosaurus, etc	200
6. Gypsum and gypsiferous shales	70–125
7. Red Beds with Belodon near top, exposed	200–300

Section on Rio Cimarron east of Garrett post office, Okla.

	Feet.
1. Massive coarse cross-bedded gray and brown sandstone of the Dakota	150
2. Dark shales with layers of brown flaggy sandstone and bands of somewhat calcareous yellow sandstone with Comanche fauna	50–60
3. Coarse brown or gray cross-bedded sandstone with irregular bands of pebbles, apparently unconformable on the underlying stratum	4–15
4. Variegated shales, gray sandstones and bands of siliceous limestone, referred to the Morrison, not well exposed. Thickness probably less than	100
5. Red Beds.	

The Comanche horizon has yielded a varied fauna which is clearly the same as the Washita fauna that has long been known as Mesa Tucumcari, New Mexico, in northern Texas, and in the Kiowa shales of southern Kansas. * * *

This horizon was traced with practical continuity westward up the Cimarron to Folsom, New Mexico, a distance of about 75 miles across the strike. Its lithologic features show little variation, and its thickness is never less than 50 feet nor more than 100 feet. Fossils gradually become less abundant in both species and individuals toward the west, until near Folsom only a small mactroid shell was found in considerable numbers. The most western point at which *Gryphæa corrugata* was collected is about 30 miles east of Folsom.

Along this line the coarse sandstone beneath the Comanche fossils is from 15 to 40 feet in thickness, and the variegated shales, sandstones, etc., of the Morrison increase to about 200 feet. Lithologically and stratigraphically this is identical with the Morrison beds seen on the Purgatoire, where characteristic dinosaurs were collected. Fragmentary, undetermined dinosaur remains were seen in it on the Cimarron near Exter, N. Mex.

Beneath the recognized Morrison some localities show 40 to 50 feet of gypsum and gypsiferous shales resting on a massive white or pinkish sandstone which Mr. Lee has described as the Exter sandstone. It varies greatly in thickness, the maximum observed being 80 feet. The Exter is separated from the red beds by a striking angular unconformity, wherever the red beds are folded in local uplifts. The red beds show the usual character and at Tod's ranch, 15 miles east of Folsom, they yielded fragmentary Triassic vertebrates.

Summing up the evidence presented by the sections quoted and also by those at Tucumcari and Canon City, Stanton says:

The question whether the Morrison formation is Jurassic or Cretaceous is still to be answered, and if a satisfactory answer is ever received it will doubtless be from vertebrate paleontology, aided by careful stratigraphic methods. If the Morrison is Cretaceous, the proof that it is so will not be by tracing it directly into marine Cretaceous strata. It has been shown that the beds supposed to be thus connected with it overlie it for more than 100 miles across the strike. But these overlying beds are by no means the earliest Cretaceous, and there is still room for the Morrison within that system if the fauna requires such a reference. On the other hand, there is ample space for it in the Jurassic [a] not otherwise represented in the region by sediments, and before the final decision is made the character of the flora in the Fuson formation of the Black Hills and in the Kootanie of Montana should be given due weight, and these formations should be closely studied and searched for other evidence.

I-K 17-18. ATLANTIC COASTAL PLAIN, MASSACHUSETTS TO NORTH CAROLINA, INCLUSIVE.

The following statement, prepared by William B. Clark, is an elaboration of a briefer article [144] covering the northern part of the Atlantic Coastal Plain:

General conditions of occurrence.—The oldest deposits of the Atlantic Coastal Plain which outcrop at the surface are of Cretaceous age. Well borings at many points throughout the district have not afforded strata of earlier age, although such deposits may exist to the east, toward the margin of the continental shelf.

The deposits as a whole have been but little changed since they were originally laid down along the continental border, but the strata present much complexity due to the variation in the angle and direction of tilting during the successive oscillations of the sea floor during Cretaceous time. The sediments in general form a series of thin sheets which are inclined seaward, so that successively later formations are encountered in a journey from the inland border of the region toward the coast, yet at no place accessible to our study do we find a complete sequence of deposits, although sedimentation must have been continuous over a large part of the continental shelf. The incompleteness, therefore, must be regarded as a purely marginal condition due to the transgressions and retrogressions of the sea along the coastal border.

The Cretaceous formations are variously transgressed in the different areas by deposits of Tertiary and Quaternary age, these later formations in places reaching to the Piedmont border or beyond and entirely concealing the earlier strata along the outcrop. The full sequence of Cretaceous deposits can therefore be observed only at favorable points and chiefly along the main river channels, although even here the later formations are buried over many wide areas in consequence of the attitude of the strata to the present sea level.

The Atlantic Coastal Plain deposits afford representatives of both the Lower and the Upper Cretaceous, the former being most extensively developed in Maryland and northern Virginia and in North Carolina, the latter in New Jersey, whence the strata gradually thin out northeastward along the New England coast and southward through Delaware and

[a] The marine Jurassic Sundance formation, characterized by *Cardioceras cordiforme* M. and M., etc., on which the Morrison rests in the northern area, does not represent the latest Jurassic according to European standards.

Maryland. In North Carolina the Upper Cretaceous reappears and covers a wide area to the south of the Hatteras axis.

Long Island and southern New England.—It has been long recognized that Upper Cretaceous deposits occur on Long Island and farther east, but although it has been apparent that the strata were the continuation of similar deposits in New Jersey, where their limits are better known, a satisfactory correlation of these deposits has never been made. It is apparent that the Raritan, the Magothy, and possibly the overlying Matawan are represented. The flora thus far studied is chiefly of the Magothy type, although the lower beds on Long Island contain forms that represent the Raritan, while the marine animal remains which have been found both in place and in reworked deposits on Long Island, Block Island, and Marthas Vineyard and at Marshfield, Mass., are of Matawan types so far as they can be determined. It is possible that they belong to beds in the upper Magothy, for marine fossils have been found in Magothy strata on the south shore of Raritan Bay, the fauna as a whole being similar to that of the Matawan.

Many contributions have been made to the knowledge of this region by those who have visited and studied it, among the more important being those of Newberry,[610, 611] Shaler,[728, 729, 730] David White,[893, 894] Hollick,[457, 458, 459] and Veatch.[837]

The strata consist of sands and clays, the former in places irregularly bedded and of varying degrees of fineness and more or less stained with iron, while the latter are plastic and locally lignitic. Sandy, more or less glauconitic clays have also been found.

New Jersey.—The deposits of Upper Cretaceous age are more extensively developed in New Jersey than elsewhere in the northern Atlantic Coastal Plain and may be regarded as forming the type section for that region. The major divisions can be more elaborately differentiated there than farther south and a much fuller classification has been proposed.

A study of the Cretaceous deposits of the New Jersey region began much earlier than in neighboring States and many contributions have resulted. Among those who have given a large amount of attention to the geology of this area are Morton,[606] Cook,[169] Newberry,[614] Whitfield,[925] Clark,[142, 145, 146, 152] Weller,[884] and Berry.[72, 76, 78]

The following scheme of classification has been adopted for the New Jersey Upper Cretaceous:

- Manasquan formation.
- Rancocas group:
  - Vincentown sand.
  - Hornerstown marl.
- Monmouth group:
  - Redbank sand.
  - Navesink marl.
  - Mount Laurel sand.
- Matawan group:
  - Wenonah sand.
  - Marshalltown formation.
  - Englishtown sand.
  - Woodbury clay.
  - Merchantville clay.
- Magothy formation.
- Raritan formation.

The Raritan formation directly overlies the crystalline rocks or the Newark group, as the case may be, and consists of clays, sands, and gravels. It has been estimated to have a maximum thickness of about 300 feet at the outcrop, but it has been penetrated in well borings to a probable depth of 500 feet. An extensive flora has been described.

The Magothy formation unconformably overlies the Raritan formation and consists of dark clays and light sands. The clays are commonly lignitic. The deposits attain a maximum thickness of about 100 feet. An extensive flora quite distinct from and more recent than the Raritan flora has been found, as well as a marine fauna closely allied to that of the succeeding Matawan.

The Matawan consists chiefly of dark-colored clays, in places micaceous and glauconitic, in its lower part, and of sands, with an interbedded clayey member, locally highly glauconitic, in its upper part. It attains a total thickness of about 275 feet, although a thickness of 400 feet has been found in deep well borings east of its outcrop. It lies unconformably on the Magothy. The Matawan group contains an extensive fauna with subordinate faunules. It has been traced throughout the north Atlantic Coastal Plain and thence southward to the Gulf.

The Monmouth group consists of sands and clays, with an interbedded glauconitic division in the northern part of the area. Toward the south the upper sandy formation disappears. The greatest thickness of the group is about 150 feet. The Monmouth is conformable to the Matawan. It has an extensive fauna marked by the introduction of *Belemnitella americana* and other forms, representing a later fauna than the Magothy and Matawan fauna hitherto described. This fauna also has been traced southward through the north Atlantic Coastal Plain into the Gulf region.

The Rancocas consists largely of greensand marls and sandy calcareous beds which have a maximum thickness in southern New Jersey of about 125 feet. It is conformable to the Monmouth and is characterized by a fauna quite distinct from the preceding, including *Gryphæa vesicularis*, *Terebratula harlani*, and other forms.

The Manasquan formation consists of greensand marls and attains a thickness of about 50 feet. It is conformable to the Rancocas. It contains a marine fauna which has some forms in common with the Rancocas and others that are quite distinct.

Maryland and Delaware.—The deposits in Maryland and Delaware contain representatives of both the Lower and the Upper Cretaceous. The Lower Cretaceous also continues northward into Pennsylvania, where a few isolated outliers are found, and the basal formation of the Upper Cretaceous occurs as a narrow strip along the eastern border of that State. In Maryland and Delaware both divisions are extensively developed, the Lower Cretaceous attaining its maximum development in Maryland.

The Maryland area has been long studied and is discussed in an extensive literature. Among those who have been most actively engaged in the study of this region may be mentioned McGee,[565] Clark,[147, 148, 150] Bibbins,[147, 148] Mathews,[150] Berry, and Miller.[595]

The following scheme of classification has been adopted for the Maryland-Delaware region:

- Upper Cretaceous:
  - Rancocas formation.
  - Monmouth formation.
  - Matawan formation.
  - Magothy formation.
  - Raritan formation.
- Lower Cretaceous (Potomac group):
  - Patapsco formation.
  - Arundel formation.
  - Patuxent formation.

The Patuxent formation consists mainly of sand, generally arkosic and in many places cross-bedded, with small masses of clay scattered through it. The formation attains a thickness of 350 feet. It has a well-defined early Cretaceous flora.

The Arundel formation consists chiefly of clays, which in places carry iron ore and are commonly lignitic. It has a thickness of about 125 feet. It is unconformable to the Patuxent. It has an extensive flora similar to that of the Patuxent and a fauna consisting chiefly of dinosaurian remains.

The Patapsco formation consists of highly colored and variegated clays and lighter-colored sandy clays and sands. It has a thickness of 200 feet and contains an extensive flora of "Meso-Cretaceous" types in which angiosperms constitute a considerable element. It is unconformable to the Arundel.

The Raritan formation consists chiefly of thick-bedded light-colored sands, with light-colored clays in the lower portion. The deposits have a thickness of about 400 feet. The Raritan overlies the Patapsco unconformably. It carries a distinctly Upper Cretaceous flora containing numerous dicotyledons.

The Magothy formation consists of alternating sands and clays, the latter in places lignitic. The maximum thickness of the formation is about 100 feet. The Magothy is unconformable to the Raritan. It contains an extensive flora of types more recent than those of the preceding formation.

The Matawan formation consists mainly of dark-colored micaceous sandy clays, the average thickness of the formation being about 50 feet. It carries an extensive marine fauna.

The Monmouth formation consists mainly of sands, more glauconitic in the upper part than in the lower. The deposits have a maximum thickness of about 100 feet on the eastern shore of Chesapeake Bay and gradually decrease in thickness until they thin out in the Potomac Valley. A fauna marked by the advent of *Belemnitella americana* and other forms is found in this formation.

The Rancocas formation consists chiefly of greensand marls, which are in many localities highly calcareous. The formation has a thickness of about 20 feet in central Delaware but gradually thins out toward the Maryland line.

Virginia.—The Cretaceous deposits which outcrop at the surface in Virginia are all Lower Cretaceous, although strata belonging without much doubt to the Upper Cretaceous have been penetrated in deep well borings to the east and have yielded a few fossils that indicate the presence of the Raritan, Magothy, and Matawan formations. The Lower Cretaceous deposits are limited to the Patuxent and the Patapsco, the Arundel formation not being recognized in Virginia.

Much study has been given to the Virginia area, the more important contributions having been made by Rogers,[676] Ward,[864, 866] Fontaine,[343] Clark and Miller,[151] and Berry.[77]

The Patuxent formation is exposed in the principal drainage channels and consists chiefly of sands, cross-bedded, highly arkosic, and locally indurated, with clay beds in places lignitic and commonly chloritic. The thickness of the formation reaches about 300 feet. The Patuxent contains a large flora which is probably the most extensive known flora from the Lower Cretaceous.

The Patapsco formation consists of highly colored and variegated clays, in places lignitic, and sand beds, cross-bedded and locally indurated. The formation is limited to the northern part of the area, where it attains a thickness of about 150 feet and has an extensive flora of later types than those found in the Patuxent.

North Carolina.—The Cretaceous deposits of North Carolina belong in part to the Lower and in part to the Upper Cretaceous. In the northern part of the State the strata are confined largely to the main river channels, but south of the Hatteras axis they spread out and occupy a wide area.

The North Carolina deposits have not received as much attention until recently as the Cretaceous deposits farther north. Among those who have studied the region are Clark,[149] Stephenson,[791] and Berry.[73, 74, 77, 79] The two latter have spent much time in recent years in a detailed field investigation, Stephenson giving his attention chiefly to the stratigraphy and marine invertebrate fossils and Berry to the fossil plants. Clark, who earlier studied the region, has devoted his attention to the interpretation of the deposits and faunas and their correlation with other areas.

The following scheme of classification has been accepted for the North Carolina area:

Upper Cretaceous:
- Peedee sand.
- Black Creek formation.

Lower Cretaceous:
- Patuxent formation.

The Patuxent formation consists chiefly of sands and clays, the former locally cross-bedded and arkosic. Its thickness is about 300 feet. No flora or fauna has been found in it.

The Black Creek formation consists of light-colored sands and interbedded clays, the latter in places lignitic and generally thinly laminated. The thickness of the formation reaches about 700 feet. The Black Creek overlies the Patuxent formation unconformably. An extensive flora is found in it, the beds carrying the plant remains being interbedded with strata containing marine invertebrate fossils in the upper portion of the formation. The fauna is extensive and is similar in type to that found farther north in the Magothy and Matawan formations and it has also been traced throughout the south Atlantic States to the Gulf.

The Peedee consists mainly of sands, commonly glauconitic, with subordinate beds of clay. The thickness of the formation reaches about 700 feet. The Peedee carries an extensive fauna of marine types, which is characterized by the introduction of *Belemnitella americana* and is similar to the Monmouth fauna farther north. It has also been traced through the south Atlantic and Gulf States.

General remarks.—The Cretaceous deposits of the Atlantic Coastal Plain form an irregular and interrupted belt along its western margin, resting for the most part on an irregularly eroded surface of ancient crystalline rocks, although the sandstones and shales of the Newark group intervene at some points. The slope of this floor is variable, but on the average it trends in an easterly direction at an angle of about 60 feet to the mile.

The thickness and angle of dip of the Cretaceous formations at the outcrop are extremely variable owing to the differential movements which have taken place along the landward margin of the Coastal Plain during the period of its building. The areas occupied by the outcrops of the several formations above described gradually diminish at varying rates from the point of their greatest development, until the formations finally disappear as outcropping deposits either because of the differential movements during Cretaceous time or because of the transgression of Tertiary and Quaternary sediments. The dip of the several formations is also variable but in general grows less with each succeeding formation, the dip of the latest Cretaceous strata being about 20 feet to the mile.

The correlation of the deposits within the limits of the northern Atlantic Coastal Plain is shown in the accompanying table, together with the approximate correlation of these deposits with the section hitherto recognized in the eastern Gulf region and in central Europe. L. W. Stephenson and E. W. Berry, under the direction of T. Wayland Vaughan, have greatly enlarged our knowledge of the stratigraphy and paleontology of the south Atlantic and Gulf States and the results of their work have been available for the comparisons with the southern districts south of North Carolina.

Cretaceous formations of northern Atlantic Coastal Plain.

	Approximate European equivalents.	Long Island and islands south of New England.	New Jersey.	Delaware and Maryland.	Virginia.	North Carolina.	Alabama.
Upper Cretaceous.	Danian.		Manasquan.				
			Rancocas.	Rancocas.			
	Senonian.		Monmouth.	Monmouth.		Peedee.	Ripley and Selma.
		Matawan.	Matawan.	Matawan.		Black Creek.	Eutaw.
	Turonian.	Magothy.	Magothy.	Magothy.			Tuscaloosa (western Alabama).
	Cenomanian.	Raritan.	Raritan.	Raritan.			......(?)....
Lower Cretaceous.	Albian.			Patapsco.	Patapsco.		......(?).... Lower Cretaceous (eastern Alabama).
	Urgonian.			Arundel.			
	Neocomian.			Patuxent.	Patuxent.	Patuxent.	......(?)....

The Lower Cretaceous formations in the area under discussion constitute part of a belt of deposits of that age extending from Pennsylvania to eastern Alabama and are apparently embraced within a single geologic province. North of central Maryland, where the most complete sequence of the Lower Cretaceous strata is found, the Arundel and Patuxent formations are gradually transgressed by the unconformably overlying Patapsco formation, which in turn disappears by the overlapping of the Raritan formation in eastern Pennsylvania and in New Jersey.

Farther south, in Virginia, the Patapsco formation disappears near Fredericksburg and does not reappear except in a single occurrence still farther south, and the Arundel formation is not known to occur south of Potomac River. With the single exception above noted the Patuxent is the only Lower Cretaceous formation exposed in south-central and southern Virginia, where in the valley of James River some of the most fossiliferous beds of this formation have been found. Although separated at the surface from the deposits of the same formation farther north, through the transgression of the Tertiary and Quaternary formations, the continuity of the beds is assumed from the similarity of the flora, with its many identical species, as well as from the characteristic lithology.

Deposits formerly called the "Cape Fear" formation but now known to be a southward continuation of the Patuxent formation of Virginia are found in North Carolina. Here again the transgression of the Tertiary and Quaternary formations interferes with the continuity of the outcrop, although there is no reason to doubt that the deposits are continuous beneath the later strata. No fossils have thus far been discovered in the Lower Cretaceous deposits of North Carolina, but the strata occupy the same stratigraphic position at the base of the Coastal Plain Cretaceous here as farther north and are unconformably overlain by Upper Cretaceous formations. The deposits are also strikingly similar to those of the Patuxent formation in Virginia and Maryland and it seems to be a reasonable assumption that they constitute part of the same formation.

To the south of North Carolina similar deposits are known to extend through South Carolina and Georgia into eastern Alabama. The more southern occurrences of the Lower Cretaceous were long erroneously associated with the Tuscaloosa formation (Upper Cretaceous) farther west in Alabama and Mississippi, but they are entirely distinct from that formation both in stratigraphic position and in lithologic character, and they are separable everywhere by marked unconformities from the overlying Upper Cretaceous deposits. According to the evidence at present available, they are physically continuous with the Patuxent formation farther north, whether or not the same formational name is employed throughout the province. Notwithstanding the physical evidence in favor of a single formational unit at the base of the Coastal Plain Cretaceous all the way from Maryland to Alabama, it must be admitted that a transgressing sea throughout so extended a coast line might well have involved considerable time for its accomplishment and if the transgression proceeded from the north toward the south, as seems probable, the deposits in Alabama would necessarily be somewhat younger than those in Virginia and Maryland.

The Upper Cretaceous deposits within the area under discussion constitute part of a belt that is known to extend from Massachusetts through the islands off the New England coast and thence to the Gulf except at a few points where transgression or erosion has removed evidence of their presence. The most complete sequence of strata is found in New Jersey, north of which the later Upper Cretaceous formations are lacking, although the earlier formations continue through Massachusetts with their characteristic if somewhat incomplete faunas and floras. To the south the Raritan and Rancocas formations finally disappear in Maryland, but the intervening Magothy, Matawan, and Monmouth formations with their characteristic faunas and floras can be traced through Maryland, can be recognized in Virginia in the deep well borings to the east of the Cretaceous outcrops, and reappear in North Carolina in the Black Creek and Peedee formations. The boundary between the Matawan and the Monmouth in the north, as well as that between the Black Creek and the Peedee in the south, marks the division between the earlier fauna and the later *Belemnitella americana* fauna. The lower fauna characteristic of the Magothy and Matawan and the Black Creek has been found in the lower part of the Ripley formation and in the Selma chalk, also in the Eutaw; the upper fauna of the Monmouth and the Peedee is found in the upper part of the Ripley and the Selma. The flora of the Magothy characteristic of the New England area and of New Jersey and Maryland is represented in the Black Creek and also in the Tuscaloosa of western Alabama and Mississippi.

The Cretaceous formations of the northern Atlantic Coastal Plain have been correlated with the recognized European subdivisions and the faunas and floras examined have led Clark and Berry to propose the approximate equivalents given in the table on page 612. The Lower Cretaceous floras are regarded as comprising the Neocomian to the Albian, the Patuxent flora being distinctly a Neocomian flora and the Patapsco an Albian flora. The Upper Cretaceous floras and faunas extend from the Cenomanian to the Danian, the Raritan flora containing a large Cenomanian element, while the Magothy and Black Creek floras are regarded as Turonian. The faunas which are found in succeeding beds are in the Matawan and Black Creek apparently Turonian, although regarded by some paleontologists as Senonian; those of the younger Monmouth and Peedee are unquestionably Senonian. The later Rancocas and Manasquan faunas of the northern part of the Coastal Plain are regarded as Danian and probably belong to the horizon of the Maestricht.

J 14. CENTRAL KANSAS.

Cragin [173] describes the occurrences of marine Lower Cretaceous in Saline County, Kans., in part as follows:

The Mentor beds, named from a small station in Saline County, Kans., within the area of their outcrop, are a terrane of variegated, earthy-textured marine shales, with intercalated beds of brown sandstone, resting in part conformably upon the Kiowa shales and in part unconformably upon the drab and purple-red laminated shales and impure limestones of the Permian, and succeeded above by the more heavily arenaceous fresh-water sediments of the Dakota. They were formerly considered by all geologists as constituting a part of the Dakota group, but are now known to belong to the upper part of the Comanche series. * * *

The shales of the Mentor beds are chiefly argillaceous, but they contain a greater or less admixture of sand, to which, as soft sandstones, they locally give place in certain horizons. They apparently contain some lime also, partly in the condition of sulphate. * * * Such outcrops of the shales as do occur present themselves either as limited, more or less steep-faced banks of marly-appearing clay, of white, ferruginous-yellow, red, or blue color, or particolored with two or more of these. Their coloring seems to be the result of the variable distribution of oxide, peroxide, and sulphates of iron.

The sandstone of the Mentor beds occurs in thin, local strata. While these are of slight consequence judged by the space they occupy, they are nevertheless of great stratigraphic importance, since it is from these alone that our knowledge of the geological age of the Mentor terrane has been derived. * * *

The thickness of the Mentor beds varies greatly, since that portion of the terrane that rests directly upon the Permian lies unconformably upon the latter and presents considerable differences in the elevation of its base. It probably nowhere greatly exceeds 50 or 60 feet.

* * * * * * * * *

The Mentor beds are thus seen to be characterized by a fauna related to that of the Denison beds and still more closely to that of the Kiowa shales. Their fauna is, in fact, especially related to that of the upper part of the latter.

The stratigraphic relation to the Kiowa shales is also close. While the Mentor beds generally rest upon the Permian in Saline County, they rest in part upon the Kiowa shales farther southward, as shown by the occurrence beneath them of black shales amongst some of whose fossils, submitted to the writer from a few miles west of Lindsborg by Prof. J. A. Udden, are *Modiola stonewallensis* nob. and *Sphenodiscus pedernalis* Roem.; but whether they are to be considered as overlying all of the Kiowa or only a lower part of it, and whether or not they merge southward into the upper part of the Kiowa, are questions that remain still unanswered.

J-K 10. CALIFORNIA.

The general character and relations of the Cretaceous of the Pacific coast from southern California to British Columbia are ably discussed by Anderson,[27] who describes and correlates the separate sections and their faunas.

The Cretaceous of California is divided into the Shasta (Lower Cretaceous, comprising the Knoxville and Horsetown formations) and the Chico (Upper Cretaceous). They have been described as the "Shasta-Chico series" by Diller and Stanton,[284] who give a comparative table of classifications according to Gabb's, White's, and their own observations, and state:

The Chico, Horsetown, and Knoxville beds have been found to grade into one another in such a way as to show that they are simply different phases of one continuous series of deposits extending without an important interruption of any kind from the bottom of the Knoxville to the top of the Chico. For this set of beds the term Shasta-Chico series has been proposed.[a]

The type section of the "Shasta-Chico series" was measured on Elder Creek, in northern California, and originally stated in detail by Diller.[270] The following is condensed from his statement:

	Feet.
Chico: Massive and thin bedded sandstone, with conglomerates	3,897
Horsetown: Sandstones, often thin bedded, and shales	6,109
Knoxville: Shales, with calcareous layers in the upper 10,000 feet, interbedded with sandstones below	19,974
Apparent total thickness of unaltered strata	[29,980]

The Chico (Upper Cretaceous), though generally conformable in the Valley of California to earlier Cretaceous formations where they occur, overlaps them in many localities. This is the case in the section on Chico Creek, in the northeastern part of the Valley of California, where the underlying rocks are metamorphosed auriferous slates.[269, 27]

Lists of the faunas from different horizons of the "Shasta-Chico series" are given in the paper by Diller and Stanton [284] already cited, but Stanton [776, 778] discusses the faunas and also the stratigraphy in two later papers, of which that of 1895 assembles the facts of distribution and stratigraphic relations more comprehensively and clearly.

The remarkable thickness assigned to the Knoxville formation in Tehama County is in a measure borne out by the observations of Osmont [624] in the region north of San Francisco Bay:

The eastern portion of both sections is largely made up of Cretaceous shales and sandstones, most if not all of which probably belong to the lower Cretaceous or Knoxville series.[b]

This series consists of an enormous thickness of rather hard tawny-yellowish sandstone, interbedded in monotonous succession with dark-blue fissile shales, with occasional thin beds of dark-blue limestone. The sandstone strata are usually less than 2 feet thick, and almost never more than 10, while their regular alternation with soft shale made the bedding very distinct and characteristic.

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[a] Bull. Geol. Soc. America, vol. 4, pp. 205–224, 245–256. Since the papers referred to were written we have spent several months in the field, completely reviewing the Cretaceous of northern California. The results fully confirm our previous views.

[b] Becker, G. F., Quicksilver deposits of the Pacific slope: Mon. U. S. Geol. Survey, vol. 13, 1888.

While standing at high angles, these beds do not show any important faulting along either of the sections. From near Knoxville, where they appear to overlie a large laccolith of serpentine, they extend in unbroken succession with steep northeasterly dip, to the head of Capay Valley, at Rumsey, where they are covered by Tertiary gravels and sandstones. The average angle of dip from Knoxville to Rumsey can not be less than 45°, which would give the series a thickness of 4 miles, and this does not represent the whole of the accumulation of sedimentary beds, since the upper limit is not exposed.

In the Coast Range south of San Francisco the Lower Cretaceous strata are less fully represented than they are to the north. In the Santa Cruz quadrangle [97] the Knoxville is but 100 feet thick and is bounded by unconformities above and below. (See Chapter XV, p. 669.) In the San Luis quadrangle [325a] the relations are as follows:

Strata of Cretaceous age in California include three main groups—the Knoxville, Horsetown, and Chico. Two of these, the Knoxville and the Chico, are widely distributed throughout the Coast Ranges, and their representatives, the Toro and Atascadero formations, are found within this quadrangle. Nothing corresponding to the Horsetown group has been recognized here, and probably the horizon is represented by an erosion unconformity.

It has been thought that the Cretaceous sediments in California formed a conformable series from top to bottom, but, in the central Coast Ranges at least, this period was broken two or more times by igneous outbursts, with one long interval of elevation and erosion.

The Toro formation within the San Luis quadrangle consists of more than 3,000 feet of dark shale and thin-bedded sandstone. The formation is named from a creek which flows across it. The shale forms almost the whole of the bottom and middle portions. The sandstone is more abundant toward the top. The formation is not supplied with many fossils, for, excepting one specimen of an ammonite, the only species found is one belonging to the genus Aucella. This is very abundant through the middle and lower portions of the formation.

The Toro formation is the local representative of the Knoxville group, but it probably corresponds to a small part only of Knoxville time, the rest being represented by the unconformities above and below. It belongs to the lower Cretaceous or Shasta series.

The Cretaceous sequence on the west side of the Valley of California, near its south end, in the Coalinga district, is thus described by Arnold and Anderson: [34a]

The next to the oldest terrane exposed in the Coalinga district is a thick series of strata of sandstone, shale, and conglomerate overlying the Franciscan formation and covering a wide belt for the most part west of the foothill region. It forms the high ridges bordering the Coalinga district on the west and may be easily recognized by the dark, thinly bedded, compact shale and sandstone of its lower portion and the massive drab concretionary sandstone of its upper portion. These strata are of Cretaceous age and comprise part or all of the two formations well known elsewhere on the west coast as Knoxville (Lower Cretaceous) and Chico (Upper Cretaceous). * * *

The Horsetown formation, which forms the middle portion of the Cretaceous in the standard Coast Range section, is not known to be represented in the Coalinga district, although it is not impossible that a portion of the great thickness of nonfossiliferous Cretaceous strata may be the equivalent of this formation. No evidence, however, has yet been found of its presence in this portion of the Coast Ranges.

A conservative estimate places the total thickness of the strata mapped as Knoxville-Chico at 12,800 feet. The maximum thickness is probably much greater. This succession of strata may be divided lithologically into three main divisions. The total thickness of the middle and upper divisions, which are probably to be referred together to the Chico formation, is at least 9,500 feet. A thickness of 8,300 feet is measurable in single sections, and even greater thicknesses may be found in single sections of the Knoxville-Chico as a whole. It is likely that at least two unconformities separating the Knoxville-Chico beds into important stratigraphic groups will be made out on further study. * * *

A zone of coarse conglomerate varying in thickness from less than 100 to over 1,000 feet extends intermittently from the summit of Juniper Ridge, south of Los Gatos Creek, to a point south of Reef Ridge, in Big Tar Canyon. It is overlain and underlain, in appearance conformably, by the thin-bedded dark shale and sandstone of the lower half of the Knoxville-Chico. The portion of the terrane lying below this conglomerate is here classed by itself as the lower division. * * * The total thickness of the lower division as exposed in the Alcalde Canyon section is between 3,100 and 3,500 feet. * * *

Fossils of Knoxville (Lower Cretaceous) age, such as *Aucella crassicollis* Keyserling and *Belemnites impressus* Gabb, have been found in beds of dark shale in the Devils Den region not many miles south of the Coalinga district, and there is little doubt that the lower division of the rocks here described as Knoxville-Chico is at least in part the equivalent of the Knoxville formation. It is possible that the great beds of conglomerate mark the base of the Chico or Upper Cretaceous and that the whole of the lower division below this line of separation represents the Knoxville formation.

For reference to the views of F. H. Knowlton and James Perrin Smith on the Jurassic age of that part of the Knoxville which contains a Jurassic flora, see the next section (K 10).

For a general correlation table of the Mesozoic and Cenozoic formations of the Coast Range, see Chapter XVII (p. 818).

K 10. KLAMATH MOUNTAINS, OREGON AND CALIFORNIA.

In his published articles Diller [276] has recognized representatives of the Knoxville, Horsetown, and Chico of the California Cretaceous section in the Klamath Mountain section.

The strata of conglomerate, sandstone and shale, which are believed to represent these epochs, are comprised in the Myrtle formation. The strata are irregular, but shale predominates. The coarser detritus is derived from disintegrated granite. In the Roseburg quadrangle the thickness is estimated at about 6,000 feet. Fossils from the upper portion include *Pecten operculiformis* and *Trigonia æquicostata,* characteristic of the Horsetown epoch. *Aucella crassicollis* and *A. piochii* are found in the lower portion, the equivalent of the Knoxville. The Myrtle formation includes limestone lentils which contain *Opis californica* and *Hoplites dilleri* or a form closely related to it. These are also found in the Knoxville.

The Myrtle formation is bounded by very marked unconformities both above and below and is intruded by igneous rocks and metamorphosed.[274, 277]

The relations of the Myrtle formation to the Horsetown and the upper part of the Knoxville are apparently established beyond doubt by the common occurrence of *Aucella piochii* and *A. crassicollis* in similar stratigraphic relations in both areas, as well as by the abundant floras which have been found in both formations and which are intimately associated in Oregon with both species of Aucella. It is not clear, however, that the Myrtle formation includes older strata that should correspond to the middle and lower parts of the Knoxville. The Knoxville is 20,000 feet thick. The Myrtle, so far as known, is but 6,000 feet thick. Diller regards this known portion of the formation, which rests on a basal unconformity, as the thin overlapping edge of the deposit and believes that the older sediments accumulated farther seaward. He says:[a]

The lower portion of the Myrtle as exposed in Oregon corresponds only to the upper part of the Knoxville as exposed in California, yet it is quite correct to say that the Myrtle as a whole is the equivalent of the Knoxville and Horsetown (Shastà) as a whole, if it is admitted that the Myrtle includes beds which are older than any of the Myrtle yet seen in Oregon but which are believed to form the base of the overlapping strata. These basal beds of the Myrtle presumably occur farther west, beyond the present coast, but they may yet be found in Oregon.

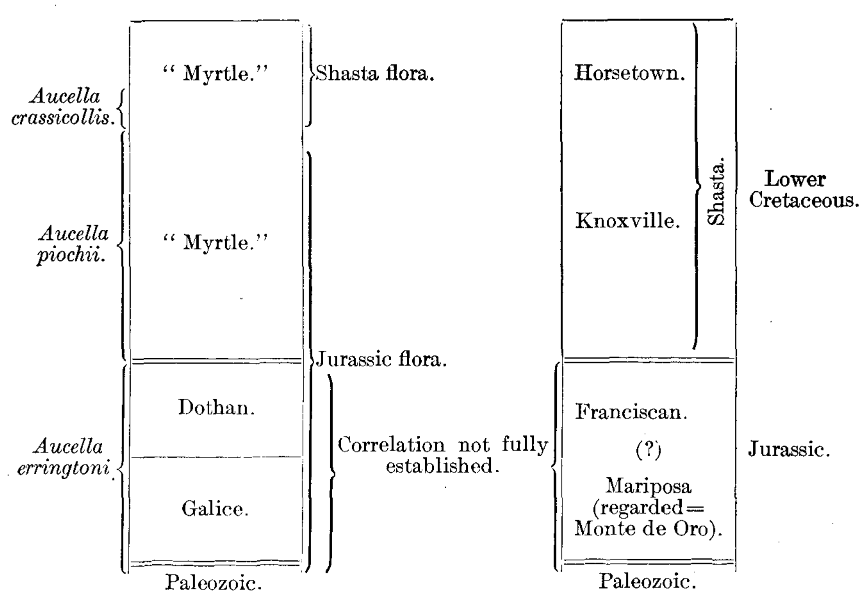
The age of the Myrtle formation is not yet satisfactorily determined, there being a difference of opinion between Stanton and Knowlton as to the correlation according to the faunas or the floras. The fauna as interpreted by Stanton is of Cretaceous age throughout. The floras as identified by Knowlton comprise a lower flora, of Jurassic age, and an upper flora, of Lower Cretaceous age.

We quote Knowlton's statement of the problem and the summary of his conclusions:[509]

In November, 1908, Mr. Diller published a paper under the title "Strata containing the Jurassic flora of Oregon,"[b] the thesis of which he sets forth as follows: "Two fossil floras have been reported from the Mesozoic rocks of California and Oregon, the one Cretaceous and the other Jurassic. With the former the fauna is Cretaceous, but with the latter the fauna has been regarded as a matter of doubt. It is the purpose of this paper to remove the doubt by showing that in parts of Oregon and California the Jurassic flora * * * is in the 'Myrtle' and Knoxville beds, while elsewhere it extends down to the horizon of the Mariposa, and the general conclusion is reached that for the Pacific coast the line between the Cretaceous and the Jurassic is the great unconformity at the base of the Knoxville."

The major portion of Mr. Diller's paper is devoted to proof that the Jurassic flora occurs in the Knoxville formation—a point conceded by the present writer. It is to the placing of the Jurasso-Cretaceous line at the base of the Knoxville that exception is taken.

Mr. Diller's interpretation of the relations of the several formations concerned in this paper, together with his conclusion regarding the ranges of the floras and the supposedly characteristic invertebrates, is shown in the following diagram, which is taken from his paper:



[a] Personal communication, February 15, 1910. [b] Bull. Geol. Soc. America, vol. 19, 1908, pp. 367–402.

THESIS OF THIS PAPER.

At variance with the conclusions above set forth, it will be shown in the present paper that the so-called "Jurassic flora of Oregon" is everywhere of true Jurassic age, that it is practically never [a] found in association with the acknowledged Cretaceous flora, and finally, that the line between the Jurassic and the Cretaceous of the region is to be drawn through the upper part of the Knoxville and not at its base.

* * * * * * * * *

SUMMARY.

1. The Lower Mesozoic strata of Oregon and California have afforded two floras, one of which is Cretaceous and the other Jurassic. These two floras, although sometimes occurring practically in the same section, have not been found commingling.

2. The Cretaceous flora ranges from the extreme upper part of the Knoxville formation through the Horsetown formation. It embraces about 60 species of plants and is regarded as being of Lower Cretaceous (Neocomian) age. It finds its closest affinity with the Kootenai of the Interior region, the Trinity of Texas, and the lower Potomac of the Atlantic coast.

3. Associated with the Lower Cretaceous flora is an invertebrate fauna regarded as being of Neocomian age, the plants and invertebrates thus being in agreement.

4. The Jurassic flora, which has been called the "Jurassic flora of Oregon," ranges from beds which have been referred to the Mariposa formation through the major portion of the Knoxville formation. It includes 100 species and finds its close affinity with the Lower Oolite floras of known position in other parts of the world. It is beyond question a true Jurassic flora.

5. Associated with the Jurassic flora is a meager, often poorly preserved invertebrate fauna of only seven species, including the two supposedly characteristic species of Aucella (*A. crassicollis* and *A. piochii*). This fauna, with the exception of *Aucella piochii*, is the same as that found in association with the Lower Cretaceous flora, and it is on account of this association that the Jurassic plant beds have been referred by some invertebrate paleontologists to the Cretaceous.

6. The age of the beds containing the "Jurassic flora of Oregon" thus hinges on the relative strength of the evidence afforded by the flora as compared with that of the associated fauna. It has been shown in this paper that of a total of 100 species of plants, 47 species are known also from known Jurassic of other, often widely separated parts of the world. Only one of these 100 species has been found in the Lower Cretaceous beds of the region. The total Knoxville fauna comprises 77 forms of invertebrates, only 7 named species of which have been found associated with the Jurassic plants. Of these 7 species of invertebrates, only a single species has been found outside the limits of the Oregon-California area, and it has been further shown that the invertebrate paleontologists are not in accord among themselves as to the interpretation to be given the age determination of the fauna. The conclusion is reached that the plants, being thoroughly consistent, afford the better criteria, and the beds are regarded as unquestionably of Jurassic age.

7. From the paleobotanical evidence which has been presented it follows that in this portion of the Pacific coast region the line between the Jurassic and Cretaceous is to be drawn through the upper part of the Knoxville formation, and not at its base. This line is fixed by the upper limit of the Jurassic flora.

In 1895 Stanton discussed the relation of the Knoxville fauna to the Volgian faunas of Russia, and after citing differences of opinion among the Russian geologists as to the Jurassic or Cretaceous age of the Volgian, he wrote:[776a]

It is evident, then, that even if it were possible to refer the Knoxville to definite horizons of the Russian Aucella beds its age might still be questioned. One important fact that should

[a] The only possible exceptions are a scrap very doubtfully identified from the area near Riddles, Oreg., and a conifer of no stratigraphic value from California.

be borne in mind is that structurally and faunally, so far as known, the Knoxville is a unit. It is true that there is a gradual change in the fauna from the lower to the upper beds, but there is no distinct break that would justify the reference of one portion to the Jurassic and another to the Cretaceous. There are some elements of the fauna, such as *Belemnites tehamaensis Hoplites storrsi,* and some of the Turbinidæ, that resemble Upper Jurassic types. *Aucella piochii* belongs to the same general type as *A. mosquensis,* which has usually been referred to the Jurassic, and it is somewhat closely related to the Aucellæ [a] of the Mariposa beds, but Prof. Pavlow informs me that Aucellæ very similar to *A. mosquensis* occur in the Neocomian of Russia also. These resemblances, which will be more fully mentioned in the description of the species, are not considered of sufficient importance to counterbalance the evidence of the Cretaceous age of the entire series. Some Jurassic elements are naturally to be expected in the Lower Neocomian, and it is a well-known fact that in Europe several species of ammonites pass up from the Jurassic to the lowest Cretaceous beds.

Prof. Hyatt's opinion as to the Cretaceous affinities of the Knoxville ammonites has been cited on a previous page. That the Upper Knoxville beds containing *Aucella crassicollis* are Neocomian is shown by the resemblance of its fauna to that of the Petschora beds, now generally admitted to be Neocomian, and by its stratigraphic and faunal relations with the immediately succeeding Horsetown beds, which have been compared with the Gault by everyone who has studied their fauna.[b] The few fossil plants that have been obtained from the Knoxville and the Horsetown also tend to show that these two formations are closely connected, and these plants are mostly either identical or closely related with species in the Lower Cretaceous Potomac formation of the eastern United States and in the Trinity beds at the base of the Comanche series in Texas.[c]

From all these lines of evidence the conclusion is reached that the entire Knoxville series is of Neocomian age.

In 1910, as this manuscript is being finished, Stanton states orally that the preceding quotation expresses the views he stills holds.

J. Perrin Smith [766] does not altogether agree with Stanton, as appears from the following statement:

The Cordilleran revolution began in the Great Basin sea in the middle of the Jurassic, when that body of water, after many vicissitudes, finally went dry, and has never since been covered by salt water, although in later ages Tertiary and Quaternary lakes have been scattered over its dead basin.

This elevation culminated, in late Jurassic time, in the upturning and metamorphism of the Triassic and Jurassic sediments of the Sierra Nevada and the Franciscan beds of the Coast Ranges. * * *

It is probable also that the Cordilleran revolution was something more than a mere orogenic disturbance, for it marks a change from the warmth of the Middle Jurassic, with its cycads and reef-building corals, to the cooler epoch of the Upper Jurassic, with its scanty boreal fauna. The Middle Jurassic was of tropical type, from Mexico to Alaska, and uniform up to Franz Joseph Land. The Upper Jurassic, on the other hand, was of boreal type from the Arctic region down as far as California, and for a short epoch in the Portland these conditions extended down as far as Mexico.

After this mountain-making epoch near the close of the Jurassic, the sea again encroached on the uplifted area, and the Knoxville sediments were laid down on the western border of the

[a] See comparisons by Prof. Hyatt, Bull. Geol. Soc. America, vol. 5, pp. 404–407.

[b] It is not probable that the limits of the divisions recognized in the California Cretaceous coincide exactly with those of the European subdivisions of the Cretaceous. It has been shown (Bull. Geol. Soc. America, vol. 5, pp. 445–449) that the Horsetown beds probably include the lowest Cenomanian, and at their base they may contain strata older than the Gault.

[c] These plants are the only means by which the Lower Cretaceous of Texas and California can be compared. So far as known, their invertebrate faunas have nothing in common.

Coast Ranges. The lower Knoxville beds contain a fauna closely related to that of the Mariposa, still with Jurassic types of Aucella, and with the same poverty of other animals. But the upper Knoxville beds, while still retaining reminiscences of the boreal region in Aucella and a few other forms, show a preponderance of life characteristic of more favorable conditions. Aucellas of northerly habit mingle with cephalopods that did not belong in the boreal region, and on the near-by land cycads abounded. The line between Jurassic and Cretaceous should be drawn, not at the beginning of the Knoxville, but between the lower and the upper Knoxville beds; the former belonging to the Portland and Aquilonian, while the latter belong to the Neocomian.

L 10. JOHN DAY BASIN, OREGON.

Merriam [589, 590] refers to exposures of conglomerate and sandstone on the west side of the John Day Basin, from which good collections of fossils were obtained. The outcrops appear to form opposite sides of a syncline, and include 3,000 or 4,000 feet of beds. The lower strata are said to "exactly duplicate" those of the Knoxville as it is usually developed in California and southern Oregon. Stanton has identified the Chico fauna in Merriam's collections.

L 12. SOUTHWESTERN AND CENTRAL MONTANA.

F. C. Calkins contributes the following notes from a manuscript for a folio on the Philipsburg quadrangle, Montana:

Both Lower and Upper Cretaceous are represented in the Philipsburg quadrangle, although they have not yielded very satisfactory fossils. The Lower Cretaceous is represented by the Kootenai formation, which may be described as follows:

The yellow-weathering beds of the Ellis formation are generally overlain by a heavy reddish sandstone, locally conglomeratic with well-rounded pebbles of quartzite like the Quadrant, which is taken to be the base of the Cretaceous. This bed is generally succeeded by argillaceous buff-weathering limestones, in the upper part of which have been found poorly preserved specimens of the fresh-water gastropod Goniobasis which, according to Dr. Stanton, tend to indicate a Kootenai age. Above these there are several hundred feet of maroon and gray-green sandstones and shales that have yielded no fossils. Near the top is a bed or several beds of gray limestone crowded with shells of fresh-water gastropods. These gastropod limestones, which are very conspicuous in the vicinity of Drummond, on the Northern Pacific Railway, seem to be very widespread and highly characteristic of this horizon. They are probably the same as those that in the Yellowstone National Park were referred to the Dakota. Above the gastropod limestones are a few feet of calcareous shale and sandstone. On Mount Princeton, in the Philipsburg quadrangle, there is a gradation to the black noncalcareous shales of the Colorado formation; elsewhere the transition is more abrupt.

These uppermost limestones have yielded two or more undescribed unios, one related to *U. douglassi* Stanton, *Goniobasis? increbescens* Stanton, and Viviparus? sp. The fauna is characterized by Dr. Stanton as probably upper Kootenai.

The total thickness of the beds referred to the Kootenai is about 1,500 feet.

The Cretaceous of the Great Falls coal field extends along the northern and northeastern flanks of the Belt Mountains. The Lower Cretaceous is represented by the Kootenai formation and the Upper Cretaceous by Colorado and Montana strata. The Morrison formation, which is doubtfully referred to the Jurassic by Stanton and others, is described under the Lower Cretaceous by Fisher,[332a] who states:

The Morrison formation, which is extensively exposed along the Rocky Mountain Front Range in southern Montana and Wyoming, is also believed to occur along the northern base of the Little Belt Mountains. In previous investigations in this field by Weed and others the Morrison formation has not been recognized, and the beds comprising it have been grouped with the Kootenai and included in the "Cascade" formation. During the last field season dinosaur bones provisionally regarded by C. W. Gilmore as of Jurassic age were found at one horizon in many different localities; and at one exposure in sec. 3, T. 16 N., R. 2 E., about 30 feet below the bone-bearing bed, a green shale containing a distinctly fresh-water fauna later than the Ellis formation was seen. These rocks, here provisionally regarded as constituting the Morrison formation, consist of sandstone and bright-colored sandy shale with scattered layers of impure limestone, many of them in lenticular form. The formation lies with apparent conformity on the Ellis and is overlain conformably by the Kootenai. The thickness ranges from 60 to 120 feet, but the exact limits of the formation are in many places difficult to determine. Fragments of bone have been found at different horizons throughout the overlying Kootenai formation, but thus far none that are sufficiently well preserved for specific determination have been discovered in this region. It is possible that future investigation may prove that the rocks here tentatively regarded as belonging to the Morrison constitute in reality a basal member of the Kootenai.

Section of supposed Morrison formation on the north side of Smith River, Montana.

	Feet.
Kootenai formation.	
Morrison formation:	
Shale, soft, sandy	52
Limestone, light-colored, nodular	4
Shale, variegated	33
Sandstone, gray, massive	11
Shale, greenish gray, sandy	20
Ellis formation.	
	120

Fisher gives other sections of the supposed Morrison and states that the rocks have yielded invertebrate fossils which Stanton regards as "a fresh-water fauna later than the Ellis and suggestive of the Morrison."

In regard to the character and extent of the Kootenai, Fisher has the following to say:

The Kootenai, as determined by the present investigation, comprises the upper one-third of the Cascade and Dakota and the basal red shale included in the Colorado shale, as described by Weed in the Fort Benton folio. * * *

[This formation] consists of alternating layers of sandstone and shale, with the former predominating, especially in the lower half. The sandstones range in thickness from 10 to 60 feet and are more or less massive in character. In the upper part shales are more abundant and are interbedded with thin layers of impure sandstone. At Belt, on the east side of Belt Creek, where a complete section was measured, the basal member of the formation consists of a sandy shale interbedded with sandstone, the latter predominating, the whole having a thickness of about 60 feet. This member consists locally of firm, massive sandstone with only a small percentage of shale. It is overlain by coal, which here has a thickness of 6 feet, including a few thin partings. Above the coal there is a dark coaly shale 5 to 6 feet thick, covered by 38 feet of massive light-gray sandstone. This sandstone is overlain by 138 feet of beds, consisting in ascending order mainly of alternating layers of sandstone, red shale, and clay, with an occasional limestone lens in the lower part. Above this alternating series there is about 200 feet of red shale, which constitutes the topmost member of the formation. The total thickness is about 450 feet, which may be regarded as representative of the Kootenai formation as exposed along the Belt Creek valley. * * *

During the present investigation a number of detailed sections measured along Belt Creek proved conclusively that the stratigraphic interval between the base of the Ellis and the

Kootenai coal, to which Weed had assigned a thickness of 736 feet, is in reality only about 300 feet. According to the present classification the lower 120 feet of these beds has been assigned to the Ellis; an equal thickness immediately overlying, in which fresh-water invertebrates and land animals occur, to the Morrison; and the upper 60 feet, which is plant bearing, to the Kootenai. * * *

The Kootenai has the greatest areal distribution of all the formations outcropping within the area. It caps the surface for a great part of the district lying between Smith River and Belt Creek and is the surface formation of the high plateaus south of Otter Creek. Beyond Otter Creek it is exposed as a band of varying width which narrows toward the east.

Fisher gives columnar sections measured along the Belt Creek valley which show the character and thickness of the several formations. As to fossil evidence and correlation he states:

The Kootenai formation of the Great Falls district carries an abundant fossil flora of Lower Cretaceous age. Fossil plants of Kootenai age were first discovered in the Great Falls coal field in 1889 by J. S. Newberry. From these fossils, which consisted of only a few species, it was possible to correlate the rocks of the Great Falls region with the Kootenai north of the international boundary line, described by George M. Dawson. * * *

During the present investigation fossil plants, all of which were studied and reported on by F. H. Knowlton, were collected from five different horizons—15, 60, 70, 150, and 300 feet above the base of the Kootenai formation. * * * The collection * * * is not large, but it is of unusual interest in that it contains a number of species before unknown in the Kootenai beds of this age; it contains also a species of the genus Protorhipis not previously found in North America, as well as some believed to be new to science.

In addition to the plants, some fresh-water invertebrates were collected from the upper part of the Kootenai during the investigation. * * * These fossils are too imperfect for positive identification, but the species with which they are compared occur a few miles south of Harlowton, Mont., in beds that belong to either the Kootenai or the Morrison.

M 10. WASHINGTON AND BRITISH COLUMBIA.

A belt of Cretaceous strata crosses the international boundary from Washington into British Columbia. The rocks were described by George Otis Smith [757a] in 1904 and by Camsell [129] in 1907. The following is quoted from Smith's account of the eastern belt on Pasayten River. Camsell's description is briefer and to the same effect.

Prof. Russell, in his reconnaissance of 1901, examined an assemblage of folded sedimentary strata in the neighborhood of Barron and Crater Pass.[a] From these rocks he collected fossils which are commented on in the following extract from his report:

"A thick bed of bluish sandstone at the base of Gold Ridge, penetrated by the tunnels of the St. Paul and Minneapolis mines, contains fossil ferns and nearly upright tree trunks. One sample of fern collected has been determined by F. H. Knowlton as approaching closely *Dryopteris œrstedi,* from the Cretaceous rocks of Greenland. A siliceous limestone in the same ridge, but several hundred feet higher in the series and extending southward to the border of Crater Pass, is abundantly charged with bivalve shells, which, as determined by T. W. Stanton, are of a species of Actæonella. The evidence furnished by the fossils just mentioned indicates a Cretaceous age."

The authors of this paper found that these Cretaceous beds extended eastward along their route to the Hidden Lakes and were very extensively developed to the north, and believe that they extend west to a point not far above the mouth of Granite Creek. In this, however, they differ from Prof. Russell, who believes that the slaty rocks with steep dips exposed along lower

[a] Russell, I. C., Geology of Cascade Mountains: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, pp. 114–117.

Slate Creek and Ruby Creek are much older than the Cretaceous.[a] * * * The authors do not consider that the assumption of the pre-Cretaceous age of these beds is justified and have provisionally considered them as belonging in the same formation with those at Barron.

To the rocks of this locality which he recognized as Cretaceous Prof. Russell provisionally applied the name Similkameen formation.[b] This name was, however, applied ten years earlier by Dawson to a Miocene formation in British Columbia.[c] * * *

The Pasayten formation is composed of sedimentary rocks without contemporaneous volcanic materials. East of the main fork of Pasayten River sandstone appears to be the dominant rock. * * * The lowest part of the section, as seen along the crest of the Hozomeen range, includes at least 1,000 feet of black shale. Above this shale is a sandy conglomerate, with pebbles from 1 to 8 inches in diameter. * * * Sandstone overlies the conglomerate and is succeeded by more black shale. The steep dips here indicate the presence of a great thickness of these rocks, * * * so that 6,000 feet would appear to be a very conservative estimate for the thickness of the Pasayten formation.

There are a few thin and discontinuous beds of limestone in the Pasayten formation, but they constitute only an insignificant proportion of its total volume. Along the lower portion of Slate Creek the supposed Cretaceous rocks are mainly black indurated shales with nearly vertical dips.

The argillaceous portions of the Pasayten formation are generally dark-colored, distinctly bedded shales. They are often siliceous and in general more or less indurated, and are popularly referred to as "slate." * * *

The sandstones, while occasionally quartzitic, are more commonly gray or greenish gray in color, and evidently composed in large part of feldspar and rock fragments. The conglomerates contain a variety of pebbles, including several granitoid rocks, gabbro, diabase, metamorphosed volcanics, chert, quartzite, and vein quartz, illustrating the character of the pre-Cretaceous formations of the region.

The whole series has undergone a considerable degree of "static" metamorphism, as shown by the generally thorough cementation of the sandstones and the presence of joints in all the varieties of rocks. Both these phenomena are exemplified strikingly in the conglomerates, which often are divided into great blocks whose faces are nearly as smooth as if made by a saw that had cut indifferently through the pebbles and their compact matrix.

The series is cut by many dikes and sheets of igneous rock; these are especially numerous along the main divide, where they must add materially to the volume of the formation. At three localities there are exposures of granitoid rock, apparently intrusive in the Pasayten formation.

M 11-12. CANADIAN ROCKIES, ALBERTA AND BRITISH COLUMBIA.[d]

The Cretaceous areas in the Canadian Rockies are best known as the Cascade and Crows Nest Pass coal fields. Dawson stated that in this region dark Cretaceous shales in apparent conformity succeed Carboniferous shales, which are lithologically similar, but the Fernie shale (Jurassic) has since been distinguished. The Cretaceous consists of shales, sandstones, conglomerates, and coals, to a total thickness of 12,000 feet or more. It comprises the Kootenai formation (Lower Cretaceous), a local volcanic intercalation, and Upper Cretaceous strata. Dawson's original description [255a] runs in part:

Over the area of the Great Plains, both in the United States and Canada, and in the Rocky Mountain region south of this district, the lowest rocks of the Cretaceous series developed are those of the Dakota, of Middle Cretaceous age. In the vicinity of the west coast Lower Creta-

[a] Russell, I. C., op. cit., p. 112.
[b] Idem, pp. 114-117.
[c] Dawson, J. W., Proc. and Trans. Royal Soc. Canada, vol. 8, sec. 4, 1890, pp. 75-91.
[d] For the Cretaceous of the plains in this latitude see p. 695.

ceous rocks are found, and in this part of the mountains we appear to enter upon the edge of the area of deposit of the Lower Cretaceous, the beds here named the Kootanie series occupying that horizon. The geological horizon of the Kootanie series is determined by its position relatively to the higher members of the Cretaceous series, and by the fossil plants which it has yielded. * * * The plants "consist of ferns, cycads, and conifers, some of them identical with or closely related to those of the Jurassic of the Amur country in Siberia, and others similarly related to the Lower Cretaceous of Greenland, as these floras have been described by Heer. This group undoubtedly represents the flora of the Lowest Cretaceous, which has not hitherto been recognized in western America." * * * That the series characterized by these plants is a widespread and important one is shown by the fact that one of the species (*Pinus suskwaensis*) had previously been found on Suskwa River, in northern British Columbia, at a distance of 580 miles northwest of the most northern locality here referred to.

* * * * * * * * *

No complete section can yet be given of the Cretaceous rocks of the mountain region, nor of those of the adjacent foothills. * * * Two horizons appear, however, to be fixed with considerable definiteness in the lower part of the Cretaceous of the mountains—that of the most important and persistent coal seams and that of the volcanic intercalation. The first of these is fixed in part by the similarity of appearance and character of the coal and beds near them, but chiefly by the very similar group of fossil plants which is found in association with these coal seams.

* * * * * * * * *

The thickness of the rocks of the Kootanie series below this coal-bearing horizon was estimated on the Crow Nest Pass and near the west summit of the North Kootanie Pass at about 7,000 feet, which may be taken as a minimum estimate of the greatest observed development of this part of the series. The beds are chiefly shales and sandstones of very varied texture and appearance.

The volcanic ash beds and agglomerates of the Cretaceous, in this region, are evidently due to local eruption, which had its center in the latitude of the Crow Nest Pass. These volcanic rocks have, however, been traced north and south from this point over a total length of 45 miles, and may probably have at one time had as great an extension east and west, though this has subsequently been diminished by the folding together of the beds. The volume of the strata between the coal-bearing horizon and the base of the volcanic rocks on the Crow Nest Pass was estimated approximately at 3,350 feet, on the South Kootanie Pass at 2,400. The mean of these approximations, 2,750 feet, may for the present be adopted as a probable result. The volcanic rocks themselves, on the Crow Nest Pass, where they attain their maximum, have a volume of about 2,200 feet, but thin out very rapidly to the north and south.

The summit of the Kootanie series is not yet precisely defined but is situated between the apparently constant coal-bearing horizon and the base of the volcanic beds, as, on the Northwest Branch of the North Fork, fossil plants believed to represent the horizon of the Dakota are found a few hundred feet below these volcanic beds.

(See also M 11, Chapter XIII, p. 574.)

M 10, N 9-10, O 9. WESTERN BRITISH COLUMBIA.

The Jackass Mountain group, so called by Selwyn from the locality of that name on Fraser River (near the mouth of the Thompson?), is described in his report[724] as consisting of "hard, close-grained, and thick-bedded greenish sandstones or quartzites, green and black shales, and, above these, massive, thick-bedded pebble conglomerates, dipping generally at low angles in various directions; some of the inclosed pebbles are of rocks belonging to the Cache Creek series."

In 1875 Dawson[249a] identified these rocks on Tatlayoco Lake (longitude 124° 30′, latitude 51° 30′), where they have the character of the strata on Jackass Mountain, and he found fossils by which the age was "determined as lower Cretaceous of the horizon of the Shasta group of the California geologists." He says further:

Along the eastern shore of the lake these rocks, as already mentioned, appear to overlie those of the Porphyrite series. * * * The series is no doubt conformable throughout, the upper beds * * * showing, however, a greater development of conglomerates. The rocks may be described as being compact bluish-gray quartzites or hard sandstones and conglomerates of all grades in regard to size of particles, associated with blackish or dark-colored slaty and shaly beds, which recur frequently at different horizons. Great fragments of highly fossiliferous quartzite strew the lower slopes in some places, but fossils were only observed in situ about 2,000 feet above the lake, where they are found not only in the quartzite but in black shaly beds. * * * It is highly probable that softer shaly beds may bear a larger proportion to the quartzites than now appears, as there are extensive hollows following the strike in which no exposures occur. Many of the beds are somewhat calcareous, and some of the shales are dark colored from carbonaceous matter. Together with the marine fossils, in some layers surfaces are found covered with obscure plant impressions, like fragments of stems or bladelike leaves. No indications of coal were, however, observed. The thickness of the entire series, as shown on the east side of Tatlayoco Lake, probably does not fall short of 7,000 feet.

In 1877 Dawson [251] reexamined the Jackass Mountain rocks in the type locality and found "*Syncyclonema meekiana* Wh., *Ancyloceras percostatus* Gabb, *Crioceras latus* Gabb, Pleuromya n. sp. allied to *P. papyracea* Gabb, an Arca * * * and a badly preserved cast of a Cucullæa." These fossils confirm the correlation with the rocks on Tatlayoco Lake.[a]

The small basin of the Jackass Mountain occurrence, above described, is crossed by the fiftieth parallel. That of Tatlayoco Lake is the south end of a large area which widens toward the north and extends nearly to latitude 58°. A section along Skeeha River and across the mountains to Babine Lake, near the fifty-fifth parallel, is described by Dawson.[253] Referring to the rocks cut by the Skeena and its tributaries, he notes that they are chiefly feldspathic rocks of purplish, grayish, greenish, or bluish tints. They "are sometimes brecciated, and the breccias occasionally pass into water-formed conglomerates, with well-rounded fragments, the finer materials graduating into ordinary quartzites, sandstones, and argillites by intermediate varieties. Fossils were found in some abundance in a bluish feldspathic rock. * * * They include belemnites, a Trigonia, with other mollusks and a branching coral."

Near Kitseguecla the rocks change somewhat in character. The sandstones are not highly indurated, as before, but rather soft, and associated with carbonaceous shales, which occur at different stages in the formation and are sometimes 10 or more feet in thickness. At a little distance these quite resemble coal seams, and on closer examination are in fact found to include films and small lumps of a material, which, though very impure and ashy, may be called true coal. Ironstone in nodules and sheets occurs in abundance in some parts of the formation, and obscure plant impressions were observed in the sandstones. The rocks have been irregularly deposited in many instances, the carbonaceous shales in particular showing a tendency to lenticular forms. * * *

It will have been observed that while the porphyrite and other feldspathic and often brecciated rocks prevail toward the western margin of the region, comparatively soft sandstone, argillites, and carbonaceous argillites characterize the eastern, the intervening region showing rocks more or less intermediate in lithologic character and degree of induration. * * *

[a] This list indicates correlation with the Horsetown of California.—T. W. Stanton.

In proceeding eastward from the forks to the northern end of Babine Lake, across the intervening mountain region, similar rocks continue to prevail. Sandstones are most abundantly represented but contain in some places carbonaceous shales and toward the summit of the pass become associated with rocks of volcanic origin like those before described. These occasionally seem to form fully one-half the thickness of the beds represented. In one place 5 miles up the Suskwa River a few impressions of leaves were found. Some of these appear to be coniferous. There is one narrow angiospermous leaf and several grasslike blades. Not far from the summit numerous fragments of silicified wood were obtained, with a few specimens of a mollusk which, according to Mr. Whiteaves, who has examined the specimens, is a Thracia of the section Corimya. The species is probably undescribed, but it is identical with one from the coal-bearing rocks of the Queen Charlotte Islands.

In 1875 Dawson [249] distinguished in southwestern British Columbia a great body of volcanic rocks and pyroclastic tuffs under the name "Porphyrite group." He says:

Porphyrite group.—This name may be provisionally employed to designate a series of rocks, chiefly feldspathic and often porphyritic, though also including diorites of varied texture, the reference of which to any of the groups formerly defined seems uncertain. They are best seen about Tatlayoco Lake, where they overlie unconformably the Cascade crystalline rocks and appear to underlie the beds of the Jackass Mountain series. The whole of the rocks of this group seem to be of igneous origin, though some of them may owe the arrangement of their material to water.

After the field work of 1876 Dawson [250] wrote:

It may now, however, be affirmed with considerable certainty that the rocks called the Porphyrite series in last year's report underlie, probably conformably, the fossiliferous series of Tatlayoco Lake and consequently bear the same relation to the Jackass Mountain beds of the preliminary classification. This inference is chiefly based on the fossils discovered on the Iltasyouco River, described by Mr. Whiteaves in an appended note.

* * * * * * * * *

The most interesting and typical sections of these rocks examined last summer are those in the vicinity of Iltasyouco and Islaho or Salmon rivers. The rocks here seen represent those described last year on Tatlayoco Lake, and though they have not been again observed in contact with the upper arenaceous and conglomerate beds of the Tatlayoco Lake sections, the discovery of fossils on the Iltasyouco River, of a horizon close to though probably lower than that of the Jackass Mountain group, together with additional evidence tending to show the blending of the ordinary aqueous sediments of the upper part of the Jackass Mountain series with the igneous products of the Porphyrite series, leaves little room for doubt that the latter is the downward continuation of the former, and that the whole constitutes a formation, bridging to some extent the gap ordinarily found between the Cretaceous and Jurassic.

Detailed sections and descriptions of these rocks, which exceed 2,000 feet in thickness, are given on pages 59 to 72 of Dawson's report.

Whiteaves [911] reports on the fossils from the "Porphyrite group" of Iltasyouco River and closes with the following comment on correlation:

The fossils above enumerated are of much interest as affording the first instance yet observed of the occurrence of a well-marked fauna of Jurassic age in British Columbia. It is true that fossils, probably from a very similar geological horizon, were collected by Mr. Selwyn in 1875, at Rock Island Gates, below Hudson's Hope, on the Peace River, but these specimens, which were described in the report of progress for 1875–76, are very few in number and so imperfect that none of the species could be satisfactorily determined.

If the identifications in the present paper be correct, it would appear that nine of Meek and Hayden's species, from the Jurassic rocks of Dakota, are found also in the Coast Range of British Columbia. These are:

Gryphæa calceola var. nebrascensis.	Grammatodon inornatus.
Camptonectes extenuatus.	Astarte fragilis.
Eumicrotis curta.	Pleuromya subelliptica.
Modiola (Volsella) formosa.	Planorbis veternus.
Modiola (Volsella) pertenuis.	

* * * * * * * * *

Trigonia dawsoni and *Astarte ventricosa*, from the Iltasyouco River, are also found in the Jurassic rocks of the western slope of the mountains in Nevada; and it may be that there is no physical or geographical break between the coast range of British Columbia and the Sierra Nevada. Mr. Gabb has pointed out that the Jurassic fossils of Nevada are probably of the age of the Lias, and some of the Iltasyouco lamellibranchs, as has already been stated, are barely distinguishable from European Liassic species. On the other hand, the few ammonites collected by Mr. Dawson, so far as very fragmentary specimens enable one to judge, appear to be conspecific for the most part with well-known forms from the English Inferior Oolite, though one, which has been doubtfully referred to *Perisphinctes anceps*, may indicate a horizon as high as the Oxford Clay or Coral Rag. On the whole, however, the evidence, as far as it goes, is in favor of the supposition that these fossils from British Columbia belong to the lower rather than to the upper part of the Jurassic series.

Subsequently Whiteaves [918] modified this conclusion in favor of a later age for the rocks in question. He says:

Certain rocks described by Dr. Dawson in the report of progress of the Geological Survey of Canada for 1876–77, and there referred to as the "Porphyrite series," occur on Sigutlat Lake and the Iltasyouco River, which flows from Sigutlat Lake into the Dean or Salmon River. The fossils collected from these porphyrites were reported upon provisionally by the writer in an appendix to Dr. Dawson's report. They were then regarded as possibly of Jurassic age, on account of their resemblance to the fossils of the so-called Jurassic rocks of the Black Hills of Dakota, but are now believed to be Cretaceous.

The collections of fossils that have been made from the Cretaceous rocks at Quatsino Sound, Vancouver Island, in 1878 and 1885, and at various localities off the coast or on the mainland of British Columbia between 1875 and 1888, have led to the conclusion that the Aucella-bearing rocks and Jackass Mountain series of that province are not older than but of about the same age as the Queen Charlotte Island formation, and that the porphyritic rocks of Sigutlat Lake and the Iltasyouco River are of the same age and not altered Jurassic sediments.

N 8-9. QUEEN CHARLOTTE ISLANDS.

The Cretaceous or coal-bearing rocks of Graham Island, the northern member of the Queen Charlotte group, are described by Ells,[316b] who, however, confines his account largely to local details and refers to Dawson for a general discussion. Dawson,[252b] following Richardson,[671a] distinguished the following strata:

	Feet.
A. Upper shales and sandstones	1,500
B. Coarse conglomerates	2,000–3,000
C. Lower shales with coal and iron ore	1,800–5,000

To these he added:

	Feet.
D. Agglomerates of volcanic origin	3,500
E. Lower sandstones	1,000?

The upper shales (A) are generally arenaceous and interstratified with sandstones from 3 to 6 inches thick. A bed of sandstone 30 feet thick occurs 70 feet above the base, and the lowest shales are interstratified with reddish-weathering, grayish-brown dolomite, which constitutes the chief part of the mass and seems to form a passage to the underlying conglomerates. The shales have yielded but one recognized fossil, "*Inoceramus problematicus*."[a]

The conglomerates (B) include for the most part well-rounded pebbles, in some layers several inches in diameter, derived from the more or less crystalline pre-Cretaceous rocks; rounded shaly fragments of the next underlying Cretaceous are also found, indicating slight erosion, but no true unconformity, during the deposition of the conglomerate. Gray and yellow sandstones are interbedded and the upper part of the conglomerate is dolomitic.

The lower shales and sandstones, at the base of which the anthracite coal is found, consist of blackish or gray shales, interbedded with gray or yellowish-gray sandstones and numerous layers composed of sandy argillaceous material, intermediate in character between shale and sandstone. The bedding is generally regular and certain zones are characterized by large calcareous nodules, generally lenticular, and occasionally several feet in diameter or even coalescing to form sheets of calcareous matter. Layers so coarse as to be called conglomerates scarcely occur. The beds immediately underlying the conglomerates of subdivision B are generally gray shales, very regular in their bedding, and quite hard. Below these is a considerable thickness of strata in which shaly beds usually preponderate, while toward the base of the subdivision sandstones are more important. The lowest beds are of interest as being those in association with * * * the coal. * * *

Subdivision C rests on a series of volcanic rocks constituting subdivision D, which apparently forms a member of the same formation. The upper surface of the agglomerate and ash rocks of D must, however, have been an irregular one, and to its undulations the lower beds of C more or less closely conform. The appearance at the junction of subdivisions C and D is therefore that of an unconformity more or less marked. * * * This partial unconformity is, however, believed to be essentially unimportant and only such as might be anticipated at the junction of two classes of deposits so dissimilar. * * * The occurrence of fossils identical with those of subdivision C in beds below the volcanic horizon, with the inclusion of marine forms in some parts of the upper portion of the rocks of volcanic origin (at points on the east side of Alliford Bay), serve to show the continuity of the conditions of deposit.

The passage beds have been observed in a number of localities to be coarse feldspathic or tufaceous sandstones, generally pale in color and formed apparently by the rearrangement of the still unconsolidated materials of the upper beds of D. These vary in thickness but are generally associated with black carbonaceous argillites, which are sometimes shaly and at the Cowgitz mine hold the seam of anthracite coal.

* * * * * * * * *

[The agglomerates which constitute subdivision D] are almost exclusively of volcanic origin, though some layers show traces of water action in the rounding of fragments. Some beds may have been flows of molten matter, but most are of a fragmental character, either agglomerates or tufaceous sandstones, of greenish, grayish, brown, or purple tints. * * * The material is almost everywhere predominantly feldspathic, and some specimens resemble typical porphyrite of rather coarse grain. At the east side of the point north of Alliford Bay, hard dark tufaceous sandstones are found graduating into agglomerates, some of which, however, have their fragments so well rounded as to be more appropriately designated conglomerates.

[a] *I. labiatus*.—T. W. Stanton.

Many layers here become calcareous from the inclusion of organic remains, of which some are evidently shells, though too poorly preserved for recognition, except in the case of one or two specimens, which appear to be Ostreæ.

The base of the Cretaceous consists of tufaceous beds with ordinary sandstones and calcareous layers that contain many fossils. "These, while in some cases specifically identical with those of subdivision C, include a few species not yet found in that part of the section, and thus present a general facies somewhat different from it."

The fossils from the Cretaceous of the Queen Charlotte Islands are described by Whiteaves.[923]

Dawson discussed the relations of the Queen Charlotte group and the Kootenai (Lower Cretaceous) of British Columbia, and reached the conclusion that "The very important fact is established of the existence of an identical earlier Cretaceous horizon on the west coast, and in and even to the east of the eastern range of the Cordillera system."

Stanton states (orally) that Dawson's reasoning was based chiefly on marine mollusks occurring below the plant-bearing beds of the Kootenai, in the Fernie formation, which is now assigned to the Jurassic. (See Chapter XII, under N 8–9, table of formations by Dawson, p. 540.)

N 9. TELKWA RIVER DISTRICT, BRITISH COLUMBIA.

Near the center of the large area mapped as Lower Cretaceous in British Columbia is Telkwa River, which traverses a district surveyed by Leach,[527] who thus describes the rocks of Dawson's "Porphyrite group" and the overlying coal-bearing strata:

Rocks of the Porphyrite group occupy by far the most extensive area in this map sheet. They consist of a great series of volcanics, composed of tuffs, andesites, agglomerates, etc., more often occurring in sheets as volcanic flows but frequently showing evidences of deposition under water, more particularly toward the top of the series, and are all more or less regularly bedded.

* * * * * * * * *

The rocks of this group vary greatly in appearance in different parts of the field, in color ranging from light greenish grays to dark purplish reds. Generally speaking it may be said that red colors predominate toward the top of the series, the beds consisting of reddish andesites, breccias, and tuffs, in many cases amygdaloidal, with inclusions of calcite and zeolites. Green is the characteristic color toward the base, the beds being composed largely of fine-grained greenish feldspathic rocks, often amygdaloidal and containing much calcite and epidote. * * *

Immediately overlying these rocks, and possibly unconformable to them, although both have been subsequently folded and faulted to such an extent that their immediate relationship to one another is somewhat doubtful, occurs a series of beds composed chiefly of clay shales and containing a number of important coal seams. The lower member of these beds consists of a coarse, loosely cemented conglomerate, mainly composed of pebbles from the underlying volcanics, in places shading into a coarse grit and not more than 60 feet in thickness in any place seen. * * * This is followed by some thin-bedded clay shales with a few soft, thin, crumbly beds of light-colored sandstone, succeeded by more clay shales and coal, carrying numerous yellow-weathering clay-ironstone nodules. These are the youngest sedimentary rocks represented in the district, and [are] not of great thickness (in no case seen showing more than 300 feet in all). * * *

A few fossil plants were collected from the coal-bearing beds of Goat Creek, [among] which * * * Prof. Penhallow [identified] * * * *Gleichemia gilbert-thompsoni* Fontaine. Along the international boundary line, on the Skagit River, * * * Daly obtained the same species [which is thought to indicate a Lower Cretaceous age].

N-O 4. ALASKA PENINSULA.

The Mesozoic area in the Alaska Peninsula includes Cretaceous as well as earlier Mesozoic rocks. Stanton and Martin summed up their general conclusions as quoted on page 574, Chapter XIII. Their statement in regard to the Cretaceous[575] is as follows:

The presence of the Russian type of Lower Cretaceous on the Alaska Peninsula is suggested by the occurrence of Aucella related to *A. crassicollis* at Port Möller and Herendeen Bay, where Jurassic types of Aucella also occur in other beds, but the details of the stratigraphy are unknown. These beds, with *Aucella* cf. *crassicollis*, comparable with the Upper Knoxville beds of California, are widespread in Alaska, though we found no indication of them at any localities studied by us. The species was obtained by Mendenhall on Bubb Creek, a branch of the Taxlina, in the Matanuska series; by Spurr in the Oklune series on the Kanektok near the mouth of the Kuskokwim; by Schrader in the Koyukuk and Anaktuvuk series in northern Alaska, and by Wright on Admiralty Island, southeast Alaska, where *Aucella piochi*, another Lower Cretaceous species, was found at a neighboring locality. It also occurs in the Mission Creek series on the Yukon. The geographic distribution of these Cretaceous Aucella beds is thus seen to differ radically from the distribution of the Naknek formation with its Jurassic Aucellæ, and this is regarded as evidence of a probable unconformity between them.

On Chignik Bay Upper Cretaceous rocks, closely associated with plant-bearing Kenai beds, occur on the lagoon 1 to 2 miles northeast of the Alaska Packers Association cannery and on Whalers Creek, 5 miles west of the same place, where they apparently include a workable coal bed. The exposures at the first locality consist of several hundred feet of shales and sandstones with some thick beds of coarse conglomerate in the middle portion. The beds beneath the conglomerate contain great numbers of fossil plants, a collection of which yielded * * * Upper Cretaceous species identified by Dr. Knowlton.[a] * * *

The shales above the conglomerates yielded * * * fossils [which] indicate correlation with a horizon in the Chico as developed in California and Vancouver Island, which includes practically all of the Upper Cretaceous, but the beds at Chignik are probably not older than basal Senonian.

Beds of possibly the same age occur on the north shore of the small bay north of Aievak or Douglas village, where there is a series of shales and sandstones with an estimated thickness of 2,000 feet. * * *

The Cretaceous beds at Chignik may be directly correlated with those on the Yukon near Nulato, and less certainly with those on the Anaktuvuk, in northern Alaska, which are the only occurrences of Upper Cretaceous hitherto reported in the Territory.

It is probable that more detailed study will reveal considerable areas of Upper Cretaceous rocks on the Alaska Peninsula, but their recognition in rapid reconnaissance is made difficult by the fact that lithologically they resemble the Eocene Kenai beds of the same region, which, like the Upper Cretaceous, are coal-bearing and contain fossil plants of similar general types. * * * There are doubtless unconformities both below and above the Upper Cretaceous of this region, since all of the Lower Cretaceous is lacking at most localities, and at some places the Kenai rests directly on the Jurassic.

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[a] For list of species see the work cited.—B. W.

Atwood[42a] reports on the Jurassic and Cretaceous of the Alaska Peninsula as follows:

Geologic sequence in western part of Alaska Peninsula.

Age.	Geographic distribution.	Lithologic character.	Thickness (feet).	Remarks.
Upper Cretaceous....	Chignik and Herendeen bays.	Conglomerate, sandstone, and shales, with coal seams.	600+	Contains valuable coal beds at Chignik and Herendeen bays.
Lower Cretaceous....	Herendeen Bay.......	Shale, sandstone, and calcareous sandstone.	1,800+	
Upper Jurassic.......	Chignik and Herendeen bays.	Sandstones, conglomerates, and arkose.	1,000+	

The Upper Jurassic sediments are * * * dense, fine-grained sandstones of bluish color, conglomerates, shales, and arkose. They are the oldest sedimentary rocks exposed in either the Chignik or the Herendeen Bay districts. * * * The Chignik localities have yielded several collections of invertebrate fossils whose age has been determined by Stanton.

The Upper Jurassic beds in Pinnacle Mountain, Herendeen Bay, are overlain by Cretaceous rocks and both have been folded, truncated, and in part covered by volcanic material, which issued from the summit of Pinnacle Mountain. The exposures on the west shore of Herendeen Bay * * * consist chiefly of fine-grained blue sandstones. [The fossils have been examined by Stanton], who reports that within the Upper Jurassic of Herendeen Bay two horizons are represented. At the upper horizon are forms related to *Aucella pallasi.* * * * At the lower horizon are forms related to *Aucella bronni.* * * *

Among the collections procured from the Chignik Bay region there are no fossils of Lower Cretaceous age. In parts of this region, at least, the Upper Cretaceous beds unconformably overlie the Upper Jurassic, and it may be that there is no Lower Cretaceous in the region. In the Herendeen Bay district the Lower Cretaceous appears in three belts extending through the Herendeen Bay coal field, coming to the surface on the flanks of the folds. The fossils * * * from these formations indicate that there are two horizons within the Lower Cretaceous. At the upper horizon are forms related to *Aucella crassicollis,* and at the lower are forms related to *Aucella piochi.* * * * The sediments * * * consist of sandstones, shales, and conglomerates.

O 8. SOUTHEASTERN ALASKA.

The Cretaceous rocks of southeastern Alaska comprise Aucella-bearing beds, which are Lower Cretaceous or possibly Jurassic, and a higher terrane, apparently unconformable to the Aucella-bearing beds, but conformable to the overlying Kenai formation (Eocene) and containing plant remains. Brooks[1011] thus sums up the known facts:

The recent studies of Wright have revealed the presence of the Aucella-bearing beds along the eastern coast of Admiralty Island in a series of conglomerates, graywackes, and slates. Stanton makes the following statement in regard to the fossils from these beds:

"The specimens of Aucella from Pybus Bay, Admiralty Island, are apparently referable to species that in California and adjacent States are characteristic of the Lower Cretaceous, *Aucella piochii* occurring in a lower zone than *Aucella crassicollis.* The Alaskan specimens probably also come from the Lower Cretaceous, although strict correlation is rendered somewhat hazardous by the fact that the genus Aucella with similar specific forms ranges down into the upper Jurassic."

Wright has also found a conglomerate sandstone and shale series on Kupreanof Island, a few miles south of Admiralty Island, which carries plant remains assigned to the Upper Cretaceous. Knowlton reports on these fossils:

"These plants indicate beyond question that the age is Cretaceous, and I would place them in the lower part of the Upper Cretaceous, or approximately of Cenomanian age."

It appears that these Upper Cretaceous beds are discordant to Aucella-bearing terranes of the adjacent region, and that they are conformably succeeded by the Kenai (Eocene) rocks, with which they are lithologically identical.

Later information by Wright [953] is as follows:

[Part of] stratigraphic column in southeastern Alaska.

Age.	Character of rocks.	Thickness (feet).	Structural characteristics.
Eocene to Upper Cretaceous.	Basalts, andesites, rhyolite tuffs, breccias, conglomerates, sandstones, and coal seams, with fossil plants.	1,500±	Flat-lying, slightly tilted, covering wide areas.
	Conformity.		
	Conglomerates, sandstone, shale, and coal seams, with fossil plants.	1,000+	Tilted, slightly folded, unmetamorphosed, occupying local basins.
	Unconformity.		
Lower Cretaceous to Jurassic.	Shale, conglomerate, and black limestone with fossils.	500+	Folded and faulted, with steep dips and variable strikes, slightly metamorphosed, occurrence local.
	Conformity.		
	Gray limestone, Aucella beds	200+	Same as above.
	(?).		
	Graywackes, slates, and conglomerates, carrying granite cobbles; lava conglomerates, and sandstones; no fossils.	2,000±	Folded and faulted, indurated, variable strike and dip, distribution limited.
	Conformity.		
	Andesite lavas, tuffs, breccia, conglomerate, and sandstone overlying granite intrusives; no fossils.	1,000±	Steeply tilted and folded with general northwesterly strike and variable dip, metamorphosed and rendered slightly schistose; distribution limited.

O–P 4. LOWER YUKON AND KUSKOKWIM BASINS, ALASKA.

The so-called Cretaceous of the Kuskokwim basin, represented as Lower Cretaceous on the map, comprises both sedimentary and volcanic rocks which constitute three different series, according to Spurr, and which may be older than Cretaceous, according to Brooks.[101j]

Spurr subdivided the Mesozoic rocks of the Kuskokwim Valley into three series, all Cretaceous, of which the Holiknuk and Kolmakof series are supposed to be synchronous, while the stratigraphic relation of the third—the Oklune series, which is Jura-Cretaceous—to the others is unknown. The Holiknuk series is made up of alternating sandstones, argillaceous and siliceous limestone containing fragmentary Cretaceous fossils, and shale and arkose, all thrown up in broad open folds. An unconformity determined the line of demarcation between these beds and the underlying Tachatna series (Devonian).

A succession of volcanic rocks of various types occurs to the southwest, and these, together with some intercalated tuffs, shales, impure limestones, and arkoses, form Spurr's Kolmakof series, supposed to be synchronous with the Holiknuk beds. A group of sediments, including shales, impure limestones, with some arkoses, received the name "Oklune series," from the mountains where they are typically exposed. These beds are referred to the Jura-Cretaceous on the evidence of some fragmentary fossils. As far as the facts presented can be interpreted, all three of these series may belong to the same horizon. All three exhibit about the same amount of deformation and are intruded by igneous rocks of various kinds. If they are not of the same age, it is probable that the Holiknuk belongs to the Jurassic or the Triassic and that the others are younger.

Maddren[569] gives the following description of the Cretaceous in a generalized table of stratigraphic sequence in the central Kuskokwim, Innoko, and lower-central Yukon region:

Conglomerates, arkoses, and shales, with some coal beds on the Yukon. Contains acidic dikes and sills on lower Kuskokwim and also basic volcanic material. Fragmentary plant remains and marine shells. Probably includes both Upper and Lower Cretaceous. Occurs throughout the lower Kuskokwim Mountains, southeast side of the Innoko Valley, northwest side of lower Yukon Valley, lower Koyukuk Valley, and upper part of central Kuskokwim Valley.

O-P 8. SOUTHERN YUKON TERRITORY AND BRITISH COLUMBIA.

In the vicinity of Lake Bennett (near latitude 60°, longitude 135°) the porphyrite and tuffaceous rocks of the middle and later Mesozoic are developed with the typical characters of the "Porphyrite group." The description by Cairnes[114] is in part as follows:

Newer than these Coast granites is a series [Windy Arm] chiefly consisting of porphyrites, diabases, andesites, tuffs, and basalts which cut through and overlie them, by far the greater part of the rocks being porphyrites which are generally fine-grained and greenish in color and present a fresh, unaltered appearance.

Following an account of the petrographic character and eruptive relations of the porphyrites, Cairnes continues:

There have been great showers of ashes and finer material which have consolidated into generally fine-grained greenish rocks showing bedding structure which is often quite pronounced, giving the rocks the appearance of fine-grained sandstones and shales. In places these particles have fallen into water and show to some extent water-sorting action and are mixed with argillaceous and other sedimentary materials. These rocks seem to grade into true sediments as shales, conglomerates, bedded cherts, cherty quartzites, etc., which carry coal seams. * * * The true sediments with some of the upper bedded ash rocks and tuffs are included in the Tutshi series described below. The rest are included in the Windy Arm series. The whole series appears to correspond to Dr. Dawson's Porphyrite series. * * * This Windy Arm series also corresponds, in all probability, to the rocks of division IV on Mr. Gwillim's Atlin map * * * and includes the corresponding representatives of the greenstones of his gold series division VI, which are newer than the granites. The corresponding representatives of the other members of division VI, which are older than the granites, have been included in this report, and on the map in the Lower Cache Creek series. * * *

Tutshi series.—This name was given by Mr. McConnell to include the "argillites, tufaceous sandstones, conglomerates, etc.," of the Windy Arm district, and the writer has adopted the name for all rocks in the area that appear to belong to this same series. These Tutshi rocks, which in all probability * * * correspond to the rocks of Mr. Gwillim's division III on his Atlin map, belong, as well as the Windy Arm series, to Dr. Dawson's Porphyrite series and correspond lithologically and stratigraphically with his Jackass Mountain series. * * * This latter consists chiefly of igneous products, and the Jackass Mountain series resembles rocks of ordinary aqueous origin. * * * All rocks, therefore, which are of aqueous origin, and all those associated and interbedded with them, are placed in this Tutshi series, as water action has had more or less effect on all of them and has not affected the rocks of the Windy Arm series. Dr. Dawson considered the Porphyrite series to be probably a link between the Jurassic and Cretaceous, making the Jackass Mountain beds Lower Cretaceous. The fossils found this season in these Tutshi beds, being all typically Lower Cretaceous, further bear out this correlation.

The fossils identified by Whiteaves from the Tutshi series of McConnell comprise:

Trigonia, small, arcuate, and beaked species. Two other Pelecypoda, imperfect and undetermined. Shales with numerous valves of an Estheria or of very young specimens of Inoceramus. Also two crushed fragments of a small ammonite, apparently referable to *Prionocyclus woolgari*. These are all placed under the head "Cretaceous" and are probably lower Cretaceous as described above.

Stanton's comment[a] on the above identifications is that the only specific name mentioned is characteristic of the Upper Cretaceous.

Q 4-5. KOYUKUK BASIN, ALASKA.

The Koyukuk "series" is a Lower Cretaceous or possibly Jurassic terrane, consisting of impure limestone, slate, and some sandstone, associated with igneous rocks. It carries *Aucella crassicollis* Keyserling. It occupies a large area in the lower Koyukuk basin, where it was first distinguished by Schrader.[1011]

Q 7. UPPER YUKON, ALASKA.

The latest report on the upper Yukon, that of Brooks and Kindle,[103] gives the following section of the later Mesozoic rocks (post-Triassic):

Provisional stratigraphic table.

System.	Series.	Lithologic character.	Locality.
Cretaceous.	Upper Cretaceous.	Conglomerates, sandstone, slate, and shale, cut by granite. Invertebrate fossils. Unconformity.	Wolverine Mountains, Quail Creek, near Rampart.
	Lower Cretaceous or Upper Jurassic.	Siliceous slate and quartzites, with some tuff and a little limestone, cut by basic dikes. Invertebrate fossils. Unconformity.	Upper Yukon River, between Fourth of July and Coal creeks.

The only member of the Mesozoic extensively developed along the Yukon is the so-called Aucella beds, which may be either Jurassic or Lower Cretaceous, but may here for convenience be assigned tò the latter system. These Lower Cretaceous beds form a practically continuous belt along the Yukon from about the mouth of Fourth of July Creek to Coal Creek. There may be, however, some of the younger Tertiary beds included within this area which were overlooked in the hasty examination.

The Lower Cretaceous of the upper Yukon comprises a series of closely folded rocks characterized by a large amount of silica. They included primarily siliceous slates, slaty sandstones, and quartzites, with which are associated some argillites and pyroclastics. One heavy bed (50 to 70 feet thick) of massive tufaceous conglomerate was observed within the Mesozoic area about 5 miles below Washington Creek, but may be an infolded older or younger terrane. The pebbles of this conglomerate, which are chiefly limestone, are well rounded, and some are 2 feet in diameter. The dominating rock type of the Lower Cretaceous is a siliceous slate or quartzite, sometimes interbedded with a clay slate. These rocks are usually pyritiferous and iron stained when weathered. Three miles below Washington Creek there is a series of beautifully banded slates and quartzites. * * *

These rocks in a general way strike easterly and northeasterly, but there are many local variations. They are usually closely folded, and no determination of thickness, which probably does not exceed a few thousand feet, could be made. On Washington Creek they appear to rest unconformably on the Devonian and in turn are unconformably overlain by the Tertiary

a Personal communication.

beds. Near Coal Creek the Aucella-bearing beds seem to underlie the Upper Carboniferous limestone, which has apparently been thrust over them.

R 3. CAPE LISBURNE, NORTHWESTERN ALASKA.

Collier[165c] found a thick sequence of strata apparently overlying the Corwin formation (Jurassic), and in the absence of fossils assigned it provisionally to the Lower Cretaceous. He describes it as follows:

Southwest of the area occupied by the Corwin formation, and lying between it and the Carboniferous rocks exposed at Cape Lisburne, there is a series of beds which, though they resemble the Corwin Jurassic rocks, are easily differentiated from them on lithologic grounds. These rocks outcrop along the coast from a point 2 miles west of Corwin Bluff to within 3 miles of Cape Lisburne and extend inland in a southeasterly direction. * * * The exact contact of this formation with the Corwin was not exposed, or if observed its significance was not understood, though the field relations of the two formations are definitely known at a number of localities. Continuous sedimentation and conformity between the formations are indicated, though the possibility of thrust faulting along the contact should not be overlooked. This formation is therefore provisionally regarded as overlying the Corwin and constituting an upper member of the Mesozoic series. * * *

Lithologically this formation consists of sandstones and shales, with the former in the ascendant. The sandstone beds range in thickness from a few inches to 20 or more feet. They resemble the sandstones of the Corwin formation, but taken as a whole are probably somewhat less gritty and contain no conglomeratic material. The shales which are interbedded with the sandstones are dark colored and sometimes micaceous, so that they have a silvery sheen on the bedding faces. In a few instances ripple marking was observed on shaly beds.

No definite fossils were found, after a diligent search, either in the sandstones or the shales, though indistinct impressions of vegetable fragments, probably detrital material, were found in some of the beds. The structure of the formation, while it consists of simple open folds near its boundary with the Corwin, becomes increasingly complicated as the fault at the contact with the Carboniferous rocks is approached. Overturned folds and minor thrust faults with axes extending in a general way northwest and southeast are typical features. * * *

Owing to the complex structure of this formation, it was impossible to definitely measure its thickness, but from the imperfect evidence obtained it is believed to be not less than 5,000 nor more than 15,000 feet, and for the purposes of this report it is estimated at 10,000 feet. Since no direct paleontologic or paleobotanic evidence was obtained, the age of the formation can only be inferred from its relation to the Jurassic Corwin formation, which it overlies. It is therefore provisionally assigned to the Lower Cretaceous. On Anaktuvuk River, 400 miles east of Cape Lisburne, Schrader found a formation somewhat similar to this, both in its lithology and in its topographic relations to the Lisburne formation, which he called the Anaktuvuk series[a] and which contains Lower Cretaceous fossils. If the above assignment is correct, the upper Mesozoic formation of the Cape Lisburne region should be correlated with the Anaktuvuk series.

R 5. NORTHERN ALASKA, ARCTIC SLOPE.

According to Schrader[101 1] the Cretaceous which he crossed in descending the Colville may be divided into two groups, which are unconformable—"the Anaktuvuk (Lower Cretaceous) and the Nanushuk series (Upper Cretaceous)."

The Anaktuvuk is made up of fine, heavy-bedded sandstones, or arkose—sometimes a grit, with little conglomerate—the whole aggregating at least 2,000 feet. Resting unconformably on these are sandstone, impure limestone, slate, quartzite, and chert, which make up the Nanushuk series. The Anaktuvuk carries *Aucella crassicolis* Keyserling, making it Jura-Cretaceous, while the Nanushuk has yielded Upper Cretaceous fossils. The Nanushuk, like the Upper Cretaceous of the lower Yukon, contains coal seams of excellent quality.

[a] Schrader, F. C., Reconnaissance in northern Alaska: Prof. Paper U. S. Geol. Survey No. 20, 1904, pp. 74–76.

Chapter XV.

UPPER CRETACEOUS.

Color, light green.
Symbol, 7.
Distribution: South America and West Indies; present but not distinguished in Mexico from Lower Cretaceous; Atlantic and Gulf coasts from Mexican boundary to New England; the Interior province, New Mexico to Mackenzie; Pacific coast, Lower California to Alaska; the Arctic coastal plain of Alaska; and the west coast of Greenland.
Content: Marine and coastal-plain deposits of the Atlantic and Gulf coasts and West Indies, comprising Raritan to Manasquan, New Jersey; Black Creek ("Bladen") and Peedee ("Burches Ferry"), North Carolina; Tuscaloosa to Ripley, Alabama; and the Gulf series—that is, Woodbine to Navarro—of Texas and Louisiana. In Mexico included on map with Lower Cretaceous (8). Marine and coastal-plain deposits of the Interior, Dakota to Fox Hills, inclusive, and equivalents. Marine deposits of the Pacific coast, Chico and its equivalents. Laramie and coal-bearing portion of the Montana of the Rocky Mountains and Great Plains mapped separately.

MONTANA, COAL-BEARING PORTION.

Color, olive-green.
Symbol, 7a.
Distribution: Rocky Mountains and northern Great Plains of the United States and Canada.
Content: Middle Montana, generally coal bearing; Mesaverde of New Mexico, Colorado, and southern Wyoming; Eagle, Claggett, and Judith River of northern Wyoming and Montana and their equivalents in Canada.

LATE UPPER CRETACEOUS, LARAMIE.

Color, yellowish green.
Symbol, 6.
Distribution: Rocky Mountains of the United States, southern Wyoming to New Mexico.
Content: Late Cretaceous coal-bearing formations; Laramie of the Denver Basin; "Lower Laramie" of southern Wyoming; and coal-bearing equivalents in Colorado and New Mexico.

Upper Cretaceous areas.

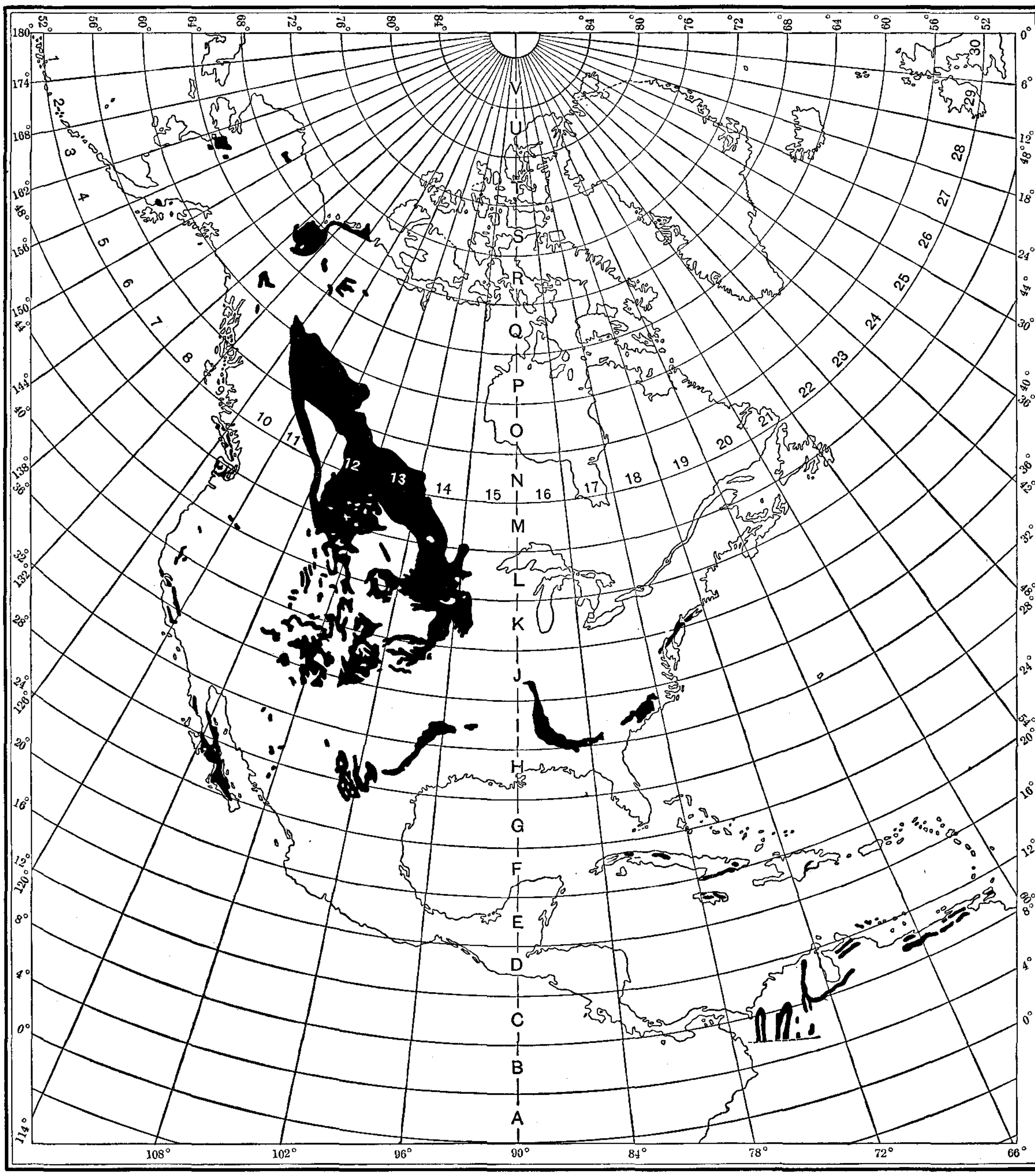

FIGURE 17.—Sketch map showing the distribution of Upper Cretaceous rocks represented on the geologic map of North America and the key to references in the text. Includes Laramie and coal-bearing Montana, which are mapped separately where their extent is known.

D 19. CURACAO, ARUBA, AND BONAIRE.

The little islands of Curacao, Aruba, and Bonaire, in the Dutch West Indies, were mapped by Martin.[576] He identified the Upper Cretaceous (Rudistenkalk), which on Curacao consists of a fine-grained crystalline limestone, of dirty blue or yellow-white color, that resembles a Paleozoic rock. The strata are rich, however, in remains of *Rudistes radialites* Lam., which are identified by Stanton on the basis of Martin's illustrations as of Upper Cretaceous age. There is also a siliceous slate formation with which the limestone occurs in immediate and conformable contact.

E 18. JAMAICA.

Hill's work on the geology of Jamaica [443a] is the basis of the mapping of that island and affords the following excerpts. Many details of the original work are necessarily omitted. Hill classifies the geologic formations of Jamaica into four great categories, as follows:

1. A fundamental series of stratified shales and conglomerates (of terrigenous origin), tuffs and other débris of volcanic material (whose source is not apparent), and, rarely, marine limestones and marls, all of which have suffered great displacement and deformation. This series characterizes the higher mountains and forms the nucleus of the island structure upon or around which all subsequent formations have accumulated.

2. A series of organically derived oceanic material—marls and limestones—which rest unconformably against and upon but do not completely overlap the more elevated outcrops of the first-mentioned series. It constitutes piedmontal formations of great thickness around bases of the higher mountain summits.

3. Laccoliths, dikes, and sills of igneous rocks, which penetrate the first series and the lower portion of the second and are, therefore, of later age than both.

4. Certain deposits of alluvium, oceanic marls, and coral reef rock, which are adjacent to the present coasts and represent fringing reefs and other accretions around the island's border after it had almost attained its present area and outline.

These four series of rocks are unconformable to one another and are the products of the greater events in the geologic history of the island.

Hill gives a tabular summary of the geologic history of the island, of which the following is a part:

Geologic formations on Jamaica.

Time.	Series.	Formation.	Material.	Fossil remains.
Late Pleistocene and Recent.	Coastal.	Bogue Island	Mangrove mud.	
		Montego	Alluvial.	
		Falmouth	Littoral marl	Marine Mollusca, reef coral, etc.
		Coast Soboruco	Elevated reef rock	Reef coral.
		Barbican	Elevated reef rock	Reef coral.
		Hopewell	Elevated reef rock	Reef coral.
Pliocene.		Manchioneal	Littoral marl.	Marine Mollusca, Foraminifera, Brachiopoda.
		Kingston	Old aggradational material.	
Miocene or late Oligocene.	Bowden.	May Pen	Impure lime	Marine Mollusca, echinoids, simple corals, Foraminifera, and Bryozoa.
		Bowden	Conglomerate and marl	Same as above, and fresh-water shells.
Middle Oligocene.		Break.		
Early Eocene to early Oligocene.	Oceanic.	Cobre	White limestone and marl.	
		Moneague	White limestone	A few mollusks and simple corals.
		Montpelier	White chalk with flints	Foraminifera and Radiolaria.
		Chapelton	Yellow-white limestone	Mollusca, corals, echinoids, and Foraminifera.
		Catadupa	Nodular limestone in clay.	
		Richmond	Alternation of clay and sandstone	A few mollusks and corals.
Late Cretaceous.	Blue Mountain.	Minho	Volcanic tuffs.	
		Ballard	Black bituminous shale	Rudistes, corals, and mollusks.
		Logie Green	Yellow marls	Rudistes, corals, and mollusks.
		Jerusalem	Irregular beds of limestone.	
		Frankenfield	Irregularly bedded lavas, tuffs, and conglomerates of hornblende andesites.	Rudistes, corals, and mollusks.

In his table Hill placed the line between the late Cretaceous and early Eocene above the Richmond. In copying the table it has been moved to a position below the Richmond, on recommendation of T. W. Vaughan and in accordance with the text of Hill's work, which shows clearly that he regarded the Richmond as early Eocene.

The late Cretaceous rocks of Jamaica are called Blue Mountain series, of which Hill says:

This series comprises the oldest rocks of the island. It consists of loose or slightly indurated beds of gravel, clay, bowlders, and tuffs, with exceptional beds or bosses of hard indurated limestones and yellow clay. The rocks are usually of dark color (black, blue, or dull chocolate), in strong contrast to the glaringly light colors which characterize the succeeding formations of the Oceanic and Coastal series. The material, with the exception of occasional limestone beds and a few outcrops of clay marls, can be traced to igneous rocks; it was first volcanic ejecta and subsequently and successively underwent various degrees of attrition and sedimentation from coarse bowlders and tuffs to finely triturated impure clay shale, a process indicating extensive working over. These rocks are the material of the Central Mountains, composing the eminences above 3,000 feet, such as the Blue Mountain Ridge. They undoubtedly underlie the surface rocks of the rest of the island, as occasionally revealed by erosion through the white limestone which veneers them, as seen in some of the central basin valleys, the canyons of the marginal streams, and certain bluffs of the back coast border along the northwest coast.

Nowhere on the island can all the beds of the series be seen in continuous exposure. As has been noted concerning the rocks of the Blue Mountain district, "the strata are so excessively disturbed, so traversed and semimetamorphosed by dikes of syenite and mixed up with porphyritic masses, that it is impossible to observe the intricacies of the stratification or to determine the sequence of the beds inter se without a lengthened and detailed investigation." Sufficient is known to state that it probably exceeds 5,000 feet.

Previous attempts to classify the rocks which are collectively arranged in this series have been confusing and unsatisfactory. * * *

While it is still impossible completely to differentiate all the beds of the Blue Mountain series, our observations have enabled us to make a more accurate classification of them than any hitherto presented, which may be stated as follows:

Blue Mountain series:
- Upper division (Eocene): Richmond beds.
- Lower division (Upper Cretaceous):
  - Minho beds.
  - Ballard beds.
  - Logie Green beds.
  - Frankenfield beds.
  - Jerusalem beds.
  - Yallahs beds.

[In classifying the basement beds the chief difficulty] is the complex folding and partial concealment which make it impossible to determine the exact base of the series. The Jamaican reports present conflicting conclusions on this subject, inconsistently stating in different places that the base of the section is composed of igneous rocks, Cretaceous limestones, and a formation termed the "Metamorphosed series."

Hill quotes various opinions and states that the visible base of the section is a great series of tuffs and conglomerates in which the fossiliferous Cretaceous beds constitute local occurrences. The limestones are certainly the oldest rocks paleontologically identifiable, but they are clearly intercalations in vast beds of igneous débris. He searched with care but in vain for evidence of some older or lower-lying rocks beneath the Blue Mountain series.

Referring to the lower division or Upper Cretaceous of the Blue Mountain series, Hill says:

All beds of the lower subdivision, taken collectively, represent the product of disturbed conditions, such as active volcanism accompanied by the piling up and contemporaneous degradation of vast quantities of igneous material much of which was deposited below the sea level, alternating with short periods of quiescence, when shales and marls were permitted to accumulate and sparse faunas to gain temporary foothold. The alterations of shale and igneous material in the Blue Mountain series indicate alternating conditions of sedimental placidity and volcanic extrusion, and a conflict between disturbed and quiescent conditions of deposition which finally culminated in the establishment of the latter in the succeeding Richmond epoch.

For a description of the Richmond and later beds of the early Tertiary, see Chapter XVI (pp. 717–721).

E 19. SANTO DOMINGO.

The Sierra group of Santo Domingo was described by Gabb as of Cretaceous age. His account of the rocks shows them to be highly metamorphosed and varied in character, and generally unfossiliferous. For this reason the major part of the terrane is mapped as Paleozoic undivided, and his description is quoted in Chapter VII (pp. 345–347). The description of the limestone which contains Cretaceous fossils is as follows:[352a]

On the Nigua River the limestone acquires its greatest development. Here the metamorphic action has been unusually well marked and the formation is represented mainly by limestones and jaspers. The stratification also is unusually well preserved, so that a good section is attainable. The lime strata of the Ocoa are apparently all repeated on the Nigua, and the conglomerates are replaced by beds containing but few pebbles, the matrix being either a pure or more usually an earthy limestone. This latter rock, at two localities on the river, yields fossils, in a bad state of preservation for extraction, although occasionally recognizable. The shell substance is completely crystallized, so that it is next to impossible to extract a thick shell in such a manner as to expose its surface. Of hundreds of attempts to obtain a specimen of a very common Trigonia I have only succeeded once or twice in obtaining a little piece of the surface; the fracture always taking place among the crystals of calc spar into which the shell has been cemented. The univalve shells invariably break across and, in a word, the collector has to content himself with the few imperfect fragments found weathered out. Nowhere else have fossil Mollusca been discovered in this formation in Santo Domingo, and only in one other instance have I found any other fossil in it. Three or four miles west of San Jose de las Matas I was fortunate enough to discover two fragments of the same limestone, being of a dark bluish-gray color, on the surface of which can be detected, faintly marked, the stars of a coral. Doubtless by means of polishing they can be brought out. These are of especial value, being the only traces of corals yielded to us by the formation; unless indeed a stray pebble, found on the surface of the ground near Bani, also containing corals, may belong to the same group. On the peninsula of Samana the limestones are highly metamorphosed, and here occurs a very curious mixture. In some cases the limestone has a few scattered scales of mica embedded in it; in others the mica is so abundant as to form layers, while not infrequently, especially in the eastern part, mica slate, alternating with the limestone, is not an unusual feature. This is the more remarkable since it occurs nowhere else on the island, and in only one other locality is mica found, and there in hardly noticeable quantities.

With so few data it would seem hazardous to venture a determination of the geological age of the group of rocks in question. But a careful study of the scanty material at my disposal reveals the existence of a serrated oyster, a Trigonia, a Turritella, shells resembling Ancillaria, Natica, Pugnellus (?), and Mactra, besides a fusoid, one fragment that seems to belong to the group of Pterocrea—at least it is an alate shell—bivalves that may prove to be Cucullæa and Lima, and better than all else a beautiful little ammonite in perfect preservation, and a fragment that I think more careful study will decide to be a piece of a baculite. From the above list it will be seen that there can be no possible doubt of the secondary age of the rocks. The ammonite restricts it so far. The style of the ammonite besides confines it to the two groups of Jurassic and Cretaceous, a determination corroborated by the Trigonia, which further belongs to a type much more common in the latter than in the former formation, resembling *T. emoryi* Con., *T. evansana* Meek, and *T. mooraena* Nob. (*T. crenulata* Roem., not Lam.). In fact I am not sure but that the second of these species is also found in New Grenada, whence it was previously described by Mr. Lea as *T. tocaimaana,* and that the present one may have to be included under the same name. The gastropodous shells are of but little real assistance, although the Ancillaria belongs to a type as yet only known by one of two species high up in the Cretaceous; the oldest members of the family being in that horizon. The naticoid of course has but little weight, while my generic determination of the (?) Pugnellus is not sufficiently sure to warrant me in availing myself of this really valuable aid.

The Mactra is not of any great stratigraphical value, and the other bivalves are of still less importance. The baculite, if it should prove to be such, is a little fragment so embedded in the matrix that it will have to be developed by grinding or polishing, since any other process would inevitably destroy it. It will be thus seen that the formation is either Cretaceous or Jurassic, and the preponderance of evidence is in favor of the Cretaceous. This receives additional weight from the results of the labors of other geologists in the Caribbean region. * * *

Dr. P. Martin Duncan has elaborately studied and described the fossil corals of the West Indies, having had large collections from nearly all of the islands at his disposal. He is quoted by Mr. Etheridge as anticipating the discovery of Cretaceous rocks in Santo Domingo on account of some corals from the Miocene of the Cibao, which seemed out of place in that formation.[a]

F 17-18. CUBA.

T. W. Vaughan has contributed the following original notes to this work:

Cretaceous formations possess an extensive development in Cuba. In the Province of Havana calcareous strata containing Upper Cretaceous fossils occur at Santiago de los Baños. Lying between the Tertiary limestones and the serpentine protaxis in the vicinity of Havana are glauconitic limestones, somewhat earthy in composition, and magnesian marls, which have been referred by Salterain to the Cretaceous. We consider the age of these beds as doubtful, as neither the paleontologic nor the stratigraphic evidence is sufficient to warrant a positive conclusion.

Occurring below the lowest observed fossiliferous Tertiary strata in the vicinity of Matanzas are limestones, sandstones, and shales which occupy the same relative stratigraphic position as the supposed Cretaceous of the region near Havana and may be referable to this geologic period. Cretaceous formations occupy extensive areas in the central portion of the Province of Santa Clara, where such typically Cretaceous fossils as Barrettia, Requienia, etc., were collected. The basement beds consist of an unfossiliferous arkose, composed very largely of material derived from the underlying serpentine and granite. Above these basement beds lies a hard grayish limestone replete with the remains of organisms characteristic of the Cretaceous period. Formations of the same age occur also in the vicinity of Cienfuegos, and Cretaceous strata of calcareous composition occupy extensive areas in the central portion of the Province of Camaguey. Strata have been referred to this age in the literature on Oriente Province, but as no fossils have been listed there is doubt as to the extent of the area underlain by the Cretaceous in this portion of the island. Coal-bearing sandstones of no economic importance occur at various places in eastern Cuba and are perhaps of Cretaceous age.

In the Province of Pinar del Rio, between Viñales and the city of Pinar del Rio, there is a hard grayish limestone overlying the schists. No paleontologic evidence as to the age of this limestone was obtained, but from its stratigraphic position and general lithologic character it is referred provisionally to the Cretaceous period.

[a] Etheridge (Geological report of Jamaica, Appendix V, 1869, p. 308) says: "Dr. Duncan has also stated his belief that 'the Hippurite limestone exists in the neighboring island of Santo Domingo, basing this opinion upon the fact that corals having very decided lower Cretaceous affinities were noticed in Miocene strata' in that island. He noticed having found the European lower chalk coral *Astrocœnia decaphyllia* in the Jamaican Miocene; *Phyllocœnia sculpta,* from the Gosau and Uchaux beds, was also found in the Nijavi shale in St. Domingo, associated with four other species of Turonien affinities in the same shale."

F-G 13-14. MEXICO.

The Upper or Neo-Cretaceous of Mexico is described in general terms by Aguilera,[9c] as follows:

The Neo-Cretaceous is encountered principally in the northern part of the Republic and commences with shales of the lower Turonian characterized by *Inoceramus labiatus* of the Ligerian substage. This substage occurs at Cerro Prieto, at the foot of Cerro Muleros, near the city of Juarez. It is also known in the north of Zacatecas, at Mazapil; in Coahuila, at Parras and Peyotes, and in the latter locality it contains, besides *Inoceramus labiatus* Schlotheim, *Ptychodus mortoni* Mantell, *Ptychodus* cf. *whiplei* Marcou, Ceratodus sp., Tryonix sp., and many teeth of fishes, etc.

The upper Turonian or the Angoumian and the Emscherian or lower Senonian have not as yet been found in Mexico characterized by their fossils. The rocks of this age in general are shales interbedded with occasional layers of limestone and are unfossiliferous. * * *

The Aturian is well represented at Cardenas and at Santa Catarina, in the State of San Luis Potosi, between the capital and Tampico, by a fauna very rich in lamellibranchs: *Gryphæa vesicularis* Lamarck, *Coralliochama G. Boehmi* Böse, *Biradiolites cardenasensis* Böse, *Radiolites austinensis* Roemer, *Exogyra costata* Say; and containing also gastropods—different species of Cerithium, Turritella, Actæonella, Nerinea; one finds also Orbitoides and a large number of corals. An Actæonella fauna is found likewise in the environs of Monterey, in Nuevo Leon, but on approaching Coahuila Actæonella disappears and *Exogyra costata* Say, *Exogyra ponderosa* Roemer, *Ostrea glabra* var. *wyomingensis* Meek and Hayden are predominant. The Senonian is found at Las Esperanzas, in Coahuila, where it is formed of calcareous and marly sandstones which alternate with shales, and is terminated in the upper part by glauconitic sandstones characterized by *Sphenodiscus lenticularis*, lamellibranchs, and gastropods. * * * In the south of Mexico the Senonian has not yet been encountered, and it is probable that erosion has destroyed it in certain places where it may have occurred.

Sapper described Upper Cretaceous strata of the Province of Chiapas, but they have been assigned to the "Meso-Cretaceous" (Comanche) by Böse. (See Chapter XIV, p. 589.)

Regarding the Upper Cretaceous of Mazapil, see quotation from Burckhardt in Chapter XIII (p. 554).

Local descriptions of the Upper Cretaceous of Mexico and its relations to the Lower Cretaceous strata will be found, together with lists of fossils and correlations with European divisions, in the "Guide des excursions" [8] of the tenth international geological congress, at Mexico, in the following sections:

No. 29. Environs de Monterrey et Saltillo.—Böse.
No. 26. Géologie de la Sierra de Mazapil et Santa Rosa.—Burckhardt.
No. 24. Géologie de la Sierra de Concepción del Oro.—Burckhardt.
No. 23. Excursion dans les environs de Parras.—Böse.
No. 27. Les gisements carbonifères de Coahuila.—Aguilera.

G 12, H 11. LOWER CALIFORNIA.

The "Mesa sandstones" of Lower California, which were described by Gabb on very slight evidence as possibly Miocene, are here assigned to the Upper Cretaceous on the evidence of their similarity to the sandstone of that age which occurs at Ensenada. (See p. 647.) From Gabb's account of the peninsula [350] we quote as follows:

The three geographical divisions into which I have separated the peninsula are dependent for their peculiar features on their geological structure. The rough mountains of the south are almost wholly granite, the table-lands of the middle are made up of nearly horizontal sandstones and volcanic rocks, while the more northern portions combine the ragged and irregularly disposed ridges of the south with occasional flat-topped mountains, capped by rocks of sedimentary or eruptive origin.

All of the higher ridges of the southern extremity of the Territory are made up of granites and syenites, and formed, during the deposition of the heavy bedded Mesa sandstones, an island of considerable height and very irregular outline. The structure of these mountains is so simple that a further description is unnecessary. It is not until within half a mile south of the mining town of San Antonio that any change in the geology occurs. Here mica slate is encountered for the first time, and forms a belt several miles wide, and running from Todos Santos, on the southwest, past San Antonio and Triunfo, northeast. It probably extends into the Cacachilas Range and forms there, as at the other mining districts, the country rock of the metalliferous veins. Beyond the mica slate again, on the road between Triunfo and La Paz, granite is encountered, making the face of the range and extending to near the latter town.

In all of the valleys scattered through these mountains and in some of the lone hills on the east side of the peninsula are sedimentary formations of a comparatively late geological age. At Santiago I was informed that 3 miles northeast of that place is a locality where large fossil oysters occur in great abundance, and that they are collected and burnt for lime. I had no opportunity of visiting the locality, a circumstance which I have regretted ever since. A short distance farther northeast, near the coast, at a rancho called Los Martyres, is a high hill of sandstones, without fossils, dipping to the westward at an angle of about 15°. From its general appearance it is, in all probability, of the same age as the sandstones which make up the mesas above La Paz. In none of these sandstones have I ever succeeded in finding fossils by which to obtain a clue to their geological age. They probably, however, belong to the same group as the Miocene sandstones of Upper California. They have in many respects the same lithological characters and bear the same relations to the granites that those rocks hold where we have had an opportunity of proving their age. Besides this very doubtful testimony, there is still another item of evidence which, in the absence of any better, should have some weight. Mr. John Xantus, an able collector, sent from Cape San Lucas to the Academy of Natural Sciences of Philadelphia a few fossil oysters, which, if my memory does not deceive me, belong to a species very characteristic of the Upper Californian Miocene—*O. titan* Conrad. Should I be correct, this is important, though half a dozen years is a long interval, particularly if one had never devoted any especial attention to the specimens remembered.

With so little evidence of their age, therefore, I have hesitated about pronouncing a decided opinion, preferring to leave it an open question, trusting that some future explorer will be more lucky than myself and discover fossils from which these rocks can be assigned to their proper place in the geological scale. In consequence of the difficulty I have adopted the provisional name of Mesa sandstone in speaking of the formation.

After leaving the granitic ranges south of La Paz the whole appearance of the country changes, and with it the geological structure. The granite itself has disappeared, only to show itself as one or two insignificant outliers, and in its place come enormous deposits of sandstones forming flat-topped mountains, ragged and precipitous along the east coast but sloping off so gradually toward the Pacific as to merge insensibly into the broad, low plains of the west. Pretty regularly bordering the west coast and occurring occasionally along the gulf are deposits of post-Pliocene age, in places filled with and almost made up of the casts or shells of Mollusca, still living in the adjoining waters. Penetrating both these formations, and often capping one or the other or both indiscriminately, are deposits of volcanic origin. These volcanic rocks usually occur as dikes or broad superficial sheets which have been spread over the top of the mesa subsequent to the deposition of the post-Pliocene, and are by no means uniform either in thickness or in the manner of their distribution. Very few volcanic cones exist. Almost the only ones are the volcano of the Virgines, north of Moleje, and a series of cones and ridges extending westward to near San Ignacio. Elsewhere the eruptions appear to have taken place in the form of long fissures, forming dikes, which, having spread their surplus over the surrounding plains, have closed, never again to reopen. In this manner immense areas have been covered with caps of eruptive rocks often 100 feet thick, the source of which is now entirely hidden, an occasional hint only existing in the denuded section of some bluff where the dike has been cut through by the agency of running water.

The post-Pliocene rocks usually lie on the lower margins of the mesa in such a manner as to show that they were deposited during the period of elevation of this portion of the peninsula. The older Mesa sandstones are usually so little disturbed that the two formations seem conformable, though sufficient evidence exists to prove that the elevating force had been acting for a long time before the oldest beds of the newer formation were deposited. This later series consists of fine-grained argillaceous sandstones and shales, some coarser light-gray sandstone, and lastly a thin bed, highly fossiliferous, as are also some of the earlier strata, but the latter highly calcareous. Where the series remains unbroken, this last stratum is always the highest, and it is nearly made up of the casts of living species of shells, *Ostrea cummingii* being almost the only one retaining its structure. At Purissima, on the west slope, the Mesa sandstones have been folded in a series of long and graceful undulations, the tops denuded to a nearly straight line and the post-Pliocene lies unconformably capping the surface. On the opposite side of the mountains bordering the gulf there are still more marked instances of unconformability, which will be described in their proper place.

The Mesa sandstones are easily distinguished from the overlying rocks by their coarser grain, greater compactness, and above all by their being highly metamorphosed along the greater part of their eastern margin. Another marked feature is the presence of large quantities of bowlders and pebbles of volcanic rocks embedded in them, sometimes to such an extent as to form even a preponderance of the bulk of some strata. These bowlders are uniformly small and very much rounded near the west coast wherever the rock is encountered, and increase in size toward the vicinity of Loreto, or rather toward that part of the coast a little below Loreto, in such a manner as to point unmistakably to this region for their origin. Not only does the size increase, but in the same ratio is the increase in number and the decrease in the amount of attrition to which they have been subjected. The lithological characters vary markedly from those of any eruptive rocks encountered in place on the peninsula; no similar rocks have been discovered between the Mesa sandstones and the underlying granite, and the only reasonable conclusion which can be arrived at is that they must have been derived from a body of land which formerly lay in that region now occupied by the gulf, and somewhere in the vicinity of or a little south of Carmin Island.

Another striking feature of this region is the peculiar manner of the elevation of the mesa. It has not been lifted by an evenly distributed force; not, like most mountain chains, by a folding along a given axis. The eastern side seems to have felt this force almost alone, the elevation of that portion lying to the west seeming to be due almost as much to the rigidity of the rocks as to the extension westward of the uptilting power. More properly speaking, the great force was exerted very nearly parallel with what is now the coast line of the gulf, and from there toward the Pacific this agency diminished so gradually as to produce no breaks or even foldings worthy of mention. We thus have the whole width of this portion of the peninsula tilted up by its edge from coast to coast, so that traveling eastward one can hardly realize the rise until, within 15 or 20 miles of the coast, he finds himself on the verge of a precipitous descent of from 2,000 to 3,000 feet in height. This eastern escarpment extends from near La Paz to near Moleje, with but few interruptions, and exhibits nearly everywhere the projecting edges of nearly horizontal beds of sandstone, sometimes unaltered, but usually metamorphosed.

The preceding description of the peninsula by Gabb should be supplemented by consulting the articles by Lindgren, and by Emmons and Merrill. Lindgren's account is quoted below and the map follows his inference in placing the "Mesa sandstones" in the Cretaceous.

Emmons and Merrill[323] sum up the work of previous writers and give their own observations in latitude 30°. The section which accompanies their article has been compiled in the map of North America, as is shown by the details of distribution of granitic and metamorphic rocks in that latitude. If we knew the distribution, the great mass of granite which is shown as the backbone of the peninsula would undoubtedly prove to be broken up by areas of metamorphic rocks of greater or less extent, which are presumably to be assigned to the Mesozoic or Paleozoic, and by patches of the "Mesa sandstones" and volcanic rocks which overlie the intrusive and metamorphic rocks that cap the peaks and ranges.

Lindgren[536] gave the following account of Cretaceous strata at Ensenada:

The first evidence of the existence of Cretaceous strata in Lower California was furnished by a few fossils sent to the National Museum by Mr. C. R. Orcutt, of San Diego, who found them at the southern shore of Todos Santos Bay.

Dr. C. A. White has mentioned and described those fossils. * * * The exposures are not very extensive; they are, in fact, limited to a patch about 3 miles long east and west and 1 mile north and south, on the northern side of Punta Banda. This promontory consists mainly of old porphyritic rocks, against which the Cretaceous strata have been deposited; they form a perpendicular sea cliff about 50 feet high and extending for about 2½ miles along the shore; in most places post-Pliocene gravel and sand cover the top of the cliff, but Cretaceous exposures may be found a little higher up, protruding from the later, covering beds.

The strata consist of a series of yellow coarse sandstones, interstratified with heavy conglomerates of well-rolled pebbles up to a foot in diameter, evidently petrographically identical with the massive rocks forming the peninsula and derived from them. * * *

In these heavy sandstones, generally void of fossils, there are at intervals strata 2 to 4 feet thick composed entirely of the calcareous shells of Coralliochama, accompanied by a small specimen of Cerithium. The fauna is decidedly monotonous, and but a few new forms were found.

There are strong reasons for believing that this isolated Cretaceous mass is but the first of a series of similar strata farther south, and I only regret that I could not extend my trip in that direction. On Todos Santos Island, about 12 miles from the coast, there appears to be an exposure of sandstone similar to that of Punta Banda. At the harbor of Santo Tomas, 40 miles south of Ensenada, a steep sandstone cliff, containing many and large pebbles, is said to form the coast. Similar sandstones occur at Cape Colnett, about 70 miles south of Ensenada. From here it is not very far to where the Mesa sandstones begin, and it appears to me quite probable that these also will eventually be found to belong to the Cretaceous period. Gabb has followed the sandstones more carefully on the eastern than on the western coast and states expressly, regarding the former, that they continue to skirt the coast for a long distance north of the end of the second or middle division, where they occupy the whole peninsula. His description of the appearance of the sandstone corresponds very well indeed with the Todos Santos occurrence. It must be remembered that Gabb did not determine the age of the Mesa sandstones, but only conjectured, based on a very slight clue, that they were Miocene. At the same time he describes the quite extensive metamorphism which has affected the strata in certain regions. This fact can not well be brought into accord with such a comparatively recent age as that to which he assigns the rocks. At least nothing has been observed in Upper California indicating that any extensive metamorphism has occurred so recently.[a]

The strata which occur at Todos Santos Bay were placed in the Wallala group of White, which has since been recognized as lower Chico.

[a] The character of the Miocene series recently found in the southern part of the peninsula at Boleo * * * appears to be very different from the Mesa sandstones and from the Todos Santos occurrence; it also incloses volcanic materials of andesitic and basaltic character. It is probable that the shells referred to above (Ostrea) came from a series equivalent to this and not from the Mesa sandstone.

G–H 13–14. COAHUILA AND ZACATECAS, MEXICO.

The Upper Cretaceous of northeastern Mexico contains important coal measures. The stratigraphy and structure of the State of Coahuila have been described by Aguilera,[10] who tabulates the stratigraphy as follows:

Stratigraphy of Coahuila, Mexico.

Series.	Stage.	Substage.	Division.	Plains.	Sierra de Santa Rosa.	
Pliocene.			Uvalde. Reynosa.	Conglomeratic limestone. Yellowish limestone.		
Eocene.				Oyster beds in shales. Variegated shales	Removed by erosion. Do.	
Neo-Cretaceous.	Laramie.		Las Esperanzas.	Glauconitic sandstones with impressions of plants and silicified wood.	Do. Exposed only in moderate thickness in a few places at foot of the Sierra.	Danien.
	Montana.	Eagle Pass.		Shales with workable beds of coal.	Carbonaceous shales on the slopes; of slight thickness.	Aturien.
		Fox Hills and Fort Pierre.		Yellowish fossiliferous calcareous sandstones, with thin beds of shale and limestone, also fossiliferous.	Calcareous shales with *Exogyra costata* on the summit of the Sierra. Fossiliferous shales of Muzquiz (Montana and Colorado).	Emscherien (?).
			Barroterán.	Bluish shales without fossils.		
	Colorado.	Niobrara. Benton.	Peyotes.	Calcareous shales with *Inoceramus labiatus*, Ptychodus Whipley.		Lower Turonien.
Meso-Cretaceous.	Edwards limestone.			Santa Rosa.	Compact ash-gray limestone.	Cenomanien.

In describing the strata Aguilera says:

The sedimentary rocks are marly sandstones, of bluish and reddish colors, and also limestones of various tones of gray, including argillaceous shales that are gray and black in the upper part and bluish in the lower part of the entire mass of the formation. The sandstones are in general of fine grain. There is a bed, varying in thickness from 5 to 30 meters, which consists of conglomerate of large limestone pebbles.

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Throughout the broad region in which the coal-bearing strata of the Cretaceous are developed in Coahuila, one may distinguish the following divisions: At the base the Barroterán, and then, following in succession upward, the Esperanzas formation comprising the fossiliferous beds of Esperanzas, Muzquiz, and other places upon the slopes of the mountains; the Sabinas, consisting of the glauconitic sandstones of the village of Sabinas, and topped by the shales which contain a bed of *Ostrea cortex;* the Arroyo Tulillo for the beds of *Ostrea glabra* Meek. To these may be added the Peyotes division with beds containing *Inoceramus labiatus* Schlotheim, etc.

Burckhardt[109] has classified and described the Jurassic and Cretaceous of the Sierra de Mazapil district, in the States of Zacatecas and Coahuila, in the "Mesa Central" of Mexico. (See table in Chapter XIII, pp. 552–553.)

H 14. SOUTHERN TEXAS.

In describing the Upper Cretaceous of the Rio Grande section near Eagle Pass, Vaughan [832a] adopted with slight modifications the classification of Dumble [294] and distinguished the Eagle Ford formation, Austin chalk, Upson clays, and Eagle Pass formation. The Eagle Ford rests upon the Buda limestone of the Comanche series. It is composed of flaggy argillaceous limestones, in places separated by calcareous shaly layers. The thickness is 250 feet or more.

The Austin chalk is a soft, chalky, argillaceous white limestone, composed in part of Foraminifera. Its thickness is undetermined but was estimated by Dumble at 1,500 feet.

The Upson clays are described as yellow at the base and as containing calcareous septaria; the upper portion is a clay shale. The thickness was estimated by Dumble at 700 feet.

The Eagle Pass formation is described as comprising three members, called San Miguel beds, Coal series, and Escondido beds. These consist of sandstone and clay with coal beds, of which Vaughan gives many detailed sections. An artesian well near Eagle Pass penetrated 1,512 feet of strata, of which Vaughan assigns 767 feet to the San Miguel beds and 745 feet to the Coal series. A summary of the formation is given as follows:

Résumé of characters and thickness of the Eagle Pass formation.

	Feet.
Escondido beds, composed of sandstones and clays, with many fossiliferous horizons, exposed for 26 miles below Eagle Pass	2,600
Coal series, as determined by artesian well bore, which begins in the uppermost bed	900
San Miguel beds, the lower 600 feet of the artesian well bore and the thickness of sandstone exposed in the hills north of the Carter ranch, 15 miles above Eagle Pass (200?)	800
	4,300

Aguilera[10a] has divided the Upper Cretaceous in the coal-bearing area of northern Coahuila, south of Eagle Pass, into the Sabinas, Las Esperanzas, Barroterán, and Peyotes formations.

In the Uvalde area, Texas (99° 30′–100° west longitude and 29°–29° 30′ north latitude), according to Vaughan,[833a] the Upper Cretaceous rests upon the Buda limestone and exhibits the following divisions:

Generalized section of Upper Cretaceous sedimentary rocks of Uvalde quadrangle, Texas.

	Formation.	Thickness (feet).	Character of rocks.
Gulf series.	Pulliam formation.	100–200	Coarse and fine grained yellowish and brown sandstones and clay; asphaltum horizon near top. Bed of *Ostrea cortex* Conrad at top. *Sphenodiscus pleurisepta* (Conrad) also occurs near the top.
	Anacacho formation.	300–400	Yellow, usually argillaceous but sometimes arenaceous limestones, with beds of yellow marl or clay. The limestones are more developed in the western portion of the quadrangle and the clay in the eastern portion. Fossils: Radiolites sp., Sphærulites sp. *Exogyra læviuscula* Roemer, *Exogyra ponderosa* Roemer, *Gryphæa vesicularis* Lam., Baculites sp.
	Austin chalk.	350–400	White and yellowish chalk, with some marly beds. Fossils: *Gryphæa aucella* Roemer, *Inoceramus* cf. *digitatus* Sowerby, *Mortoniceras texanum* (Roemer), *Pyrina parryi* Hall.
	Eagle Ford formation.	75+	Argillaceous and calcareous flags.

H-I 14. NORTHEASTERN TEXAS.

According to Hill,[445a] the Upper Cretaceous of northeastern Texas is characterized as follows:

The upper Cretaceous or Gulf series rests unconformably upon the Comanche series and may be divided into five conspicuous formations, the beds of which grade into one another by imperceptible transition. The lowest of these north of the Brazos, the Woodbine, consists of ferruginous sands and clays. Above this is a formation characterized by bituminous clays, the Eagle Ford. Then follows a conspicuous formation of chalk, the Austin chalk. Succeeding this is a formation of marly clay, the Taylor marl. The uppermost formation, the Navarro, is composed of unindurated beds of glauconitic sands, clays, and a little chalk, as will be described later. There is no sedimental break between these formations, the whole series being practically continuous. All are characterized, with certain exceptions, by their general lack of consolidation, little or no hard rock being found. The beds grade into one another so gradually that partings are mappable only with the greatest difficulty. * * *

The Woodbine formation apparently rests unconformably upon the Grayson marls and Main Street limestones of the Denison beds of the Washita division, at the top of the Comanche series. The upper beds pass, by inseparable transition, from sands into sandy clays and finally into the bituminous clays of the Eagle Ford formation. This transition is so gradual that no exact line of separation can be drawn between the Woodbine and Eagle Ford formations. The parting is arbitrarily established at the zone of *Exogyra columbella*, which is considered as the top of the Woodbine formation.

The formation has a thickness of at least 600 feet in the northern section and diminishes southward until it disappears by thinning out and overlap at the Brazos. On Aquilla Creek north of Waco the formation is 45 feet thick. According to Taff, it is 200 feet thick in the Cleburne section. On Cottonwood Creek northwest of Hillsboro it is 95 feet thick. In the Fort Worth section its thickness is about 300 feet and in the Denison section about 500 feet.

* * * * * * * * *

The Eagle Ford formation is essentially a bituminous clay, accompanied in places by thin laminated clay limestones and nodular septaria of blue limestone. These clays are notable in the Texas section, where the other clay formations are mostly of a marly nature by reason of their bituminous character, resembling the shales of the Cretaceous formations of the Rocky Mountain region and the northern part of the Great Plains. Even these dark-blue clays become more calcareous in the upper layers and in the extension of the beds south of the Brazos, but north of that stream they form most of the medial and lower portion of the beds. From Dallas north the nodular septaria are of large size and abundant. In age these beds are identical with the Benton formation of the Meek and Hayden section. On Red River, in the Paris section, their thickness is estimated at 600 feet; in the Sherman section, 600 feet; in the Dallas section, about 480 to 500 feet; near Midlothian, 350 feet; in the Waco section, south of South Bosque, 200 feet; in the Austin section, 30 feet; on the Nueces, 200 feet.

* * * * * * * * *

The Austin chalk consists of beds of impure chalk containing 85 per cent or more of carbonate of lime, interstratified with softer beds of marl. It is usually of an earthy texture, free from grit, and when freshly exposed easily cut with a handsaw. Under the microscope the material shows calcite crystals, particles of amorphous calcite, and the shells of foraminifers, mollusks, echinoids, and other marine organic débris, such as usually constitute chalk formations.

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Throughout the area included in this report the Austin chalk rests upon 5 to 10 feet of finely laminated and usually arenaceous, calcareous, argillaceous yellow to bluish material constituting the top of the Eagle Ford formation and ordinarily termed the Fish beds. The formation passes upward into the Taylor marls without stratigraphic break. Southeast of Waxahachie, at the upper contact or parting between the Austin chalk and the Taylor marl, the marl rests directly on the massive upper strata of the chalk, the transition being very abrupt; but south of Waxahachie there are several feet of calcareous arenaceous marl intervening between the two divisions which are included with the chalk.

The thickness of this formation is difficult to determine with accuracy. Southeast of McKinney it is 625 feet; at Waxahachie, 550 feet; and southeast of Sherman, Dallas, and Waco it is estimated to be very nearly 600 feet thick. At Austin, according to the log of the Manor well, it is about 410 feet thick, but the exact thickness has not been determined.

* * * * * * * * *

The Cretaceous section above the Austin chalk in the Black Prairie region of Texas is composed almost entirely of unindurated layers, firm rock strata being very few and exceptional. The beds are principally calcareous clays which weather so rapidly into a mantle of thick black soil that continuous sections of them can not be seen or measured with accuracy, and hence their thickness, sequence, and general character must be judged largely from well holes. These unindurated uppermost Cretaceous strata in places, as at Corsicana, are fully 2,000 feet thick. They can be differentiated, after a manner, into two general formations, the lower of which may be termed the Taylor and the upper the Navarro. In some places, notably in the northeastern corner of the State, the upper formation, which will be described later, is separable into several members.

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The Taylor formation consists of calcareous clay marls which are locally known as "joint clays." These are blue-black in the substructure but weather into a deep regolith consisting of a whitish-yellow subsoil and a dense black soil which characterizes the main "black waxy" belt of the Black Prairie. The regolith is jointed, laminated, and friable throughout, having a crackled appearance when dry. Because of their rapid surface disintegration the character of the unaltered beds is seldom seen except when their material is brought up by the well digger or is exposed in freshly cut ravines or creeks. To the eye this clay marl is generally lacking in siliceous material, although a portion may be detected by chemical analysis. The bituminous matter which characterizes the Eagle Ford formation and the grains of glauconite which are found in the rocks of the overlying Navarro beds are also less notable. Their accessory constituent is lime, in a chalky condition. The marls are of fine consistency, compact, and apparently massive until their laminated character is developed by exposure.

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Owing to lack of outcropping sections for measurement it is difficult to ascertain the exact thickness of this formation or to separate it from the overlying Navarro formation. In the latitude of Austin, as determined from the well at Manor, the beds are about 650 feet thick. In north Texas we have no reliable records by which to estimate their thickness. At Corsicana there are at least 1,500 feet of clays above the Austin chalk, a portion of which belong to the Taylor marls. Taff gives the Taylor marls nearly 1,000 feet in Williamson County, but this is probably overestimated.

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The Navarro formation includes the highest beds of the Cretaceous which outcrop along the eastern portion of the Black Prairie region and of the northern margin of the Rio Grande Plain. This formation is the upward continuation of the Taylor marls, the one passing into the other by gradual transition. The chief lithologic differences are that the clays, chalks, and sands composing the Navarro formation contain more or less sand and glauconite, while the Taylor marls are apparently free from those substances. Besides these lithologic differences, there are conspicuous changes in the fossils. The latter become more plentiful in the Navarro formation and have the same character as those of the Upper Cretaceous of the New Jersey and Alabama regions, of which they are the equivalent and continuous beds, being especially marked by *Gryphæa vesicularis, Exogyra costata, Ostrea larva, Sphenodiscus lenticularis,* and numerous other forms.

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In the southwest corner of Arkansas and in the Red River counties the uppermost Cretaceous beds show considerable stratigraphic differentiation, consisting of beds of glauconitic clay marl, chalks, and glauconitic sands. South of the Sulphur Fork of Red River to the Colorado the beds consist almost exclusively of glauconitic sand and clay marls, there being only a few local occurrences of secondary limestone or arenaceous flags.

I 15. NORTHEASTERN TEXAS, ARKANSAS, AND LOUISIANA.

According to Veatch [838c]—

The upper Cretaceous of Arkansas is composed of the following members, beginning with the lowest:

1. Sands with bituminous laminated clays containing leaf impressions and lignite beds—the Bingen formation.
2. Blue calcareous clay with *Exogyra ponderosa*—the Brownstown formation.
3. White chalk—the Annona chalk.
4. Calcareous clay or clayey chalk, with considerable greensand—the Marlbrook formation.
5. Indurated sand, with thin calcareous and quartzitic layers locally called "water rocks," glauconitic in part—the Nacatoch sand.
6. Dark calcareous clays, fossiliferous below, which pass upward without a sharp break into the sandy, lignitiferous lower Eocene beds—the Arkadelphia clay.

The near-shore character of the Bingen sand is in such contrast to the overlying and underlying Cretaceous marls and in the outcrop is so similar to the overlying sandy surficial deposits of the late Tertiary that in Arkansas it has heretofore, with the exception of a limited outcrop near Morris Ferry, either been confused with the surficial deposits or been regarded as an outlier of the Lower Eocene beds, which it closely resembles lithologically.[a]

This formation consists of white or brown sands and clays containing some greensand and considerable lignite or lignitiferous matter, in which respect it differs from the overlying formations.

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To the west and south the beds below the Brownstown and Taylor marls thicken rapidly, and the various sand beds encountered together in southern Sevier and Howard counties, Ark., become greatly separated by layers of clay. * * *

The Bingen sand, while the lithological counterpart of the Woodbine formation, is apparently the time equivalent of all the beds of the lower [upper] Cretaceous below the Brownstown and Taylor formations.

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The Brownstown formation, into which the Bingen sand gradually grades, is well developed in the southern part of Sevier County, Ark., about Brownstown, from which place it takes its name. It is a blue or gray calcareous clay containing many fossil oysters and is characterized by the presence of the large oyster *Exogyra ponderosa*, whence it has sometimes been called the *Exogyra ponderosa* marl. * * * It is limited above by the Annona chalk and has a total thickness of 150 feet in the eastern part of the area and 600 feet in the western.

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The White Cliffs chalk,[b] [so named] from the bluffs and village of that name on Little River, in the northeastern part of Little River County, Ark., was renamed the Annona chalk[c] from the town of Annona, Red River County, Tex., because it was found that White Cliffs as a formation name had been applied by Powell[d] to certain Juratrias beds in Utah. It consists of white chalk, which at White Cliffs has a thickness of over 100 feet, but thins out rapidly to the east, disappearing entirely before reaching Okolona, where Taff has found only the chalky marl which, at the type locality, underlies it.

[a] Hill, R. T., Ann. Rept. Geol. Survey Arkansas for 1888, vol. 2, 1888, pp. 56–58; Bull. Geol. Soc. America, vol. 5, 1894, p. 309, Pl. XII; Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1901, p. 195, fig. 21.

[b] Hill, R. T., Ann. Rept. Geol. Survey Arkansas for 1888, vol. 2, 1888, pp. 87–89.

[c] Hill, R. T., Bull. Geol. Soc. America, vol. 5, 1894, p. 308; Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1901, p. 340. Hill's spelling Anona has been changed to Annona, the spelling used in the Postal Guide and on Hill's map of the Black and Grand prairies of Texas, 1899 (Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1901, Pl. LXV).

[d] Geology of the Uinta Mountains: U. S. Geol. and Geog. Survey Terr., 2d div., 1876, pp. 41, 51, 151.

The Annona chalk is succeeded by a series of blue, chalky, somewhat glauconitic marls, in places impure chalk [the Marlbrook formation]. * * * About 200 to 300 feet above the base of this formation is a very chalky layer 20 to 50 feet thick, which has been called the Saratoga chalk marl or the Saratoga formation.[a] * * * The thickness of the Marlbrook formation ranges from 750 feet at Texarkana to 50 feet or less at Arkadelphia.

Above the Marlbrook marl is a series of sandy beds which are of vast economic importance to a strip of country along the Iron Mountain Railway between Arkadelphia and Texarkana, since they are the source of the main water supply of that region. Like the other sandy beds of the Cretaceous, at the outcrop they are distinguished with difficulty from the surficial sands that mantle the region. * * *

The outcrop at Nacatoch Bluff, on Little Missouri River, in Clark County, is one of the most complete exposures occurring along this belt and shows the calcareous and quartzitic rocks which, when encountered in wells, are called "water rocks."

Section of Nacatoch Bluff on Little Missouri River, Clark County, Ark.

	Feet.
1. Slope not well exposed; seems to be composed entirely of chert and quartz gravel	20
2. Ledge of fossiliferous arenaceous limestone, containing many large fossil shells: *Exogyra costata*, Pectunculus sp., and *Ostrea subspatulata*	1
3. Sand	10
4. Very impure sandy limestone or calcareous sandstone, with many imperfect fossils	.1
5. Sand	4
6. Hard fossiliferous calcareous sandstone	.5
7. Sand	5
8. Slope on which landslip masses render positive determination difficult; seems to be composed of sand	25
Level of Little Missouri River.	

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The dark laminated clays which overlie the Nacatoch sand and form the "blue dirt" of the well drillers along the line of the Iron Mountain Railway from Arkadelphia to Texarkana were named by Hill in 1888 the Arkadelphia shales, from the outcrops at Arkadelphia, Clark County.[b] These beds contain uppermost Cretaceous fossils for 100 to 200 feet above the Nacatoch sands, the fossil-bearing beds being well developed on Yellow Creek 3 to 4 miles northwest of Fulton, 5 to 6 miles north of Hope, north and northwest of Emmet, and at Arkadelphia. Thus far no fossils have been found in the upper portion of this formation, which extends without any apparent break to the Eocene sand beds forming the sandy hills (the crest of the Sulphur Wold) south of the Iron Mountain Railway. This absence of fossils, together with the fact that the Midway (Eocene) formation, though commonly characterized by limestones, contains dark-colored clays, makes the exact determination of the top of the Cretaceous in this section particularly difficult.

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The total thickness of the Arkadelphia clay, excluding the beds which appear to be stratigraphically Eocene, is from 200 to 300 feet at Arkadelphia, 500 feet at Lanesburg, 500 to 600 feet at Hope and Spring Hill, and 500 feet at Texarkana and Shreveport.

I 16. WESTERN TENNESSEE.

The Cretaceous of western Tennessee comprises the Coffee sand member of the Eutaw formation, the Selma chalk ("Rotten limestone"), and the Ripley formation. The deposits are described by Safford[687c] and Glenn.[368] The section does not differ materially from that in Mississippi.[891a] (See p. 654.) According to recent field studies by L. W. Stephenson the Coffee sand member represents all of the Eutaw formation that is present in western Tennessee.

[a] Branner, J. C., Trans. Am. Inst. Min. Eng., 1897, pp. 42–63; Taff, J. A., Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1902, pp. 714–723.

[b] Ann. Rept. Geol. Survey Arkansas for 1888, vol. 2, 1888, pp. 53–56.

I 16–17, J 16. EASTERN GULF REGION, GEORGIA, AND SOUTH CAROLINA.

As a result of the recent studies of the Coastal Plain of the United States, conducted in cooperation between the Federal and the State geological surveys, data have been procured on the stratigraphic and age relations of the several Cretaceous formations. L. W. Stephenson contributes the following review of the literature and discussion of the subject:

C. A. White [891] in 1891 published a résumé of the literature on the Cretaceous of these areas to that date. The more important previous investigators were Tuomey,[812] Winchell,[943] and Smith and Johnson [750] in Alabama, Hilgard [438, 439] in Mississippi, Safford [688, 687] in Tennessee, and Ruffin [682] and Tuomey [811] in South Carolina.

The principal contributions to the geology of these regions, since the publication of those enumerated by White,[891] have been by Langdon,[520] Smith, Johnson, and Langdon,[751a] Crider,[178a] Glenn,[369a] Sloan,[743, 744c] and Veatch.[842]

A table which sets forth in condensed form the present writer's views regarding the age relations of the lithologic divisions heretofore recognized in the region is inserted opposite to enable the reader to understand more clearly the following discussion of past and present interpretations.

In 1860 Eugene W. Hilgard,[438a] State geologist of Mississippi, differentiated four major divisions in the Cretaceous deposits of that State. These were, in ascending order, the Eutaw group, Tombigbee sand group, Rotten limestone group, and Ripley group.

His Eutaw group rests upon Carboniferous rocks and includes all the Cretaceous deposits below the Tombigbee sand. These deposits consist of "bluish-black or reddish laminated clays, often lignitic, alternating with and usually overlain by noneffervescent sands, mostly (though not always) poor in mica, and of a gray or yellow tint. Contains beds of lignite, very rarely other fossils." [438b]

Hilgard's reason for adopting the name "Eutaw group" is given in the following quotation: "I adopt this name in view of these beds having been first examined in detail and recognized as being of Cretaceous age, by Tuomey,[a] near Eutaw, Ala., where they are characteristically developed." [438c]

The type region of the Tombigbee sand is in the vicinity of Columbus, in Lowndes County, Miss., where the beds are mapped as a belt 15 or 18 miles wide. The type exposures occur in bluffs of Tombigbee River. To the north of Lowndes County the Tombigbee belt is represented as narrowing down to a strip 2 to 4 miles wide, with a corresponding widening of the Eutaw area. By thus narrowing the Tombigbee belt, what Hilgard actually did was to run his Eutaw-Tombigbee boundary line obliquely across the strike of the beds so that to the north of the line he represented as belonging to the Eutaw a thickness of strata which correspond in age and stratigraphic position to the lower two-thirds or three-fourths of the Tombigbee as mapped south of the line; indeed the sections given as typical of the Eutaw are within these northward Tombigbee representatives.

In 1887 Eugene A. Smith, State geologist of Alabama, and Lawrence C. Johnson [750a] published a classification of the Cretaceous deposits of Alabama, the divisions recognized being, in ascending order, the Tuscaloosa formation, Eutaw formation, Rotten Limestone, and Ripley formation. They described the Tuscaloosa formation as consisting of at least 1,000 feet of "purple and mottled clays interstratified with white, yellowish-white, pink, and light-purple micaceous sands, and near the base of the formation dark-gray, nearly black, thinly laminated clays, with sand partings." The Eutaw formation is described as "a series of laminated sands and sandy clays at least 300 feet in thickness."

If only those parts of the area in Mississippi immediately west of the Alabama line, mapped by Hilgard respectively as Eutaw and Tombigbee, are considered, his Eutaw division corresponds almost exactly to the Tuscaloosa formation of Smith and Johnson, and the Eutaw divi-

[a] Tuomey's account of the beds near Eutaw to which reference is made is given in First Bienn. Rept. Geol. Survey Alabama, 1850, pp. 118–120.—L. W. S.

Correlation of the Cretaceous deposits of the eastern Gulf region and of the Carolinas.[a]

[By L. W. Stephenson.]

	Kentucky and Illinois.	Tennessee.	Northern Mississippi.	Western Alabama and east-central Mississippi.	Central Alabama.	Eastern Alabama, including immediate Chattahoochee region in Georgia.	Western Georgia east of immediate Chattahoochee region.	Central Georgia.	South Carolina.	North Carolina.
	Eocene.	Eocene.	Eocene.	Eocene.	Eocene.	Eocene.	Eocene.	Eocene.	Eocene.	Eocene.
Upper Cretaceous.	Absent. Ripley formation (shallow-water phase). Absent.	Absent. Ripley formation. Shallow-water phase. Ripley formation. Marine phase. Selma chalk (impure phase). Coffee sand member of Eutaw formation.[d] Absent.	Absent. Ripley formation (marine phase). Selma chalk. Eutaw formation. Coffee sand member.[d] Eutaw formation. Tombigbee sand member. Eutaw formation. Laminated sands and clays. Tuscaloosa formation. Absent.	Absent. Selma chalk. Eutaw formation. Tombigbee sand member. Eutaw formation. Laminated sands and clays. Tuscaloosa formation.	Absent. Ripley formation.[b] Selma chalk. Eutaw formation. Tombigbee sand member. Eutaw formation. Laminated sands and clays. Tuscaloosa formation.	Ripley formation.[b] Eutaw formation. Tombigbee sand member.[c] Eutaw formation. Laminated and massive sands, clays, and marls. Absent.	Ripley formation.[b] Providence sand member. Ripley formation.[b] Typical marine beds. Ripley formation.[b] Cusseta sand member. Eutaw formation. Tombigbee sand member.[c] Eutaw formation. Laminated and massive sands, clays, and marls. Absent.	Ripley formation. Providence sand member. Ripley formation. Cusseta sand member. Absent.	Absent. Peedee sand. Black Creek formation. Typical irregularly bedded sands and clays. Black Creek formation. Middendorf arkose member. ?[e] Absent.	Absent. Peedee sand. Black Creek formation. ?[e] Absent.
	Absent.	Absent.	Absent.	Absent.	Absent.	Lower Cretaceous.[f]	Lower Cretaceous.[f]	Lower Cretaceous.[f]	Lower Cretaceous.	Patuxent formation.[g]
	Paleozoic.	Paleozoic.	Paleozoic.	Paleozoic.	Paleozoic.	Crystalline rocks.	Crystalline rocks.	Crystalline rocks.	Crystalline rocks.	Crystalline rocks.

[a] For extension of the correlation northward, see p. 612.
[b] A series of nonchalky equivalents of the Selma chalk referred by Langdon to the Ripley.
[c] Included by Langdon in his Ripley group.
[d] Correlated by Safford and subsequent investigators with the Eutaw formation, but now considered to represent only the upper part of the Eutaw.
[e] The stratigraphic position of the base of the Black Creek formation with reference to the eastern Gulf section has not been established with accuracy.
[f] Correlated by Langdon and others with the Tuscaloosa formation (Upper Cretaceous) of central and western Alabama, but on the evidence of fossil plants now referred to the Lower Cretaceous. It has not been proved that this division is synchronous with the Patuxent ("Cape Fear") formation of the Carolinas, as indicated in the table.
[g] Correlated with the Patuxent formation on physical evidence only. Since the extension of this name to include the "Cape Fear" formation of North Carolina some doubt has arisen as to the correctness of the correlation.

~~~~~ Unconformity. ...... Line of separation between members of a formation.
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sion of those authors corresponds to the Tombigbee sand of Hilgard. However, the sections of the Eutaw described by Hilgard, all of which are north of Columbus in Mississippi, do not correspond to the Tuscaloosa formation but, as previously stated, represent a part of the northward extension of the Tombigbee division as mapped and hence correspond in stratigraphic position to a part of the Eutaw of Smith and Johnson.

The essential difference between the Tuscaloosa and Eutaw divisions of Smith and Johnson may perhaps best be stated as follows. The Tuscaloosa consists of a series of sands, clays, and gravels in large part of shallow-water origin, characterized by irregularity of bedding and, where the conditions for their preservation were favorable, by the presence of fossil leaves. The Eutaw consists predominantly of glauconitic sand of marine origin which in approximately the lower two-thirds or three-fourths of its thickness contains subordinate lenses of dark clay and exhibits fine cross-bedding and in its upper one-third or one-fourth is made up of massive beds of glauconitic sand with calcareous sand beds in its upper part. So far as known no structural break exists between the Tuscaloosa and Eutaw formations, sedimentation apparently having been continuous from the one to the other. Nor has it been possible to recognize any sharp lithologic line of separation between them, the change from the one kind of sedimentation to the other having been transitional.

Beds representing the Tuscaloosa formation extend from western Alabama northward, occurring in a wide belt that includes the northwestern part of Alabama and a relatively narrow area in the adjoining northeastern part of Mississippi. The formation as a whole, however, becomes much thinner toward the north and disappears in the vicinity of the Tennessee State line. It is doubtful if, in the region of their outcrop, the Mississippi representatives of the division exceed a maximum thickness of 400 feet. Hilgard did not differentiate these lower beds of shallow-water origin from the higher beds of marine origin but included them in his Eutaw formation, as shown by the map accompanying his report.

The Mississippi representatives of the Eutaw formation of Smith and Johnson include, as previously stated, all of the Tombigbee sand and a part of the Eutaw group of Hilgard. Although the width of the Tombigbee belt as mapped by Hilgard immediately west of the Alabama line is 15 or 18 miles, corresponding to a thickness of 400 or 500 feet, the actual sections given by him in this part of the area are all near the western border of the belt and probably include only about the upper 150 or 200 feet of the strata mapped. Farther north in Mississippi beds which correspond in stratigraphic position to the lower two-thirds or three-fourths of the Tombigbee as mapped in Lowndes County are included by Hilgard in his Eutaw group, and among these are the sections which he indicated as typical of this division in Mississippi. These correspond in age and position to a part of the Eutaw division of Smith and Johnson, although in the intervening area in Lowndes County beds of the same age were mapped as Tombigbee. This confusion was due apparently to the fact that Hilgard failed to find in Lowndes County any of the beds of dark clay corresponding in position to those farther north, upon the basis of which he seems to have differentiated his Eutaw group. These clays are of a resistant character and where they occur in stream bluffs form rather conspicuous exposures; but when the division as a whole is considered they constitute subordinate lenses only of deposits made up in the main of glauconitic sands. Such clay beds, however, do occur in Lowndes County, being exposed in the banks of Floating Turtle Creek a short distance east of Columbus.

From the facts brought out in the above discussion it is apparent that a readjustment of the nomenclature as applied by Hilgard to the beds subjacent to the Selma chalk in Mississippi is necessary. The classification of the corresponding deposits in Alabama by Smith and Johnson is based on essential physical differences, namely, those depending on origin. In Mississippi these differences were not recognized. It would appear, therefore, that the Alabama nomenclature is the more logical. For this reason, in the opinion of the writer, the name Tuscaloosa, which stands for the lower shallow-water portion of the series, should be extended to include the corresponding deposits in Mississippi. The name Eutaw, which in Alabama stands for the upper or marine portion of the series, can appropriately be extended to include the corresponding beds in Mississippi, although this will mean the expansion of the term as Hilgard used it, to include the Tombigbee sand above, and its contraction with reference to the Mississippi representatives of the Tuscaloosa formation below.

The name Tombigbee sand, however, if applied to the actual type sections of the division described by Hilgard and their equivalents, is expressive of a natural phase or subdivision of the Eutaw formation and is eminently worthy of preservation in the literature. If we disregard Hilgard's imperfect mapping, the sections of the Tombigbee sand described by him are all included within a thickness of strata which probably does not exceed 150 or 200 feet. Thus limited the division includes the uppermost massive, more or less calcareous and phosphatic beds of the Eutaw formation, as distinguished from the more irregularly bedded and more argillaceous portion of the formation beneath it. These upper, massive beds are traceable for many miles to the north of Lowndes County in Mississippi and they extend eastward, with certain modifications, entirely across the State of Alabama into Georgia. They were recognized by Smith and Johnson, who spoke of them as the "upper member of the Eutaw formation." This member, however, can not be sharply differentiated from the remainder or lower member of the formation, for massive lenses of glauconitic sand of greater or less extent occur in places at lower levels than the Tombigbee member proper, and where these appear in small exposures they are not distinguishable from that member.

The Eutaw formation as thus defined (including the Tombigbee sand member) extends from Alabama northward through Mississippi to the vicinity of the Tennessee State line, where it ends against the unconformably subjacent Paleozoic rocks.

The term "Rotten limestone" was introduced by Alexander Winchell [943a] in 1857. This name was the commonly accepted designation of this great body of chalk rock until 1894, when Smith, Johnson, and Langdon [751b] proposed the geographic appellation Selma chalk, as a coname with "Rotten limestone," and since that time the geographic term has been the accepted designation. It has been found that the Selma chalk makes up all of the Upper Cretaceous strata above the Tombigbee sand member in western Alabama and east-central Mississippi, where it has an approximate thickness of 1,000 feet, the terrane being overlain unconformably by Eocene strata carrying characteristic fossils from the eastern part of Marengo County, Ala., to the northern part of Noxubee County, Miss. To the north in Mississippi and to the east in Alabama the Selma chalk as such becomes thinner and in each direction finally disappears. The thinning of the formation is due, not to the actual thinning or disappearance of the beds, but to their replacement along the strike by nonchalky materials (sands, clays, marls, etc.) having the same age and stratigraphic position. In the region of its fullest development the formation is divisible on paleontologic grounds into two parts; the lower, embracing approximately the lower half of the formation, is most conspicuously characterized by the presence of *Exogyra ponderosa* Roemer; the upper, embracing the remainder of the formation, is characterized by the presence of *Exogyra costata* Say, and carries a fauna which corresponds in a general way with that of the Ripley formation of northern Mississippi, though it contains fewer species.

The Ripley formation, which in its type region in northern Mississippi conformably overlies beds of the Selma chalk, is not younger than the youngest of the Selma chalk beds where the latter are most completely developed in western Alabama and east-central Mississippi; on the contrary, it is of the same age as the upper 300 or 400 feet of the Selma, the nonchalky, sandy, and argillaceous beds of the Ripley being the representatives in northern Mississippi of the upper part of the Selma chalk. To the north in Tennessee both the Selma chalk and the Ripley eventually lose their distinguishing lithologic characters, the former merging into marine and estuarine equivalents and the latter into shallower-water equivalents, probably largely of estuarine origin. The Ripley formation with these lithologic modifications is traceable northward through Kentucky to the head of the embayment region in southern Illinois, to which limit the beds maintain their shallow-water characteristics.

What has been said thus far applies more especially to the Cretaceous beds of the eastern Gulf region between central Alabama and Mississippi River. The conditions of deposition which prevailed in the region of the Chattahoochee Valley in eastern Alabama and western Georgia were, during much of Cretaceous time, markedly different from those existing farther west.

The lowest Cretaceous division of the Chattahoochee region, the Tuscaloosa group of Langdon,[520] was supposed by that author to represent the eastward extension of the Tuscaloosa of Smith and Johnson. The physical aspects and relations of these deposits, and the paleontologic evidence furnished by a collection of poorly preserved fossil plants from Old Fort Decatur, on Tallapoosa River, studied by E. W. Berry, have led both Mr. Berry and the writer to doubt the correctness of this correlation. It is believed that they are of Lower Cretaceous age and hence older than the Tuscaloosa formation.

The Eutaw group of Langdon in the Chattahoochee region is approximately the eastward extension of the Eutaw of Smith and Johnson except that in the opinion of the writer, based on paleontologic evidence, it should have included at least 120 feet of the overlying beds which Langdon referred to the base of his Ripley group. The beds of the division exposed on Chattahoochee River are in the main of marine origin, although in places they exhibit in part the characters of shallow near-shore or estuarine deposits. To the northeast in Georgia they pass into shallow-water equivalents and eventually end unconformably against the underlying older terrane (Lower Cretaceous).

The conditions which favored the deposition of chalklike rocks in central and western Alabama were entirely lacking in the Chattahoochee region, and we have in place of the chalk a series of marine sands and clays which as a whole are synchronous with the fully developed Selma chalk of western Alabama. The conditions unfavorable to the deposition of chalk, which at the beginning of Selma time existed only from Macon County eastward, gradually spread westward as Upper Cretaceous time proceeded, ending, so far as the record has been preserved, a short distance east of Tombigbee River in Marengo County, Ala. These nonchalky deposits of the Chattahoochee region were by Langdon referred in their entirety to his Ripley group. Recent studies by the writer in this region have shown that Langdon's Ripley group of the Chattahoochee region is divisible on paleontologic grounds into two parts—a lower part carrying a number of species restricted to the lower one-third or one-half of the formation, and an upper part carrying a large number of species that do not range lower than the upper one-half or two-thirds of the formation, and characterized especially by the presence of *Exogyra costata* Say. These two parts, with the exception of the Tombigbee representatives at the base of the lower one, correspond to the two parts recognized paleontologically in the Selma chalk. There are, however, in the Chattahoochee region, a large number of wide-ranging species common to both the lower and upper divisions noted.

Northeastward from Chattahoochee River in Georgia the equivalents of Langdon's Ripley group pass first into a series of alternating marine and shallow-water beds, and finally, still farther to the northeast, into irregularly bedded sands and clays of shallow-water origin. The latter are overlapped and concealed in central and eastern Georgia by Eocene beds.

The classification of the Georgia Cretaceous deposits adopted by Otto Veatch [842] in 1909, is essentially the same as that of Langdon, except that Veatch subdivided the Ripley into four parts on the basis of the alternation of beds of marine and shallow-water origin recognizable in a part of the area. These subdivisions are, in ascending order, the Blufftown marl, Cusseta sand, Renfroes marl, and Providence sand.

The lower part of the "Blufftown marl" is probably synchronous with the Tombigbee sand member. The upper part of the "Blufftown marl," the Cusseta sand, the so-called Renfroes marl, and the Providence sand together are the equivalents of the Selma chalk where that formation is most fully developed in western Alabama and east-central Mississippi.

As regards the correlation of the Upper Cretaceous deposits of the eastern Gulf region with deposits in regions outside of this area, the following may be said: That part of the series characterized by the presence of *Exogyra costata* Say, which includes the Ripley formation of northern Mississippi; about the upper half of the Selma chalk where most fully developed; and the upper one-half or two-thirds of the Ripley formation as developed in the Chattahoochee region are correlated on the evidence of the invertebrates they contain, with the Peedee sand of the Carolinas and with the Monmouth formation of Maryland and New Jersey.

The invertebrates present in that part of the Chattahoochee section lying below the beds characterized by the presence of *Exogyra costata* Say and above the top of the Eutaw formation indicate synchroneity with the upper marine invertebrate-bearing beds of the Black Creek formation of the Carolinas; the few species of plants found in the same beds offer no evidence in contradiction of this correlation. The invertebrates also point to synchroneity with all but the lowermost beds of the Matawan formation of Maryland and New Jersey. This portion of the Chattahoochee section is believed to correspond approximately to the lower one-half of the Selma chalk where the latter is most fully developed. No paleozoologic data have been obtained for a direct comparison of the Eutaw formation with the Black Creek formation; however, the invertebrate fauna present in the upper part of the Chattahoochee representatives of the Eutaw ("Blufftown marl") includes a considerable number of Black Creek species which do not range up into the beds carrying *Exogyra costata* Say. On account of this close faunal relationship it is believed that the Eutaw is represented in North Carolina by an undetermined portion of the Black Creek formation lying immediately beneath the invertebrate-bearing beds of that formation. There is evidence for considering the upper part of the Eutaw (Tombigbee sand member) as corresponding to the lowermost beds of the Matawan group (Merchantville clay) of New Jersey.

Fossil plants have been collected from the Chattahoochee representatives of the Eutaw formation, and on the evidence thus furnished the beds have been correlated by E. W. Berry with the Black Creek formation of the Carolinas, no particular horizon in that formation, however, being designated, and with the Magothy formation of Maryland and New Jersey. The Tuscaloosa formation in Alabama has furnished an extensive flora which Berry considers in part contemporaneous with the Black Creek flora, in this case likewise the reference being made to no particular horizon in the Black Creek formation, and in part contemporaneous with the Magothy formation.

In this connection it may be stated that in an unpublished manuscript on the Cretaceous flora of South Carolina Berry admits the possibility of the Magothy flora having persisted during the time of deposition of the Matawan equivalents in the Carolina and Chattahoochee regions.

The question of the correlation of the eastern Gulf Upper Cretaceous with the Cretaceous of the western Gulf and western interior region is at the present time under investigation. As regards the age relations of the beds toward the lower part of the series the two classes of biologic evidence, plant and animal, have led to certain differences of opinion between the students of each class. Until further facts have been obtained and a closer comparison of the species in the two regions has been made, it seems inadvisable to attempt a statement of exact correlation. As regards that portion of the eastern Gulf Cretaceous, however, characterized by the presence of *Exogyra costata* Say, there is general agreement that it corresponds approximately to the Navarro formation of Texas and to an undetermined upper portion of the Montana group of the western interior region.

The Upper Cretaceous deposits present in South Carolina belong regionally with the deposits of the same age in North Carolina, the former being the southward continuation of the latter. The Carolina Upper Cretaceous is separated, geographically, from the corresponding Gulf Cretaceous deposits by a great overlap of Eocene strata. The two formational units recognizable in North Carolina, the Black Creek and Peedee formations, are also easily distinguishable in South Carolina.

The Black Creek formation, the older of the divisions, received its name from Black Creek, South Carolina, along whose banks and valley sides it is best exposed in this State.[743a] Better exposures occur, however, in the bluffs of Cape Fear River, in Bladen County, N. C.

The deposits typical of the formation consist of an estimated thickness of 500 to 700 feet of irregularly bedded, laminated carbonaceous clays and thin laminæ and lenses of sand, the whole being more or less lignitic and pyritiferous. The sand lenses and laminæ are slightly glauconitic in places throughout the formation, and toward the top occur rather massive interbedded layers of glauconitic sand some of which bear marine invertebrates. The clays carry fossil leaves in various stages of preservation. The sands and clays are believed to be in part of estuarine and in part of marine origin. An Upper Cretaceous terrane which has not been differentiated in North Carolina but which is developed in South Carolina from Chesterfield County southwestward consists mainly of light-colored clays and coarse arkosic sands. These beds, designated the Middendorf beds by Sloan,[744b] although lithologically different from the Black Creek, and evidently of shallower-water origin, are regarded by E. W. Berry, on the evidence of fossil plants, as contemporaneous with the lower portion of the Black Creek formation, and they are treated as a member of the Black Creek under the name Middendorf arkose member.

The Black Creek formation rests unconformably upon the Lower Cretaceous deposits of the region and is overlain by the Peedee sand. The typical beds of the Black Creek formation occur in the valley of Peedee River and its tributaries in parts of Marion, Florence, Marlboro, and Darlington counties, and the Middendorf arkose member appears in a relatively narrow area from Chesterfield County southwestward to Aiken County. The failure of the upper part of the Black Creek formation to appear at the surface to the south and the narrowing down of the Middendorf member in that direction are due to an overlap of Eocene beds from the southeast. Over much of the area of its occurrence the formation is concealed at the immediate surface by thin surficial deposits of late Tertiary or Pleistocene age.

The Peedee sand received its name from Peedee River, South Carolina.[682] It was later designated by Sloan[743,744c] the "Burches Ferry marl." The formation consists of 800 feet or more of marine sands and clays, more or less calcareous and glauconitic, carrying marine invertebrates. It appears at the surface in bluffs of Peedee River and its tributaries in Florence, Williamsburg, Georgetown, Marion, and Horry counties and is present in considerable areas in these counties beneath thin patches of Tertiary deposits and beneath a thin but almost continuous covering of Pleistocene and Recent deposits. Southward from this area the formation is overlapped and completely buried by Eocene strata.

As previously stated, the Upper Cretaceous formations of this State constitute the southward continuation of deposits which have their most extensive areal distribution in North Carolina. More complete collections of fossil leaves and invertebrates have been made in that State than in South Carolina, and it is largely on the results of paleontologic investigation carried on in North Carolina that the following attempt at correlation with Cretaceous deposits in outside regions is based. The plants have been studied by E. W. Berry and the invertebrates by the writer.

The invertebrates present in the upper part of the Black Creek formation indicate a pre-Peedee, or, in terms of the Maryland-New Jersey section, a pre-Monmouth age of the beds containing them. This part of the formation would appear, therefore, on this evidence to be synchronous with a part of the Matawan formation. The plants which occur throughout the vertical extent of the formation, being interbedded with the invertebrates in the upper part of the terrane, constitute a flora, according to Berry, analogous with that contained in the Magothy formation of Maryland and New Jersey, the Matawan formation in these States not having yielded any considerable flora. The Black Creek beds below the invertebrate-bearing beds of the formation are doubtless referable, therefore, in part or in whole to the Magothy formation, but the presence of the flora in supposed Matawan equivalents in the Carolinas would seem to indicate its persistence here to a later time than the record preserved in the New Jersey-Maryland deposits would indicate.

Referred to the Upper Cretaceous deposits of the Chattahoochee region (Georgia-Alabama) the invertebrates in the upper beds of the Black Creek indicate close synchroneity with the beds exposed along Chattahoochee River from Roods Bend, in Stewart County, northward to the vicinity of Florence, in the same county, or to that part of the Ripley formation below the beds characterized by the presence of *Exogyra costata* Say. Fossil plants referable to the Black Creek flora have been found at several horizons from beds at the extreme base of the Upper Cretaceous deposits (Eutaw formation) of the region up almost to the base of the beds carrying

Exogyra costata Say. The Black Creek would appear, therefore, to represent all the Upper Cretaceous deposits of the Chattahoochee region subjacent to the beds carrying the above-named species. This would mean the correspondence of the Black Creek to about the basal one-half of the Selma chalk, where that formation is most fully developed in western Alabama and east-central Mississippi, and to all of the Eutaw formation of the same region. According to Berry, on the evidence of the plants, the Black Creek includes also representatives of at least a part of the Tuscaloosa formation of Alabama, which forms the basal division of the Cretaceous in central and western Alabama and northeastern Mississippi.

The Peedee sand is correlated, on the evidence furnished by invertebrates, with the Monmouth of the Maryland-New Jersey Cretaceous, with the beds of the eastern Gulf region carrying *Exogyra costata* Say (which would include the upper one-half or two-thirds of the Ripley formation of the Chattahoochee region, the upper half of the Selma chalk, and the Ripley formation of northern Mississippi), and with the Navarro formation of Texas.

I-J 13. COLORADO AND NEW MEXICO.

Concerning the Cretaceous of southwestern Colorado, Cross[187] states:

The lowest Cretaceous formation recognized is the Dakota, which alone, of all the divisions, has the lithologic character common in other parts of the Rocky Mountain region.

Succeeding the Dakota comes a very homogeneous clay shale formation more than 1,000 feet thick, which from the invertebrate fossils found at several horizons must be supposed to represent the Benton, Niobrara, and a part of the Pierre formations as distinguished at the eastern base of the Front Range in Colorado. But the fossil-bearing strata are neither sufficiently numerous nor well enough developed to serve as horizons for a satisfactory subdivision of this shale formation, which was named the Mancos shale in the Telluride folio.

The next higher distinguishable series in the Cretaceous section is the variable complex whose more massive sandstones cause the principal scarps of the Mesa Verde. Holmes named this series after the Mesa Verde in the Hayden reports and his designation is here accepted. It was not used, however, on the Hayden map. The Mesaverde formation consists of alternating sandstones and shales with several seams of excellent coal. The invertebrate fossils, which are not uncommon at several horizons in the shales and sandstones, range throughout the Montana group, and hence give no ground for a reference of the Mesaverde strata to the Fox Hills, as was done on the Hayden map.

Above the Mesaverde formation occurs another formation of clay shale, reaching an observed thickness of nearly 2,000 feet, which is very much like the Mancos shale but contains fewer fossils. The only identifiable form thus far found in this shale occurs also in the Mancos shale, so that this division is still apparently below the true Fox Hills. This formation is called the Lewis shale. Holmes designated it the "Sand Shale group."

Still above the Lewis shale is a second series of sandstones, shales, and coals, bearing some resemblance to the Mesaverde formation but differing in detail. The lowest member of this complex is the "Pictured Cliff sandstone" of Holmes's San Juan section, which he placed in the Fox Hills upon the evidence of invertebrate remains. The remainder was referred by Holmes to the Laramie, but without fossil evidence. The present survey has also failed to bring to light valid ground for assigning any of the beds in question to the Laramie, while there is some reason to believe that more than the lower sandstone belongs to the Montana group.

Between the uppermost quartzose sandstones of the Cretaceous and the Puerco marls (Eocene), which are well developed below Durango on the Animas, there occurs a series of beds not recognized by Holmes. These strata are composed mainly of andesitic débris, tuffs, or conglomerates, and it has been proposed by the writer to call them the Animas beds or formation. The fossil plants obtained from the tuff layers clearly indicated that the beds may be correlated with the Denver, Middle Park, Livingston, and other post-Laramie formations, which paleontologists refer to the Mesozoic, although they are stratigraphically shown to be later than the great revolution which terminated the conformable succession of Cretaceous sediments.

The strata thus described by Cross extend southward in New Mexico around the east side of the San Juan basin, where they have been traced by Gardner:[358]

The San Juan coal region is a basin of more or less circular outline, with an area of about 13,500 square miles, about one-seventh of which lies in Colorado and the remainder in New Mexico. The region receives its name from San Juan River. The two chief coal-producing localities are Durango, in the extreme southwestern part of Colorado, on the Denver & Rio Grande Railroad, and Gallup, in New Mexico, on the Atchison, Topeka & Santa Fe Railway.

The formations known to occur in the San Juan district are as follows:

Generalized section of rocks in coal field between Gallina and Raton Spring, N. Mex.

System.	Series or formation.	Thickness (feet).
Quaternary	Recent	0–50
Tertiary	Wasatch formation	(?) 1,000
	Unconformity.	
	Torrejon formation	110
	Unconformity (?).	
	Puerco formation	690
	Unconformity.	
Cretaceous	Laramie formation	900
	Lewis shale	250–2,000
	Mesaverde formation	200– 900
	Mancos shale	500–1,000
	Dakota sandstone.	

The Dakota or basal formation of the Cretaceous throughout the San Juan region * * * consists chiefly of hard quartzite with intercalated shale toward the top but near the base is made up of reddish sandstone and yellowish shale that grade gradually into the Jurassic-Triassic rocks below. No signs of coal beds were observed in the Dakota, but they are known to occur in other parts of the basin.

The Mancos shale rests conformably upon the Dakota. In the type-locality at Mancos, Colo., the formation is all shale, but in New Mexico there are transitional sandy beds toward the top. At a point 10 miles north of Gallina a part of the formation becomes arenaceous and forms a hogback in the shale valley. This sandy bed is about 30 feet thick and about 275 feet below the top of the formation. It is no doubt the beginning of the sandstone and shale formation that increases in thickness toward the south and is coal bearing on the south side of the basin. In the vicinity of San Miguel, 12 miles down Rio Puerco from Cuba, the writer observed a thickness of 300 feet of argillaceous sandstone and sandy shale in the Mancos, grading upward through a transition zone to the Mesaverde.

The Mesaverde is the most important coal-bearing formation in the area, as well as throughout the San Juan region. It forms a prominent hogback across the east side of the Gallina-Raton Spring field. * * * Coal beds occur at varying intervals between a prominent basal and a capping sandstone. The main coal bed of the area is just below the top sandstone.

The Lewis is much like the Mancos in appearance. It changes notably in thickness across the field. From about 2,000 feet north of Gallina it thins to 250 feet on the Arroyo Torrejon and in the vicinity of Raton Spring. It may be, however, that the lower part of the shale in that region is replaced by sandstone which has heretofore been considered Mesaverde.

The Laramie is without workable coal beds at the north limit of the field. In fact, Schrader[a] maps the entire area northward to the Colorado State line as barren. West of Gallina the Laramie and underlying Lewis shale disappear beneath unconformable Eocene beds. The next

[a] Schrader, F. C., The Durango-Gallup coal field, Colorado and New Mexico: Bull. U. S. Geol. Survey No. 285, 1906, p. 243.

point to the south at which the Laramie shows is where it emerges from beneath the Puerco, about 10½ miles southwest of Cuba. The Laramie strata exposed between this point and Raton Spring are coal bearing, the coal beds increasing in thickness and number toward the west.

The section given by Gardner applies in a general way to the region originally described by Holmes in the valley of San Juan River and may be compared with that observed by Dutton in the Zuni Plateau farther south. Sections by both Holmes and Dutton are given in the latter's report.[301c]

South of Santa Fe, N. Mex., Lee [a] observed the following section. The lower 555 feet of the section was measured about 2 miles north of Galisteo Canyon; the upper part about 1½ miles south of Galisteo.

Section of rocks exposed in Galisteo Canyon, south of Santa Fe, N. Mex.

Age.	Formation.	Character.	Thickness (feet).
(?)	Galisteo sandstone.	Sandstone, conglomeratic, red, containing petrified trunks of palm wood and trees of deciduous varieties.	
Upper Cretaceous.	Montana.	Sandstone and shale, coal bearing (Madrid group of Johnson)	460±
		Sandstone with layers of black shale	200±
		Sandstone, brown, massive, cliff-making	50–100
		Shale, dark colored, with limestone concretions containing Benton fossils near the base; calcareous layers with Niobrara fossils a little higher; and limestone concretions containing Pierre fossils near the middle and at the top	2,000
	Colorado.	Limestone in thin plates alternating with black shale (probably Greenhorn limestone)	20
		Shale, black, with sandy layers near the base	110
		Sandstone, brown, in thin layers, alternating with black shale and characterized by numerous worm borings	15
		Sandstone, massive, buff colored, irregular texture	10
		Shale, black, with concretions of impure limestone that weathers yellow	70
	Dakota sandstone.	Sandstone, white, conglomeratic at the base	40
		Shale, blue	10
		Sandstone, white, friable, coarse grained, cross-bedded	70
Jurassic or Cretaceous.	Morrison formation.	Shale and sandstone, variegated	210
Carboniferous (Pennsylvanian).		Sandstone and shale with beds of gypsum, red.	

The Cretaceous of the western Great Plains near the southern boundary of Colorado is described by Hills,[450, 451] from whose account the following notes are derived.

The lowest Upper Cretaceous in the Elmoro quadrangle is the Dakota sandstone, the base of which is not there exposed. On Purgatoire River, farther east, it rests upon the Comanche series and, as described by Stanton,[781a] is a gray and brown, mostly massive cross-bedded sandstone about 100 feet thick. On the same stream in the Elmoro quadrangle Hills measured 300 feet and estimated the total

[a] Lee, W. T., unpublished notes.

at 375 feet, but it is probable that he included in the Dakota some Comanche strata which had not at that time been recognized in the region. Hills says:[450]

The lower two-thirds of the Dakota consists of sandstones, with fine conglomerates, imperfectly stratified or cross-bedded, and the heavy layers which make up this part of the formation are separated from one another by thin bands of finer, shaly material. The upper one-third also consists of sandstone layers parted from one another by thin bands of shale, but the individual beds are not so thick and the shale partings are more numerous. These two portions are separated from each other by a prominent bed of hard shale—fire clay—the position of which, in cliff exposures, is often indicated by a narrow shelf or terrace immediately below it.

The color of the upper sandstone is generally grayish white, the lower somewhat darker, with yellowish and brownish weathered surfaces. The pebbles of the coarser layers are quartzite, quartz, and chert. The finer-grained layers are made up of quartz grains, among which white, kaolin-like specks are included. The lower sandstone is of an open, porous texture and more loosely aggregated than that lying above the fire-clay stratum. But the texture of any particular layer varies from place to place, and the same is true of the thickness of the individual beds, so that the only constant features are the fine-grained, compact sandstone above and the coarser, porous sandstone below the persistent bed of fire clay separating them.

The Dakota is followed in succession by the Graneros shale, the Greenhorn limestone, and the Carlile shale, which constitute the Benton group. Of these formations Hills says:

The Graneros formation, which marks the beginning of the marine conditions following the subsidence that terminated the Dakota epoch, consists of dark-gray clay shale, from 200 to 210 feet in thickness, darker near the center than elsewhere, resting on the Dakota sandstone and graduating rather abruptly into it. Large limestone concretions are not uncommon in the upper half but are not a distinguishing feature, as similar concretions are met with in the other shale formations of the district. At a distance of about 30 feet above the base there is a layer, from 1 to 2 feet thick, of hard concretionary limestone, weathering an orange tint, which is noticeable and characteristic.

The Greenhorn formation is made up of layers of dove-colored limestone, usually less than 12 inches thick, separated from one another by somewhat thicker layers of shaly material. It graduates into the Graneros shale below and the Carlile shale above. Fossil shells are abundant in the limestone layers, especially the flat, oval, concentrically ridged *Inoceramus labiatus*. The coiled ammonite Prionocyclus is sometimes present. The thickness varies from place to place, owing to the thickening or thinning of the shaly layers. At the same time the graduation into the Graneros and Carlile formations is more abrupt in some places than in others, thus rendering it doubtful at times where to draw the line. The maximum thickness occurs in the northeastern part of the quadrangle, where it is often 50 feet. In the southeastern part the exposed sections are not so complete and it is thought that in some places the thickness may not exceed 30 feet. * * *

The Carlile formation consists of about 180 feet of dark-gray shale, the middle portion the darkest, overlain by from 10 to 15 feet of soft, shaly yellowish-gray sandstone, into which it graduates through a varying thickness of more distinctively shaly material. A thin band of purplish bituminous limestone containing large numbers of coiled ammonites is persistently present capping the formation. Concretionary nodules several feet in diameter and seamed with lime spar are rather common, especially in the upper half of the beds.

Overlying the Benton group is the Niobrara group, concerning which Hills says:[451a]

The Timpas and Apishapa formations, both of which are characterized by the presence of limestone strata, or of shale containing a considerable proportion of lime, constitute a Niobrara group and are elsewhere mapped undivided as the Niobrara formation. The Niobrara beds are distinguishable by their limy character from all other Cretaceous formations, except the Greenhorn limestone of the Benton group, from which, however, the limestone of the former is readily distinguished by its color and fracture.

The Timpas formation comprises about 200 feet of strata, of which the lower 45 to 50 feet is limestone and the remaining 150 feet calcareo-argillaceous shale interrupted by thin limestone bands, which become prominent toward the top. The limestone at the base is made up of layers, usually less than 12 inches thick, which are separated from one another by very much thinner layers of calcareous shale. The fracture is conchoidal and rudely parallel with the bedding planes, and the grayish-white weathered surfaces break off naturally into thin conchoidal flakes. As the Greenhorn limestone is dove colored and has a cross fracture, the two are easily distinguished. The only fossil at all noticeable is the large oval, concentrically ridged shell *Inoceramus deformis*, characterized by the excessive bulge of the ventral valve. The limestone itself, however, consists largely of the skeletons of foraminiferal organisms, readily seen in thin, transparent sections under the microscope. The middle and upper portions of the formation consist mainly of bluish or dove-colored shale, with thin bands of limestone at intervals. There are three of these bands from 1 to 3 feet thick in the upper 40 feet of the section, and one of these marks the top of the formation. * * *

The total thickness of the Apishapa approaches 500 feet. The lower portion for about 40 feet consists of dark-gray or blue-gray shales, followed by rotten shales of paper-like lamination about 90 feet thick, which grade through blue sandy shale into calcareo-arenaceous shales. The latter become coarser and flaglike toward the middle of the formation and constitute about one-third of it. The upper 100 feet resembles the basal portion, but includes two and at times three thin layers of limestone and usually lens-shaped concretions of similar but more impure material. The middle zone is always more or less bituminous and fairly constant in character. The remainder of the formation varies considerably except in its general shaly features and the presence of limestone strata near the top. The fossil remains consist of fish scales, which are generally abundant in the shales and sometimes in the coarser flaglike layers. In the sandy shales at the base of the middle zone the tracks of what was probably a small crustacean are characteristic. These tracks appear as a double row of short, straight lines, those on one side inclined toward those on the other.

The Pierre shale succeeds the Apishapa formation of the Niobrara group, and of it Hills says:

The beds of the Pierre epoch consist of argillaceous shales throughout. The thickness is estimated at from 1,300 feet at the southeast extremity of the outcrop to 1,500 feet at the northwest extremity, the changing dip and small number of exposures making accurate measurement very difficult, if not impossible. The shales vary much in appearance. The basal and upper zones weather to a yellowish-green color; the middle zone is dark gray to lead-gray, occasionally almost black. The latter zone contains an abundance of lime-iron concretions that break up readily and impart a rusty tint to the surface. They are always arranged parallel with the bedding.

The Trinidad sandstone follows the Pierre shale. According to Hills it represents—

some part or possibly the whole of the Fox Hills group, but on account of its relation to the Laramie and the thickening of the lower zone of the formation northward it is presumably the upper portion only. In the Spanish Peaks quadrangle the total thickness is about 150 feet in the vicinity of Trinidad and 170 feet toward the north boundary. As elsewhere the formation consists of a basal zone of thin-bedded, fine-grained dark-gray sandstone layers, separated from one another by thinner partings of shale; and an upper zone of massive light-gray sandstone, capped by a few feet of brown sandstone in contact with the overlying Laramie. * * *

The marine Cretaceous ended with the Trinidad. The conditions of the succeeding Laramie epoch were shallow waters connected with the ocean. * * *

Owing partly to a certain amount of erosion preceding the deposition of the succeeding Eocene formation, though mostly to the general thinning out of the measures toward the north, the thickness of the Laramie varies considerably. Thus, along the southwestern border of the district and in the Raton Mountains near the southern border it is not less than 2,000 feet, and doubtless exceeds this amount near the crest of the high ridge immediately south of the line; while in the central and northern portions it does not exceed 1,700 feet, and is even less than this in the northeastern area near the north boundary, where it is about 1,500 feet.

The sections of the Laramie in different parts of the district vary but little in their general features. There is always an alternation of massive or thick-bedded gray sandstone beds with thick shaly beds. The latter predominate toward the base of the group, the former toward the top. The shaly beds of the upper half of the group are shale or clay shale, but in the lower half, noticeably in the lower portion of it, they consist of sand shale—that is, thin layers of greenish-gray fine-grained sandstone with partings of shale of the same color. The lower shaly beds are occasionally interrupted by bands of sandstone a few feet in thickness and by beds of clay shale associated with seams of coal, which may occur toward the center of the shale bed or entirely above it and may equal the latter in thickness. Some of the upper sandstone beds are disposed to weather into cavernous forms, and some of the alternating beds associated with them consist of fine-grained greenish-gray fissile sandstone instead of shale. But aside from the general features the sections possess little in common. It is only the lower, main sandstone bed and the shaly beds above and below it that are really persistent throughout the district. * * *

The group is characterized by a rich semitropical flora, very similar to what is found in the Gulf States to-day, and leaf imprints of certain species of oak, fan palm, fig, poplar, willow, and tulip tree are of common occurrence in the thin-bedded sandstone and lower shaly beds.

Lee's recent work in southern Colorado and northern New Mexico [529] throws doubt on the Laramie age of the coal-bearing rocks of this region, or at least of the upper part of them.

The Cretaceous of the Denver district was described in great detail by Eldridge [322] in the Denver monograph. The original description should be consulted. Fenneman [328a] has published a report on the Boulder quadrangle, which lies partly in the Denver Basin, and his descriptions are here abstracted as follows:

Above the Jurassic [Morrison] comes the prominent Dakota formation, easily recognized and well known in the great hogback which parallels the Front Range for hundreds of miles. It is a firm sandstone that is often quartzite, is generally thick bedded, and is characterized by frequent cross-bedding and ripple marks. * * * At its base, though not everywhere present, is a pebble conglomerate. The constituent pebbles include "abundant limestones, quartzites, clays, flints, jaspers, and rocks of granitic composition, together with the separate mineral constituents of the last." The whole is so firmly cemented that, where unweathered, the rock fractures in broad planes which pass through the pebbles. Frequently a series of thin pebble beds in a mass of sandstone takes the place of the continuous conglomerate. This alternation of beds makes the thickness of the basal zone indefinite, but there are few pebble beds above the first 20 or 30 feet. Considerable variation may be discerned in the sandstone, but with the exception of the basal conglomerate no one bed has a constant position in the column. Generally the sandstone is composed of quartz grains, with a siliceous cement, and is gray or yellowish gray. With increase of iron oxide the sandstone exhibits striking features of differential coloring. * * * At intervals between the stronger ridge-making ledges occur layers of thinly laminated shaly sands, aggregating in thickness only a few feet. * * * The line between the Dakota and the overlying Benton shales, while very distinct in a large way, is not so easily located in detail. Alternations of sandstone and shale occur over a zone of 50 feet or more. The thickness of the Dakota at Bear Canyon is about 320 feet, and at Fourmile Canyon a little greater.

The Benton shales have a thickness of more than 500 feet at the north end of the field. They are somewhat thinner at the south end and taper uniformly from both ends toward Boulder Creek, where the formation almost disappears. The great body of the shale is dark. There are frequent layers a few inches thick which are strongly impregnated with iron. The formation is calcareous in varying degree. At many places some beds are composed of a black limestone showing a crystalline surface when broken and having a strong bituminous odor. * * * As the summit is approached the blackness disappears and the last 75 feet (observed near the north end of the field) show light-colored limestone, shale, and sandstone. North of Sixmile Canyon these beds, which may be regarded as transitional to the Niobrara, show the following section:

Section of upper part of Benton formation north of Sixmile Canyon.

	Feet.
Greenish sandstone, calcareous in upper third	15
Shales, blue to yellow, noncalcareous	15
Sandstone, noncalcareous, firm, rather purplish	10
Shale, iron stained at intervals	10
Shale, calcareous (or calcareous at top).	

Below these beds is a limestone of variable thickness strongly resembling the basal Niobrara. It occurs in lenses only. The greenish sandstone at the top is found below the basal Niobrara wherever the latter is exposed in this district. It is generally 10 or 15 feet thick and is not calcareous except in the upper portion. As it is often very much fractured and the cracks are abundantly filled with carbonate of lime, this calcareous character may be due to infiltration from the limestone above. The blue and yellow shales below are also seen wherever the base of the greenish sandstone is exposed.

The Benton is succeeded by the Niobrara, whose prominent characteristic is its calcareous nature. It is composed in small part of true limestones, but the greater mass is made up of calcareous shales, while considerable portions are of intermediate character. Its thickness at Fourmile Canyon is a little more than 400 feet. The basal stratum of compact limestone rests upon the greenish sandstone which is at the top of the Benton. Occasionally a foot or more of light-colored marl intervenes. Below the Niobrara, as pointed out above, are occasional beds of similar limestone and calcareous shales interbedded with noncalcareous sandstones.

Above the Niobrara are the Pierre shales, which are more than 5,000 feet thick. They are slate colored, leaden gray, dark brown, and sometimes nearly black. * * * While in general noncalcareous, the Pierre has local limy beds. At places these form continuous strata, as, for example, 4 miles north of Boulder, one-half mile east of the contact with the Niobrara. Here, for a thickness of nearly 40 feet, strong limestone beds are so closely grouped as to give the outcrop the appearance of the basal Niobrara. At other places the limestone beds are smaller and more isolated or are divided into concretionary masses often containing fossils. Less prominent calcareous masses may be found at any horizon, either in beds or in more or less perfect concretions. Concentrations of iron occur in similar but less massive forms, ranging from clear-cut beds to well-formed nodules. The lime and the iron may or may not occur in the same concretionary mass. Many of the calcareous nodules mentioned contain much iron carbonate, which, in progressive oxidation toward the center, gives rise to sharply marked concentric shells differing in color. Sandy beds may occur at any place in the section. The most prominent and persistent of these is about one-third way up from the base, or a little higher. * * * From pure sands at one extreme to pure clay shales at the other, the Pierre shows all gradations in composition. The sandy layers are generally firm and gritty, almost as dark colored as the shales themselves, and not very porous. In rare instances light-colored, friable sands are encountered in drilling oil wells. The thickness of the sandy beds is as variable as their constitution, while the lateral extent of such beds, as indicated by occasional outcrops and by the records of wells, is, in a large majority of cases, a small fraction of a mile. Some of these beds may be lenses, but doubtless the more common mode of lateral limitation of the sands is by a gradual change in composition of the beds into the shales.

Within the limits of this area the great body of the Fox Hills is but indefinitely distinguished from the Pierre. In mild contrast with the latter its shales are yellowish instead of slate colored and are also more arenaceous. * * * The topmost stratum of the Fox Hills is, however, a very definite feature in the stratigraphy. For many feet below it there are occasional sandstone beds, and the intervening shales are highly sandy, but at the top is a continuous bed of sandstone 40 feet thick.

The Laramie outcrops in the southeast corner of the area. Within the limits here defined this formation consists essentially of (1) sandstones at the base, (2) sandstones alternating with shales and coal overlying, (3) sandstones above the coal, and (4) clays, containing isolated sandstone beds and lignitic streaks. * * * The basal sandstones are exposed at various places in the Marshall coal field, but best of all at White Rocks, on the eastern border of the area mapped. Here the bold sandstone escarpment comprises two distinct and massive beds, whose topographic effect, however, is that of a single stratum continuous with the Fox Hills sandstone beneath. The lower Laramie sandstone is 40 feet thick, equaling the underlying Fox Hills sandstone, while between the two are a few feet of thinly laminated sandstones, varying to a lignitic shale. The second and thicker stratum of Laramie is separated from the first by gray shaly sands, inclosing 10 inches of lignitic shale and above 10 inches of coal. Both Laramie beds are clearly distinguished from the Fox Hills by their gray or white color and coarser grain. They are composed of coarse quartz sand and in addition always show some black specks of an undetermined mineral. The two sandstones differ in the following respects: The upper is distinctly whiter and, where exposed along bedding planes (and to a less degree on fracture planes), the surface is marked by weathered-out cracks, making polygonal patterns a few feet across. Both strata are weakly cemented and noncalcareous but contain giant concretions which are very calcareous, hard, and, on weathered surfaces, are stained brown with iron oxide. The 75 feet of thinner-bedded sandstones above, containing some shale and coal, are best seen at Marshall. The shales occur at frequent intervals and are often lignitic. The one workable coal seam is sometimes at the top of this division but again is overlain by 5 or 10 feet of shales and thin sands; all, however, lie below the more persistent sandstone referred to under (3) above. Aside from the coal seam, no horizon above the basal sandstones is more definite than the *Ostrea glabra* zone, which occurs 15 or 20 feet from the base of the series. The sandstone above the coal is not unlike the second massive bed above the bottom. It weathers into the same angular patterns and has the same appearance in the hand specimen. Its thickness is from 8 to 15 feet. The overlying clays, as shown in this area, are yellow and purple, and have frequent lignitic bands but no coal, at least within the limits of the area covered by the map.

I–K 10. CALIFORNIA AND SOUTHERN OREGON.

The Upper Cretaceous (Chico formation) of California has long been known. It was described by Diller and Stanton[284b] as part of the "Shasta-Chico series." (See J-K 10, Chapter XIV, p. 615.) Anderson[27] discussed its general relations. Stanton[782a] has recently stated the following regarding the fauna:

On the Pacific coast the Horsetown fauna is succeeded by the littoral Chico fauna, which is distributed from the Yukon River to Lower California, occurring on the lower Yukon, the Alaska Peninsula, Queen Charlotte and Vancouver islands, in middle and southern Oregon, in the Sacramento Valley and the Coast Ranges of California to San Diego, and on the peninsula of Lower California as far south as latitude 31° 30′. There are considerable local variations in this fauna, as would be expected in view of its great range in latitude. The assemblage of forms found on the Yukon is quite different from that occurring in the Sacramento Valley, and still another facies is found in southern California, but these are all connected by common species, so that there is no hesitation about referring both the northern and the southern facies to the Chico fauna. The fauna as a whole, like the later Horsetown fauna, is Indo-Pacific in its affinities and is strikingly different from the faunas of the Atlantic border and interior regions of North America. Whiteaves and F. M. Anderson have argued for a connection during Chico time between the Pacific and interior seas, but the evidence brought forward in support of this view is based on types that have a world-wide distribution and on those that are only similar, not specifically identical. In my opinion direct connection has not been proved. In time range the Chico formation apparently began somewhat earlier and continued somewhat later than the Colorado fauna of the interior seas, but it did not extend to the end of the Cretaceous, and latest Cretaceous time is probably not represented by marine deposits on the Pacific coast.

The character and relations of the Chico vary in different localities from southern California northward through the Coast Range and the northern Sacramento Valley. The Chico in the San Luis quadrangle is described by Fairbanks [325] as follows:

The Atascadero formation, the local representative of the Chico group, consists mainly of certain soft sandstones of a grayish-yellow color. The formation derives its name from Atascadero Creek. A few poorly preserved fossils were found in it at several points along the northern slope of the Santa Lucia Range.

* * * * * * * * *

Near the coast the Atascadero formation occurs above the San Luis (pre-Cretaceous) formation, but northeast of the Santa Lucia Range it rests on the Toro (lower Cretaceous). In the latter region the Atascadero terminates downward in a conglomerate which is in places 100 feet thick and contains large granite bowlders. The striking contrast in general lithologic character between the Atascadero and Toro formations is indicative of a marked change in conditions of deposition. The hypothesis that there is a hiatus in the Cretaceous sediments is well founded. It is based, on the one hand, on the fact that the Atascadero sediments extend over the Toro across both strike and dip, indicating that the Toro had been upturned and planed off before the Atascadero began to be deposited (as may be seen at many points, particularly on the divide between Atascadero and Santa Margarita creeks), and, on the other hand, on the fact that the Atascadero in the same locality rests indiscriminately upon the Toro and San Luis formations.

Another interesting fact should be mentioned in connection with the discussion of an unconformity. The serpentine here, as in other portions of the Coast Ranges, wherever it comes in contact with the lower Cretaceous is intrusive, while it has nowhere been observed to penetrate the Atascadero formation. There were at least two epochs of igneous activity during the Cretaceous, and three if the formation of the San Luis Buttes be included; this supports the view that marked movements occurred during Cretaceous time.

The Chico is developed on the east side of the Coast Range in the mountains bordering the San Joaquin Valley, according to Arnold and Anderson.[34b] A quotation from their paper has been given in Chapter XIV (pp. 616–617), outlining the general sequence of the Cretaceous beds in the Coalinga district. The rocks are there separable into three divisions, of which the lowest is supposedly of Knoxville (Lower Cretaceous) age, and the middle and uppermost contain Chico (Upper Cretaceous) fossils. The Chico portion is described as follows:

The middle one of the main divisions into which the Knoxville-Chico rocks are divisible upon lithologic grounds comprises a thick series of alternating thin beds of dark shale and sandstone with the above-mentioned heavy conglomerate at its base and with the characteristic massive, concretionary sandstone beds that form the upper division overlying. Its thickness, including the conglomerate zone, measures at least 4,800 feet. * * * The conglomerate is locally extremely variable and is not continuous. It may in places be traced directly into massive sandstone or even into thinly bedded sandstone and shale, as along Alcalde Canyon between 2 and 3 miles west of Alcalde. It represents throughout the district, however, an important stratigraphic horizon characterized by a coarsening of the sediments. * * *

The uppermost of the three divisions of the Knoxville-Chico is predominantly concretionary sandstone in the lower part and shale in the upper part and has a thickness of at least 4,700 feet. * * * Taken as a whole the upper division is strikingly distinct from other formations in the district and seems to represent a separate stratigraphic unit, although no unconformity has been made out at its base.

The lower half of the upper division consists chiefly of massive sandstone beds, often weathering cavernous. * * * The sandstone is usually drab, medium grained, and not very hard.

Above the succession of concretionary sandstone beds, and forming the upper half of the upper division of the Knoxville-Chico, comes a less prominent and less uniform succession of beds in which shale is predominant. * * * This upper half of the upper division consists of two main members predominantly of shale, each approximating 1,000 feet thick, separated by a much thinner but more prominent member of concretionary sandstone, in general similar to that lower down. * * * The lower of the two shale members has few exposures but is notable for the presence in it of different kinds of deposits, such as blackish, thinly bedded clay shale and yellowish and whitish calcareous and arenaceous shale and sand, and for the presence of ammonites, baculites, Inoceramus, and other fossils, which weather out in a fragmentary state on the surface of the clayey soil. * * * The sandstone separating the two shale members varies from 200 to 300 or 400 feet in thickness and consists of yellowish-gray and brown sandstone full of large brown concretions. It is of the same type as the characteristic Chico concretionary sandstone farther down in the section. * * * The uppermost member is one of particular interest owing to its individuality among the known types of Cretaceous deposits, its large content of organic material, its petroliferous nature, and its similarity to the Eocene beds. It is at least 1,200 feet thick and consists principally of shale but has a considerable admixture of sand and sandstone. For convenience it will be referred to as a whole as the purple shale member. The most characteristic beds of this zone are of purplish-brown, fairly hard, thinly bedded, both siliceous and calcareous clay shale, in which the tests of Foraminifera are very abundant. This shale bears a resemblance to some of the less siliceous shale in the upper part of the overlying Tejon (Eocene), especially to that shale as it occurs in the southern part of this district, and is not unlike some argillaceous phases of the Monterey shale (middle Miocene) of the outer Coast Ranges and the shale mapped as Santa Margarita (?) (middle Miocene) along Reef Ridge and at other points in this district. * * *

Above the purple shale of the uppermost Cretaceous lie dark clay and clay shale beds aggregating several hundred feet in thickness, which appear to form an upward continuation of the shale of the Chico but which are mapped with the Tejon (Eocene). Fossils recently found near the northern edge of the Coalinga district show that the higher of these beds belong with the sandstone of the Tejon above, but there is reason to believe that 200 feet or so of beds at the base belong in the Chico. * * * Whether the line of separation between the Cretaceous and Tertiary occurs at the top of the purple shale or somewhat higher, within the darker clay shale, it is noteworthy that it should occur within a zone of fine sediments and be marked by no break of evident stratigraphic importance. However, in spite of the apparent transition between the shale of the Cretaceous and that of the Eocene in the northern part of the Coalinga district, it is believed that they are separated by an unconformity. The evidence of this is the progressive disappearance of the upper members of the Knoxville-Chico southward in the district, whereas the basal Tejon is believed to represent a fairly constant horizon. * * * This thinning and disappearance of the members is probably the effect of erosion upon them before the deposition of the Eocene.

For a general correlation of the Mesozoic and Cenozoic formations of the Coast Range, see Chapter XVII (p. 818).

In the Santa Cruz quadrangle the Chico is very thick. Branner [97a] states:

The Chico strata along the coast are made up for the most part of hard siliceous shale, sandstone, and massive, coarse conglomerate. The general dip of the beds, for a distance of 3 miles along the coast south of the mouth of Pescadero Creek, is toward the southwest and the section apparently exposes about 9,400 feet of strata. These strata dip at high angles, however, and may be repeated by folds, or to some extent by faults, thereby making the thickness appear greater than it is. This is the case 2 miles north of Pigeon Point, where massive conglomerate is faulted into contact with sandstone and shale.

The upper portion of the formation is characterized by massive, coarse conglomerate with interbedded sandstone. The conglomerate shows evidences of much crushing, faulted and crushed pebbles being plentiful in it.[a]

The Chico of the northern portion of the valley of California was described by Diller and Stanton.[284b] A recent account by Diller [279a] is contained in the Redding folio. He says in part that the Chico formation is composed chiefly of yellowish sandstone which is in places pebbly and which, though conglomeratic toward the base, passes upward into gray shales. It extends throughout the Sacramento Valley and is covered by later formations except around the valley borders. Northeastward it extends through Lassen Strait between the Klamath Mountains and the Sierra and possibly connects with the Chico of northern California and Oregon. The greatest thickness observed in the Redding quadrangle is about 500 feet. The formation thickens rapidly southwestward from Redding and is conformably underlain by the older beds that constitute the Horsetown and the Knoxville. It rests with marked unconformity on the older formations around the north end of the Sacramento Valley, and it is unconformably overlain by the Ione, which has generally been assigned to the Miocene.

I-K 17-18. ATLANTIC COASTAL PLAIN.

See contribution by W. B. Clark, Chapter XIV (pp. 608-614).

J 12. PLATEAU PROVINCE OF UTAH AND COLORADO.

In southwestern Utah the Upper Cretaceous comprises Colorado strata and Montana (?) strata, and the Colorado is coal bearing. The stratigraphy is stated by Richardson [669] in the following table and comment:

Outline of coal-bearing and associated rocks in the southern Utah coal region.

System.	Series.	Formation.	Character.	Thickness (feet).
Tertiary	Eocene	Wasatch	Varicolored shale, limestone, sandstone, and conglomerate.	500+
		Unconformity.		
Cretaceous	Upper Cretaceous	Montana (?)	Buff sandstone and drab shale	500±
		Colorado	Buff sandstone and drab shale, including workable beds of coal in the lower part.	2,500±
		Unconformity.		
Jurassic			Varicolored shale and sandstone, with lenses of limestone and gypsum overlying massive marine limestone.	800±

Throughout the plateau province * * * Upper Cretaceous strata lie directly upon beds of Jurassic age. * * * A thin bed of conglomerate at the base may be of Dakota age. The greater part of the Cretaceous rocks, including the coal, are assigned to the Colorado, but the upper few hundred feet contain fresh-water shells and plants of undetermined age, which may possibly belong to the Montana. The succession of Cretaceous strata in the southern Utah region is unlike that in western Colorado and northeastern Utah, so that the formation names used in the coal fields of those areas can not be applied to the rocks in the area under consideration. The coal in southern Utah is older than that in the Uinta Basin region, which includes the

[a] For list of fossils see the work cited.—B. W.

Book Cliffs field, the largest and most important in the State. The southern Utah coal belongs to the same group as that in the Weber River field.

The Cretaceous strata which form the escarpment of the Roan or Book Cliffs extend south of the fortieth parallel across the basin of Green River and around that of Grand River from central Utah to western-central Colorado. They comprise the Dakota sandstone, the Mancos shale, and the Mesaverde formation, and are unconformably succeeded by the Eocene. The following section is summarized from Richardson:[667]

Eocene.
Unconformity.
Mesaverde: Alternating buff sandstone and drab or carbonaceous shale, with beds of coal in lower part; shale prevails in the lower part, and sandstone in the upper; beds of sandstone lenticular; sections variable; thickness 1,200 to 2,200 feet, decreasing westward; fossils consist of plants and invertebrates of fresh and brackish water. Transition marked by increase of sands upward and appearance of brackish and fresh water, in place of marine conditions.
Mancos: Clay shale, black or blue gray, with local lenses of limestone and near the top thin beds of buff sandstone, contains Montana fossils in the upper part and Colorado fossils near the base; thickness about 3,000 feet.
Dakota: Quartzitic buff sandstone, commonly conglomeratic, with layers of carbonaceous shale and low-grade coal; thickness 25 to 200 feet, but formation sometimes wanting on account of irregularities of surface on which it was deposited.
Unconformity.

The following section is given by Lee[530] in an account of the Grand Mesa coal field:

Generalized section of [Cretaceous] rocks in the Grand Mesa coal field, Colorado.

System.	Group.	Formation.	Member.	Thickness (feet).	Characteristics.
Tertiary.					
		—Unconformity—			
Cretaceous.	Montana.	Mesaverde.		2,000±	Gray quartzose sandstone, varying from soft and friable to hard and cliff making, and shale with plant remains and shells of fresh-water invertebrates.
			Paonia shale.	400+	Shale, carbonaceous in places, and sandstone, with plant remains and shells of fresh-water invertebrates.
			Bowie shale.	425±	Dark-colored shale and gray sandstone, containing marine and brackish water invertebrates. (Absent from central part of field.)
			Rollins sandstone.	100±	White cliff-making sandstone containing marine invertebrates.
	Colorado.	Mancos.		3,000+	Dark-colored shale, with limestone concretions and marine invertebrates. Sandy limestone occurs locally near the top, and the base consists of black carbonaceous coal-bearing shale and flinty sandstone. The upper portion is correlated on fossil evidence with part of the Pierre shale and the lower portion with the Benton.
		Dakota.		10-100+	Conglomeratic sandstone.
Jurassic (?).		Gunnison.		600	Variegated shale and sandstone ranging from fine-grained and flinty to coarse-grained, conglomeratic, and friable. Colored in various shades of red, yellow, green, blue, etc.

J-K 13-14. EASTERN COLORADO, KANSAS, AND NEBRASKA.

Darton [238a] gives the following general account of the Cretaceous of the Great Plains:

Dakota-Lakota formations.—In 1893 Prof. Lester Ward discovered that the so-called Dakota sandstone of the Black Hills contained not only a Dakota flora but in its lower beds extensive flora of lower Cretaceous age. As the Dakota sandstone in its type region is characterized by a distinct upper Cretaceous flora, it became necessary to restrict the term "Dakota" in the Black Hills to the upper sandstone carrying the upper Cretaceous plants. In investigating the stratigraphy of the uplift it was found that the upper sandstone is separated from the lower sandstone, which was designated the Lakota sandstones, by a persistent body of shale which has been designated the Fuson formation. In tracing these formations northward, it was found that the principal plant-bearing horizon in the northern Black Hills was in the Fuson formation, which has yielded a large and beautiful flora of lower Cretaceous plants, which Professor Ward has described. The tripartite composition of the old "Dakota" group in the Black Hills is very distinct throughout the uplift and apparently is a widespread feature in adjoining regions.

* * * * * * * * *

Benton group.—The rocks of this group are the most widespread and constant in characteristics of all the sedimentary deposits of the Central Plains region, their salient feature being a thick succession of shales overlying the Dakota sandstone. They present, however, persistent subdivisions or horizons of variation. The thickness is variable, ranging from about 400 feet in the southeast to 1,600 feet in the Black Hills.

In nearly all the half million square miles under consideration the group comprises three members—a basal, dark shale series known as the Graneros shale, a medial limestone known as the Greenhorn limestone, and an upper shale series with sandy layers known as the Carlile formation. Toward its base the Graneros shale includes a horizon marked by local deposits of sandstone; the Greenhorn limestone always presents alternations of slabby limestone and shales; the Carlile formation generally has a sandstone bed at or near its top, not far below which concretions usually occur. The Greenhorn limestone is characterized by great colonies of *Inoceramus labiatus*, a species rarely found at all in other horizons; the upper portion of the Carlile contains *Prionotropis woolgari*, which appear to be restricted to that horizon and to characterize it throughout the region and even in the Bighorn Basin. Throughout east Wyoming and Black Hills region the middle part of the Graneros shales includes, not far above the local sandstone horizon a series of hard gray shales and fine-grained thin-bedded sandstones filled with fish scales, which weather light gray and from their hardness often give rise to a ridge or cliff. These have been termed the Mowrie beds and are conspicuous along both sides of the Bighorn uplift, all around the Black Hills, and along the Laramie Front Range to the Colorado line.

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Niobrara formation.—This deposit occupies a wide area in the central Great Plains region, succeeding the Carlile without suggestion of unconformity and, except in the vicinity of the Bighorn Mountains, consisting largely of carbonate of lime. Its thickness varies considerably from apparently less than 100 feet in some portions of eastern South Dakota to 700 feet in central-southeast Colorado.

At the type locality on Missouri River at the mouth of the Niobrara the formation is represented by a chalk rock having a thickness of about 200 feet. In southern Nebraska and Kansas, where it appears extensively, the amount is considerably greater, 350 feet being the estimate of the Kansas geologists. The formation usually presents purer and harder carbonate of lime deposits near its base, constituting the Fort Hays limestone in Kansas and the Timpas formation in Colorado. The characteristic fossil of this horizon is the *Inoceramus deformis*, which is a conspicuous feature in Colorado and for some distance north into Wyoming.

Along the foot of the Rocky Mountains and the Laramie Front Range the formation usually presents three limestone layers, a lower massive bed and two upper layers, separated by limy shales, the uppermost overlain by impure limestones, which weather to a bright-yellow color and always contain flat masses of limestone consisting of colonies of *Ostrea congesta*. The formation thins to the north in Colorado and Wyoming, becoming about 400 feet thick northwest of Cheyenne, and about 200 feet on the slopes of the Black Hills. The bright-yellow color of the weathered beds is a conspicuous feature. The point farthest west at which the formation was noted is southwest of Casper. It is not characterized along the slopes of the Bighorn Mountains, although doubtless it is there represented by some gray shales, not distinguishable from those of the adjoining formations, for there is no suggestion of hiatus in the sedimentary series.

Pierre shale.—The great shale series of the Pierre formation occupies a vast area in the central Great Plains and was probably originally of even greater extent, for it appears to have been removed by erosion in the mountain uplifts, in eastern Nebraska, and in southern and eastern Kansas. No special investigation has been made of the Pierre stratigraphy, and, although the beds seem to be uniform in composition, probably a careful study of the distribution of its numerous fossils would show widespread stages. One of these is the upper horizon of concretions with *Lucina occidentalis*, giving rise to "tepee buttes," which appears to extend from Arkansas Valley through Colorado to and all around the Black Hills. In places along the western margin of the area great variations in thickness are presented, the shales becoming thicker and local sandstone beds being included. West of Denver the formation appears to have a thickness of over 7,700 feet, and of considerably over 3,000 feet at Florence and near Boulder.

Fox Hills formation.—The Fox Hills formation appears to be present everywhere between the Pierre and the Laramie, merging into both formations and constituting beds of passage between them. In some districts the Fox Hills beds begin abruptly with a sudden change from the dark shales of the Pierre to sandstones or sandy shales of the Fox Hills containing some distinctive species. It is probable that this change does not take place at the same horizon throughout, and the Fox Hills fauna appears in connection with the sandy sediments.

Usually the Fox Hills deposits are less than 300 feet thick, but in the Denver region, where they comprise a thick mass of sandy clays in their lower portion, they attain a thickness of a thousand feet. The top member in this region is a persistent characteristic sandstone, 50 feet thick, which appears to be the same as the Trinidad sandstone in the Spanish Peaks district in south Colorado. The top of the Fox Hills formation is not always clearly definable and in most cases can only be placed arbitrarily at the horizon where the first deposits of evident fresh-water origin appear.

The divisions thus distinguished are commonly classified as the Dakota sandstone, the Colorado group (Benton and Niobrara formations), and the Montana group (Pierre and Fox Hills of the eastern plains). The term Dakota was proposed by King [505c] and given the present definition by Eldridge,[303] who at the same time proposed the term Montana. The strata, faunas, and distribution of the Colorado have been described in detail by Stanton.[775]

K 12. NORTHEASTERN UTAH, NORTHWESTERN COLORADO, AND SOUTHWESTERN WYOMING.

The Cretaceous strata of the eastern Uinta Range were described by Powell [638] under the names Henrys Fork, Sulphur Creek, Salt Wells, and Point of Rocks groups. The latest work in this region has been by Gale,[353] who has described the Rangely oil district, which lies in Colorado just north of the fortieth parallel. In a correlation table Gale shows that the Cretaceous of western Colorado is now divided into five formations—Dakota, Mancos, Mesaverde, Lewis, and Laramie—and he gives [353d] the relations of this classification to those of Hayden, King, Powell, and White, as well as the reasons for abandoning the earlier ones.

For the Rangely field Gale gives in substance the following account [353c] of the several Cretaceous formations:

The Dakota sandstone presents the following descending section at the southern foot of Blue Mountain, a southern outlier of the Uinta Range:

Section of Dakota sandstone at Willow Creek.

	Feet.
1. Sandstone, weathered brown (overlain by dark-gray and black slaty shale, supposed to represent the base of the Mancos [Benton])	10
2. Shale with beds of white clay and a hard siliceous conglomerate; shale very black and slaty near its base	110
3. Sandstone, white, cross-bedded, containing conglomerate layers	40
4. Interval, probably shale, covered by sandstone slide rock	180
5. Sandstone	3
6. Shale, variegated in colors of pink and green, containing also one or more beds of dense reddish-purple limestone	95
7. Conglomerate of coarse, perfectly rounded pebbles in a scant sandy matrix; pebbles largely of chert and siliceous material	45
	483

According to Stanton Nos. 4 to 7 may be older than Dakota and may correspond to the Fuson or the Lakota (both Lower Cretaceous?) or to the Morrison formation (Jurassic?). Farther west, in Utah, the Dakota shows much the same divisions as those given above, but the basal conglomerate thins out eastward and the formation is reduced to two thin sandstone beds separated by shale.

The Mancos shale, which overlies the Dakota, is homogeneous, with the exception of a few sandy layers, and is probably nearly 5,000 feet thick. It includes Benton, Niobrara, and part of the Pierre, and is characterized by Benton fossils near the base and by a Montana fauna having some Fox Hills elements near the top.

The Mesaverde succeeds the Mancos and is the youngest Cretaceous remaining in the Rangely field. It consists of massive sandstones, interbedded with sandy shales and many beds of carbonaceous shale and coal. The thickness is about 5,000 feet. Gale describes its members in detail.

North of the Rangely field, in southern Wyoming, Cretaceous strata form the Rock Springs dome in the great area of Eocene. Schultz [716] describes the strata there exposed as Mesaverde, Lewis, and Laramie(?) and says:

The present investigation led to the conclusion that the subdivisions previously mapped by King and Powell could not be applied to the sequence of rock in this region. The fossils collected by this party and studied by F. H. Knowlton and T. W. Stanton indicate that the several formations have the geologic time values indicated in the accompanying table, where the general character and succession of the Cretaceous and Tertiary rocks, together with their economic importance, are set forth. [Only the Cretaceous part of the table referred to is quoted here.]

Cretaceous rocks in northern part of Rock Springs coal field, Wyoming.

Group.	Formation.	Economic designation.	Thickness (feet).	Description.
	Laramie(?).	Black Buttes coal group.	2,371±	Massive basal bed of white and yellow sandstones, showing traces of conglomerate in places; forms prominent scarp. The overlying bed consists of variable sandstones, clay, and coal beds. Fossils abound in places.
Montana.	Lewis shale.		750±	Dark-gray, drab, and black shales, highly gypsiferous, with some soft shaly sandstone and large concretions. Produces region of low relief.
	Mesaverde.	Almond coal group.	900	Soft white and brown sandstones, sandy shale, and clay with numerous beds of coal and bituminous shale.
			800	Massive white and yellowish sandstones, with little shale and ferruginous matter. Upper third conglomeratic, with fine black and gray quartz pebbles. Sandstone forms pronounced escarpments and hogback ridges.
		Rock Springs coal group.	2,400	White to yellow sandstone, interbedded shale and clay with several large coal beds ranging from a few inches to 2 or 3 feet. The heaviest sandstones are grouped near the base of the formation.
			860	Drab, yellow, and brown sandstones and interbedded shale and shaly sandstone with little or no bituminous matter. Massive sandstones are grouped near top of formation, giving rise to the "Golden Wall."
			940	Shaly sandstone and arenaceous shale, in places highly gypsiferous. Much of it very friable, producing low benches and badland ridges.
			550+	Black and drab shales, very soft and friable.

The Cretaceous of southwestern Wyoming has been described by Veatch,[839a] who gives the following classification from Jurassic up to Eocene, inclusive, the upper and lower parts of his geologic column not being here quoted:

Section in southwestern Wyoming.

Systems and groups.		Formations.	Character of rocks.	Thickness (feet).
Eocene.	Bridger.	Bridger formation......	Greenish sand and clays, composed largely of volcanic ash, with occasional calcareous white bands filled with fresh-water shells. Contains a large mammalian fauna.	1,200–1,800
	Green River.	Green River formation..	Predominantly light-colored calcareous beds, characterized by light-colored thin-bedded shales with abundant fish and plant remains. Layers of dark bituminous shales show near Fossil at base of formation.	[c] 2,000±
	Wasatch.	Knight formation.......	Variegated yellow and red sandy clays, with irregularly bedded white and yellow sandstones. Contain Coryphodon and other animal remains.	500–1,500±
		~~Unconformity~~~		
		Fowkes formation......	"White beds;" light-colored rhyolitic ash beds with interbedded limestones containing fresh-water shells, fish, and plants.	0–2,500+
		Almy formation........	Yellow and reddish-yellow sandy clays, with irregularly bedded sandstone and near the base conglomerate beds.	2,100–2,200
	"Upper Laramie."	Evanston formation....	Yellow, gray, and black carbonaceous clays, with irregular yellow sandstone, in places conglomeratic. Several coal beds. Characterized by plants which are distinctive of the upper Laramie or Denver beds, and by invertebrates, some of which are common to the Laramie and Fort Union. Rests on Bear River and Beckwith beds.	0–1,600+
		~~Unconformity~~~		
Cretaceous.	"Lower Laramie."	Adaville formation, with basal Lazeart sandstone.	Yellow, gray, and black carbonaceous clays, with irregularly bedded brown and yellow sandstones and numerous coal beds. South of Hodges Pass tunnel there is at the base of this formation a prominent white sandstone, 100 to 200 feet thick. Immediately above this is the Adaville-Lazeart coal, 20–84 feet thick, and associated with it are beds containing plants and invertebrate remains, which are older than Laramie. The overlying strata contain lower Laramie leaves.	4,000+
	Montana. / Colorado: Niobrara.	Hilliard formation......	Gray to black sandy shales and shaly sandstones, which weather readily and produce a region of low relief, Mammoth Hollow, affording few exposures. West of Frontier and 3,000 to 3,800 feet above the base of the formation there are several thick lenses of white sandstone. These contain numerous specimens of large *Inoceramus exogyroides*, a species characteristic of the basal Niobrara or upper Benton in the Cretaceous east of the Rocky Mountains.	5,500?–6,800
	Colorado: Benton.	Frontier formation, with Oyster Ridge sandstone member.	Alternating beds of yellow and gray sandstone and yellow, gray, and black carbonaceous clays with numerous coal beds. Forms pronounced parallel ridges or hogbacks. Contains distinctive Benton fossils. In upper part of formation is a pronounced bed of coarse sandstone, occasionally conglomeratic, containing numerous large oysters. This is the "Oyster Ridge sandstone."	2,200–2,600
		Aspen formation.......	Black and gray shales containing abundant fish scales; often weathering silvery gray.	1,500–2,000
	Bear River, Dakota?, and Lower Cretaceous?	Bear River formation....	Dark-colored shales with thin-bedded shaly sandstones and limestones, containing abundant invertebrate fossils and several thin beds of impure coal.	500–5,000±
		Beckwith formation....	Red, yellow, and reddish-yellow shales and sandstones, at many places containing thick reddish conglomerate beds.	3,800–5,500
Jurassic.		Twin Creek formation...	Black and gray shales and shaly limestones with occasional beds of yellow sandstone, the whole containing numerous characteristic marine upper Jurassic fossils.	3,500–3,800

The numerous formations listed in the above table are described in detail by Veatch, who states the general relations as follows: [839d]

The exact base of the Cretaceous in this region is not known. The lowest fossiliferous Cretaceous beds are clearly near the base of the Upper Cretaceous, and the Dakota, as well as the Cretaceous beds which Darton has found beneath the Dakota in eastern Wyoming, if they exist in this region, are thus inferred to be represented in the upper part of the Beckwith formation. The top of the Cretaceous is likewise in doubt, involving, as it does in other parts of the Rocky Mountains, rather conflicting lines of stratigraphic and paleontologic evidence. In the present discussion the Cretaceous is made to terminate with the great dynamic revolution which interrupted the period of relative quiescence in this area, which extended without important interruption from the earliest Carboniferous to late Cretaceous time. These disturbances produced important folds and faults, involving the movement of these sediments through thousands of feet. This known portion of the Upper Cretaceous series has the enormous thickness of over 20,000 feet. Its fossils indicate that it contains the time equivalents of the Benton, Niobrara, Montana, and Laramie groups of the eastern section, but the natural lithologic subdivisions do not correspond with these faunal subdivisions and do not agree with those east of the Rocky Mountains. There is in this section an entire new member—the Bear River formation—characterized by brackish and fresh water forms, which, although attaining a great thickness, is essentially of local development.

Regarding the division line between the Cretaceous and the Eocene of southwestern Wyoming, Veatch [839e] makes the following statement:

In the Wasatch group as thus defined by Hayden the field work of the season of 1905 showed three divisions—(1) a basal member composed of reddish-yellow sandy clays, in many places containing pronounced conglomerate beds, which has been named the Almy formation; (2) a great thickness of light-colored rhyolitic ash beds containing intercalated lenses of white limestones with fresh-water shells and leaves, the Fowkes formation; and (3) a group of reddish-yellow sandy clays with irregular sandstone beds closely resembling (1) lithologically and separated from (1) and (2) by a pronounced period of folding and erosion. The last group has been called the Knight formation and is the horizon of the Coryphodon remains found in this vicinity. The Almy and Fowkes formations belong, with the Evanston, in the conformable series separated on the one hand by a pronounced period of folding and erosion from the Laramie beds, and on the other from the Coryphodon Wasatch beds by a period of folding and erosion of great magnitude though of much less importance than the one between the Adaville and the Evanston. The fossils from the Almy and Fowkes have, without exception, been considered Eocene, but the formations are treated with the Evanston because of their very intimate stratigraphic relation to it and the stratigraphic isolation of the Evanston, Almy, and Fowkes from the beds above and below. Whether it can ever be conclusively proved from the limited paleontologic data available that the line between the Cretaceous and Eocene should be drawn in this section between the Evanston and Almy, so that one great physical break will be thrown into the Cretaceous and the other secondary physical break into the Tertiary, is very doubtful. Stratigraphic geologists will, in the absence of very positive paleontologic data to the contrary, and none such exist at present, favor taking one physical break or the other for the line between the Cretaceous and Tertiary, preferably the earlier and greater one. The Knight formation is not in dispute and has therefore been treated under the Eocene.

The formations distinguished by Veatch in southwestern Wyoming have been identified and traced northward from the forty-second parallel to the Gros Ventre Range by Schultz.[a]

In the Wind River Basin, which lies northeast of the western Wyoming area just described and is separated from it by the Wind River Range, the stratigraphic

[a] Unpublished manuscript.

development of the Cretaceous is more like that of the Rock Springs dome and other areas farther north, though the upper beds are largely concealed by overlap of the Wind River Eocene. Woodruff [948] has described the part of the basin that is included within the Lander oil field and gives the following tabular description of the Cenozoic and Mesozoic formations:

Geologic formations [Cenozoic and Mesozoic] in the Lander oil field.

Era.	System.	Series.	Group.	Formation.	Character.	Thickness (feet).
Cenozoic.	Quaternary.	Recent.			Alluvium.	
	Tertiary.	Eocene.		Wind River formation.	Sandy shale, shaly sandstone, and local beds of conglomerate.	Only the lower part exposed.
		—Unconformity—				
Mesozoic.	Cretaceous.	Upper Cretaceous.	Montana.	Mesaverde formation.	Massive light-buff sandstone and sandy shale.	Less than 200 feet exposed.
			Montana. / Colorado.	Mancos shale.	Drab sandy shale merging upward into moderately rusty very sandy shale.	6,110.
				Dakota sandstone.	Massive ferruginous sandstone.	20 to 56.
		Lower Cretaceous (?).			Shale, sandy, and sandstone in both massive and shaly beds and beds of conglomerate locally developed.	400 to 410.
	Jurassic (?).			Morrison formation.	Variegated sandy shale and conglomerate composed of waterworn pebbles.	236 to 242.
	Jurassic.			Sundance formation.	Olive-green fossiliferous limestone and shale.	347 to 350.
	Triassic (?).			Chugwater formation ("Red Beds").	Sandy shale and massive sandstone.	1,500.

K 13. NORTHERN COLORADO AND WYOMING.

In northwestern Colorado Cretaceous strata outcrop between the pre-Cambrian of the Park Range and the Tertiary of the wide basin on the west. Just north of the fortieth parallel is the Yampa coal field, which has been examined by Fenneman and Gale.[329] They give the following section:

Generalized columnar section in Yampa coal field, Colorado.

	Feet.
Cretaceous:	
Laramie formation—sandstone and shale, with coal	1,000
Lewis shale—dark shale, calcareous layers	1,000–2,000
Mesaverde formation—sandstone, shale, and coal seams	2,500–3,500
Mancos shale—dark shale, containing limestone and sandstone layers	2,000–2,500±
Dakota formation—conglomerate and shale	200±
Jurassic-Triassic (?) "Red Beds" (Triassic to Carboniferous?).	
Archean (ancient crystalline and metamorphic rocks).	

The Dakota and Mancos present no special peculiarities. The Mesaverde, being the coal-bearing formation, was studied in detail and yielded the following generalized section:

Generalized section of the Mesaverde formation in Yampa coal field, Colorado.

	Feet.
Sandstones (occasionally massive) and shales, containing coal, especially in upper part (upper coal group)	400
Twentymile sandstone member	75
Weak sandstones and shales, with frequently a prominent ledge-making yellow sandstone about 250 feet from the top	600
Sandstones (occasionally massive), shales, and coals of the middle group	400
Trout Creek sandstone member	75
Shales and weak sandstones, with few massive beds, containing in the lower part the upper seams of the lower group of coals	400
Massive sandstone, with subordinate shaly sandstones and shales, containing near the top the lower seams of the lower group of coals	750
Slabby or shaly sandstones with some shales, frequently having greater strength at two or three horizons, on erosion giving rise to hogbacks	750
	3,450

Above the coal-bearing Mesaverde lies the Lewis shale, a marine formation between 1,000 and 2,000 feet thick, which grades into the sandstones below and above by thin sandy strata. The Lewis is followed by the "Laramie," a terrane characterized by sandstones and coal beds, with shales, which occupies the stratigraphic position of the Laramie of adjacent areas but from which in this district no fossils have been obtained. A part of the "Laramie" is shown to have a thickness of 312 feet, but this is presumably but a small part of the thick terrane.

North of the Yampa field the Cretaceous outcrops range into Wyoming, on the southern boundary line of which Ball[53a] determined the following section:

Section of Cretaceous rocks in the western portion of the Little Snake River coal field, Wyoming.

Formation.		Description.	Thickness (feet).	
			North end of field.	South end of field.
Laramie formation.		Brown and gray shaly and concretionary sandstones and dark shale, with several beds of coal. In the southern end of the field the lower half is yellow, softer and more sandy and apparently contains little coal. Marine fossils in base.	4,000	0–2,500
Montana group.	Lewis shale.	Drab, slightly sandy, highly gypsiferous shale, with a few thin, soft sandstones. Not coal bearing.	1,600	2,300 (?)
	Mesaverde formation.	Upper and lower members consist of heavy sandstone with a few interbedded shales. Intermediate member consists of shaly sandstone and shale. Upper member coal bearing.	2,500	Bottom not seen.
		Dark-drab concretionary calcareous shale, with several thin, soft brown sandstones. Not coal bearing.	Bottom not seen.	

Still farther north the following section of the Cretaceous in southern Wyoming west of Rawlins was observed by E. E. Smith[752a] in the Great Divide Basin coal field:

Section of Cretaceous rocks of Great Divide Basin coal field, Wyoming.

Group.	Formation.	Thickness (feet).		General characteristics.
		South end of field.	North end of field.	
(?)	Laramie.	3,900±	1,050	Alternating layers of yellowish-brown and white massive sandstones, thin brown sandstone, and drab, brown, and black shales. Sandstones are very resistant in southern portion. At north end the sandstones in the basal part are more resistant than those in the upper part and constitute prominent topographic features.
Montana.	Lewis shale.	1,520±	520	In southern part of the area it consists of very dark drab shale with considerable gypsum and several thin layers of rusty sandstone. In the northern part of the area it consists of drab shale and soft yellowish-brown sandstone containing some thin layers of gypsum. Produces a region of low relief.
	Mesaverde.	3,600±	2,000±	Near the top and at the base are two massive white sandstones which are resistant and form two prominent ridges or hogbacks. Between them is a soft brown sandstone interbedded with drab to brown shale.
	([a])	5,000±	4,000±	Upper portion is exposed only at south end of field and consists of soft brown shaly sandstone interbedded with drab to brown shale. Lower portion consists of very dark drab calcareous shale, containing numerous thin, soft brown sandstones near the top. Produces areas of low relief.
Colorado.	Frontier sandstone member.	900±	500	Three massive yellowish-brown sandstones with dark shale between, containing numerous concretions. Upper sandstone is slightly conglomeratic.
	Mowry shale member.	700±	1,000	Compact gray and black shales which break with conchoidal fracture and contain abundant fish scales.
		30±	20±	Massive yellowish-brown to pink sandstone resembling Dakota.
		100±	60±	Black shale which breaks with conchoidal fracture.
	Dakota sandstone.	100–150	100–175	Massive yellowish-brown to pink sandstone, containing small chert pebbles near base. Locally quartzitic.

[a] This formation is equivalent to the Niobrara and the basal shale portion of the Montana. A local name will probably be applied to it.

Regarding the formations, Smith remarks:

The coal-bearing formations show considerable change in character from the southern to the northern edge of the field. Those of the Cretaceous system thin rapidly toward the north and the outcrops of the beds of the undifferentiated Tertiary become more and more narrow, owing to the overlap of Wasatch conglomerate. The accompanying section [above] shows the thickness and general characteristics of the coal-bearing formations near the Union Pacific Railroad and in the gap between Whisky Peak and the Ferris Mountains.

East of Rawlins the Cretaceous strata extend around the Park and Medicine Bow ranges into the Laramie Plains. They surround the Fort Union (Tertiary) in the Hanna coal field of Carbon County. Veatch[841] has reported on the section, in which he found a marked unconformity between the "Lower Laramie" (equivalent to Laramie of Denver Basin) and the "Upper Laramie" (Lance formation). He gives the following classification:

Generalized section of Cretaceous and Tertiary rocks of central Carbon County, Wyo.

System.	Group.		Formation.	Thickness (feet).	Characteristics.
Tertiary.			North Park.	4,500	White volcanic-ash beds, cherty bands; base conglomeratic.
			Unconformity.		
			Fort Union.	1,200±	Dark-colored shales and shaly sandstones.
	Laramie—hitherto so called.		"Upper Laramie."	6,800±	Dark-colored shales and gray to brown, irregularly bedded sandstones; coal bearing. Contains conglomerate at base composed largely of pebbles derived from the underlying Cretaceous rocks. Fresh-water fauna.
			Unconformity.		
Cretaceous.			"Lower Laramie."	6,500	Dark-colored shales and gray to brown, irregularly bedded sandstones; coal bearing. Fresh-water fauna.
	Montana.		Lewis.	1,800–3,000	Shales and shaly sandstones. Coal bearing. Has in parts of field a very persistent white sandstone near top. Marine and brackish-water faunas.
			Mesaverde	1,500–3,200	White to yellow sandstones and interbedded shales, coal bearing, producing areas of marked relief. Heaviest sandstones are grouped near top and at base of formation, and thus produce, under favorable conditions, two terraces or hogbacks.
			Pierre shale.[a]	3,000–3,500	Dark-gray to brown, sandy, concretionary shale and thin, soft shaly sandstones, producing areas of low relief.
	Colorado.		Niobrara.	750–850	Dark-colored, very calcareous shale, weathering light gray.
		Benton.		150	Black shale.
			Frontier.	400–800	Brown sandstones and shales, producing marked ridges.
			Mowry.	300–750	Black fish-scale shale, weathering silver-gray.
				10–15	Yellow quartzitic sandstone, resembling the Dakota.
				60–150	Black shale, with thin coal beds.
			Dakota.	80–125	Coarse conglomeratic sandstones.

[a] It is the belief of Dr. T. W. Stanton that the Mesaverde and part of the Lewis also belong to the Pierre, as that formation is developed east of the Rocky Mountains. A local name will therefore probably be applied to this lowest division of the Montana in this region.

K 14-15. IOWA AND MINNESOTA.

In Iowa the Cretaceous is represented by the Dakota sandstone and the Colorado group. The Dakota is exposed in the western part of the State where it was originally studied and was named from the town of Dakota, Nebr., on Missouri River. It is also penetrated in many artesian wells and has a thickness of 50 to 100 feet. The formation consists of more or less calcareous shale and sandstone, with thin bands of lignite.[586]

The Colorado exhibits a section of shale and chalky limestone, having near Hawarden, Iowa, a thickness of 50 feet but elsewhere ranging from a thin edge to 150 feet. The strata carry *Prionocyclus wyomingensis*, *Inoceramus labiatus*, and *Ostrea congesta*. Selenite is of common occurrence in the shales.

In Minnesota the Cretaceous is widely distributed over the western part of the State but so heavily covered by drift that but few outcrops appear. Hall[394a] gives a total of 500 feet of beds, white sandstone of the Dakota at the base and soft blue shale and incoherent sandstone of the Benton above.

K 18. LONG ISLAND.

The Cretaceous strata which appear along the northern shore of Long Island have been carefully correlated with the New Jersey section by Veatch,[837a] who concludes that the "basal beds are the stratigraphic equivalents of the Raritan and are Upper Cretaceous. The Matawan beds are apparently well represented but their character changes going seaward" to gray sands and clays. "No greensand beds comparable to the great greensand marl beds of New Jersey have been found, their stratigraphic position being occupied by fine lignitiferous sand with occasional clay beds." Hollick[460] expresses another view.

K 19. MASSACHUSETTS.

At Gay Head and elsewhere on the island of Marthas Vineyard are exposures of the Vineyard series of Shaler,[728a] which comprises Cretaceous strata and Miocene beds (unconformable?) upon them. Shaler says:

> The Gay Head section consists of three divisions. The central part (that is, that part which faces nearly west) has a length of about 3,500 and an average height above the sea of about 80 feet. At the southern end of this section there is an exposure of about 2,000 feet in length, which trends toward the southeast. At the northern end of the principal section there is another short and incomplete section which trends nearly east and west. These three divisions constitute one great and nearly continuous sea cliff having a length of over 6,000 feet.
>
> * * * * * * * * *
>
> The face of this cliff shows us a great number of thick, steeply inclined beds of sand, clay, and lignitic matter, of extremely vivid and contrasted colors. The colors range from the dazzling white of the sandy beds to the nearly pure black of the carbonaceous layers, with intermediate hues of brown, green, yellow, and red. * * *
>
> The orderly arrangement of the beds in the section is greatly masked by the continued slipping of large wedges of the deposits down the steep incline of the talus. When we apply a correction for this slipping the beds are seen to lie in a tolerably regular order, dipping usually to the northeast, with inclinations varying in general from 20° to 60° of declivity but rising in one place to 90°.

In 1890 Shaler was able to reexamine the section at Gay Head, then more clearly exposed by exceptional rains, and determined that the strata were closely folded, not monoclinal. He distinguished certain divisions of the "Vineyard series" as follows:[730a]

The section at Gay Head is apparently divisible into two tolerably distinct elements, viz, a lower division, the upper limits of which are not determined, which is likely to prove of Cretaceous age; and an upper part of the section, which from the fact that it contains bones of cetaceans is likely to prove of Tertiary age—the two together forming the greater part of the longitudinal section of Gay Head. Above these two more ancient portions of the escarpment lies an extended series of unfossiliferous sands, which apparently belong to a somewhat later age than the other portion of the section. To this age we may also presumably assign the extensive series of beds exhibited in the Weyquosque series. These later-formed beds are, at least in the Weyquosque cliffs, deposited unconformably upon the earlier series. A portion of these later unfossiliferous sands are involved in the contortions at Gay Head, and a portion of them lie unconformably upon the edges of the beds which were involved in the dislocation. It seems likely, therefore, that this later series will in the end be found divisible into two parts—a portion which was laid down before and a portion formed after the greater part of the disturbance had been effected.

Shaler was in doubt as to the age of the different divisions. White[894] identified a number of Cretaceous plants from "several localities and horizons in the Vineyard 'series.'" Dall[209] described Miocene faunas apparently from the same closely folded strata, and Pliocene forms from sands which lie unconformably upon them. (See Chapter XVII, p. 823.)

Supposed Cretaceous clays have been reported in well borings in Boston. W. O. Crosby[184] was the first to suggest that these clays were pre-Pleistocene. Later F. G. Clapp[139] reported these distinctive clays from several wells in Boston, and discussed in detail the boring at Ames Building, the samples of which he examined critically. The following log and notes are taken from Clapp's paper:

Record of boring at Ames Building, Boston.

	Thickness.	Depth.
	Feet.	*Feet.*
Coarse sand and gravel	17	17
Sand	1	18
Gravel and sand	5	23
Coarse gravel and white clay	3	26
Stony sand, gravel and clay with much water (very hard)	16	42
Blue clay	18	60
Fine sand	5	65
Clay, sand, and gravel, with water (till)	12	77
Hard dry nearly white clay, with bowlders	136	213
Slate (Carboniferous)	15	228

The material below 77 feet is dry and in a previous boring had been called rock and not entered by the drill. All the samples of this bed were seen by the writer and found to consist mostly of a very fine grained gray to white clay, which became plastic when wet. It varied from very soft and putty-like to nearly as hard as the underlying slate. The material when examined by Dr. W. T. Schaller, of the United States Geological Survey, was found to consist of $SiO_2=59.18$ per cent and $(Al_2O_3, Fe_2O_3, P_2O_5, TiO_2)=27.11$ per cent, thus being a very pure clay. * * *

This clay is important for the reason that it is unlike the general type of clay found at Boston. All the Pleistocene clays of the vicinity are of blue-gray to brown or buff colors; this clay is light gray to nearly white. The Pleistocene clays contain numerous bowlders and pebbles composed of all kinds of rock found in New England, but in this clay only two bowlders have been discovered, and these consist of rock only found in the vicinity of Boston, and which forms the bedrock of the region. The Pleistocene clays are interstratified with glacial deposits; this clay rests on bedrock and is separated from the overlying Pleistocene clay by a bed of till. This clay is much dryer than the overlying Pleistocene clay. * * *

Samples of the white clay from the Ames Building boring were compared at the office of the United States Geological Survey with samples of clay collected by Mr. Veatch from a number of borings on Long Island, New York, and found to agree very closely with them in appearance. Mr. Veatch has correlated the Long Island deposits with the Raritan formation of New Jersey. If this correlation is correct, it is possible that the Boston deposits may be of similar age. This is rendered more probable by the similarity of the material in the Boston borings to some of the clays on Marthas Vineyard.

K-L 12-13. NORTHERN WYOMING.

The Bighorn Basin, in northern Wyoming, is surrounded by Cretaceous strata which Fisher [331b] described under the names Morrison, Cloverly, Colorado, Pierre, and Laramie and associated formations. Recent surveys by Woodruff [947a] yield the following section of the southwestern portion of the Bighorn Basin:

Section along Shoshone River near Cody, Wyo.

System.	Formation.		Thickness (feet).	Characteristics.
Tertiary.	Wasatch formation.			[See p. 774.]
	Unconformity.			
	Fort Union formation.		3,100	[See p. 774.]
	Unconformity (?)			
Cretaceous.	Laramie (?) formation.		2,630	Dull green sandy shale with local brown leaf-bearing beds and gray massive sandstone.
	Montana group.	Undifferentiated Montana.	760	In lower part gray massive sandstone and dark-colored sandy shale in alternating layers; in upper part dark and light gray shale alternating, and numerous lignitic beds.
		Eagle sandstone.	220	Gray massive sandstone, weathering tan, and gray sandy shale with dark coaly bands. Locally coal bearing.
	Colorado shale.		3,375	Black to dark-gray shale with rusty sandstone at base and gray massive sandstone at short intervals in lower half. Thin beds of coal occur a little below the middle.
	Cloverly formation.		300	Gray, green, and maroon shales and gray compact sandstone.

As shown in the above table, the thickness of sandstone and shale between the top of the Colorado formation and the great unconformity at the base of the Wasatch formerly mapped by Fisher [a] as "Laramie and associated formations" is here tentatively subdivided into Eagle, undifferentiated Montana, Laramie (?), and Fort Union. These formations are suggested on

[a] Fisher, C. A., Prof. Paper U. S. Geol. Survey No. 53, 1906, p. 8.

lithologic and paleontologic evidence. * * * At the beginning of the field season, in the absence of definite fossil evidence, differences in lithology alone were accepted as a basis for the subdivision into formations. A subsequent study of the fossils, both in the field and in the laboratory, by T. W. Stanton and F. H. Knowlton, has shown that the lithologic units do not coincide in all particulars with the formations as they are recognized farther north and elsewhere. Fossils collected at various localities in the fields point to the presence of the Eagle and Laramie formations, though the evidence is not conclusive, as many of the species are either new or heretofore unknown to the formations, and strictly characteristic specimens are lacking. A fresh-water fauna which contains forms suggestive of upper Montana occurs in beds between the Eagle and Laramie (?). There is abundant fossil evidence to prove the presence of the Fort Union formation. A suggestive break occurs at the base of the conglomerate beds noted in the table, which was thought in the field to be an unconformity at the base of the Fort Union, but later study of the plant collections shows that Fort Union forms occur a few feet below this horizon. As the final determinative evidence has not been obtained, the divisions shown in the table are only provisionally introduced.

For notes on the northeast side of the Bighorn Basin, see L 12–13 (p. 690).

K–L 13. SOUTH DAKOTA AND NORTHWESTERN NEBRASKA.

Darton [232, 233, 237, 238] has described the strata of South Dakota and northwestern Nebraska in several publications. In the Newcastle folio [236] he gives the local development of the Cretaceous as follows :

	Feet.
Upper Cretaceous:	
Laramie formation—massive soft buff sandstone with concretions and carbonaceous shales.	800
Fox Hills formation—thin hard sandstone in sandy shale, and soft clayey sandstone below.	75–150
Pierre shale—dark gray shale or clay with concretions containing many fossils	1,250
Niobrara formation—gray calcareous shale, and impure chalk	200
Carlile formation—variable gray shale	700
Greenhorn limestone—thin bedded, hard gray limestone, with *Inoceramus labiatus*	50
Graneros formation—dark shale	1,000
Dakota sandstone—gray to buff sandstone mostly very massive	50–100
Lower Cretaceous:	
Fuson formation—gray to red shales with thin sandstones	15–30
Lakota sandstone—massive cross-bedded gray to buff sandstone, with local coal beds and conglomerate	150–200
Morrison shale—massive sandy shale and fine sandstone	150
Unconformity.	

L 10. WESTERN WASHINGTON.

Cretaceous sandstones are supposed to form a large part of the Olympic Peninsula, in Washington. Arnold [29a] examined them on the western coast and states:

The rocks supposed to be Cretaceous in age, the correlation being based on their stratigraphic position and lithologic character, are confined to the western coast of the peninsula. They extend over most of the territory from 1½ miles south of Point of the Arches to 1 mile north of Cape Elizabeth and consist almost entirely of a coarse gray sandstone, with occasional zones of black shale and rarely a little conglomerate. The thickness of the formation is probably over 5,000 feet, although, owing to its complex structure, this is only a very rough approximation.

L 10–11. JOHN DAY BASIN, OREGON.

(See Chapter XIV, p. 621.)

L 12–13. EASTERN IDAHO, NORTHWESTERN WYOMING, AND MONTANA.

Cretaceous strata occur here and there in the Yellowstone Park and vicinity. Stanton [779] reported on the strata and their correlation and showed that representatives of the Colorado and Montana are present. Certain strata which were doubtfully referred to the Dakota are now[a] regarded as in part referable to the Kootenai and in part probably to the Bear River.

In an unpublished manuscript F. C. Calkins describes and correlates the Colorado formation in the Philipsburg quadrangle, Montana, as follows:

Immediately above the Kootenai formation in the Philipsburg district is a very homogeneous accumulation of fissile black shale whose upper part contains thin beds of low-grade coal near Drummond. On Mount Princeton the shale is about 450 feet thick. The greater part of the shale is barren of fossils, but according to Dr. Stanton it lithologically resembles the Colorado shale of areas farther east. Immediately above the coal near Drummond a Unio which may be of Colorado age was found.

At the top these shales pass by a rapid gradation into beds dominantly arenaceous, attaining a thickness of more than a thousand feet. They consist mainly of greenish flaggy sandstones but comprise considerable shale and several beds of conglomerate.

In the lower part of the sandstone on Mount Princeton and about 4½ miles east of Drummond, very imperfect specimens doubtfully referred by Dr. Stanton to Mactra and Callista were collected which appear to be of Colorado age. About 1½ miles southeast of Drummond a small collection of plants from a horizon a few hundred feet above the base of the sandstones is reported upon as follows by Dr. Knowlton:[b]

"There are three things in this little collection—a Marchantia which is probably new, a conifer which is probably a Glyptostrobus, and a fern that is pretty close to if not identical with *Aspidium oerstedi* Heer. The latter is from Patoot, which=Senonian=Fox Hills. I can not place this material definitely, but should incline to regard it as possibly Upper Cretaceous."

In 1910 Mr. Pardee collected more satisfactory fossils from a limestone outcrop in Coberly Gulch, 10 miles north-northwest of the northeast corner of the quadrangle. The exact position of the horizon is not known; the limestone bed, however, is underlain by about 400 feet of sandstone and shale similar to those above the black shale, so that it is virtually certain that the fossils occur at least 400 feet stratigraphically above the main body of black shale.

The list of forms identified by Dr. Stanton and his comment on them follows:

6552. Specimen No. 10–P, 4. NE. ¼ NW. ¼ sec. 34 and SW. ¼ sec. 27, T. 10 N., R. 12 W., Granite County, Mont.
Modiola sp.
Cyrena securis White.
Corbula sp.
Glauconia coalvillensis Meek.
Admetopsis subfusiformis Meek.

"The horizon is in the Colorado group. The same association of forms occurs in the Oyster Ridge sandstone member of the Frontier formation of southwestern Wyoming."

By way of summary it may be said that lithologic and paleontologic evidence put the correlation of the black shale and about 400 feet of the overlying beds with the Colorado beyond reasonable doubt. It is probable, however, that some beds of Montana age occur in this district.

Calvert [115] describes the Cretaceous of the Lewistown coal field, in central Montana, as follows:

The Lewistown coal field * * * lies between longitude 109° and 110° 15′ west, and the 47th parallel divides it into two nearly equal portions. It is thus located in the center of Montana, including the west-central part of Fergus County and a few square miles of northeastern Meagher County. The greater part of the field lies in the Judith Basin, a name applied to the upper drainage area of Judith River. * * * The Little Belt and Big Snowy mountains are in the southern part of the field and the Judith and South Moccasin groups lie well within its northern borders. The area as described includes about 1,500 square miles. * * *

The rocks of the Lewistown coal field range in age from lower Carboniferous to Quaternary, inclusive. * * * The succession of the rocks and the relation of the principal coal-bearing beds to strata above and below are shown in the following generalized section:

[a] Stanton, T. W., comment on manuscript.
[b] Personal communication to Dr. Stanton.

Generalized section of sedimentary rocks in the Lewistown coal field.

	Feet.
Claggett formation (Upper Cretaceous): White and brown sandstone in lower part and greenish sandy shale above.	
Eagle sandstone (Upper Cretaceous):	
Shale, dark bluish, containing carbonized wood fragments	5
Sandstone, soft, yellowish, cross-bedded, containing iron concretions and woody fragments	53
Sandstone, soft, white, usually without bedding	170
Sandstone, white, with coaly layer at top	10
Colorado shale (Upper Cretaceous):	
Shale, dark gray to black, with a few thin sandy members	720
Sandstone, hard, greenish, weathering brown, fine grained, ferruginous	3
Shale, dark gray to black, with a hard bed 420 feet above base	675
Sandstone, grayish brown, thinly bedded, containing an abundance of fish scales (supposed Mowry)	47
Shale, dark gray to black, alternating hard and soft layers	890
Sandstone and shale, alternating, brownish in color throughout	25
Kootenai formation (Lower Cretaceous):	
Shale, maroon, argillaceous	200
Sandstone, grayish, coarse grained, cross-bedded	8
Shale, maroon, argillaceous	60
Sandstone, gray, coarse grained, cross-bedded	25
Shale, maroon, argillaceous	72
Sandstone, massive, coarse grained to pebbly, weathering soft gray	50
Coal and coaly shale	10
Shale and sandstone, alternating; the shale is sandy and the sandstone thinly bedded	87
Morrison formation (Jurassic?).	

The above section, being compiled from measurements made in several places in the field, should not be considered as a type of any one locality.

The Colorado shale decreases in thickness northward from the Big Snowy Mountains, for a section of that formation to the south of the uplift shows that the interval between the Kootenai red shale and the Eagle sandstone is 2,400 feet, whereas the same interval 15 miles northeast of Lewistown is less than 1,600 feet.

Throughout the field the Kootenai is fairly uniform in thickness, although the individual members comprising the formation vary locally. As a formation it is readily distinguished by the bright maroon-colored shales and by the coarsely cross-bedded sandstone just above the coal.

In 1908 Stone [798] gave an account of the Cretaceous and Tertiary rocks surrounding the Crazy Mountains, west of longitude 115°. Further studies in 1908–9 by Stone and Calvert [799] led to a revision of the classification and nomenclature, which is expressed in the following table and notes abstracted from their report:

Stratigraphy of the Upper Cretaceous and early Tertiary in the vicinity of the Crazy Mountains, Montana.

Fort Union formation, 4,000+ feet: Massive sandstones and intercalated shales.	
Lebo andesitic member, 450–2,200 feet: Fort Union fossils; Torrejon mammals.	Livingston formation as originally defined for a lithologic unit (andesitic material).
Lance formation ("Laramie" or "Ceratops beds"), 1,000–2,400 feet: Light-gray sandstone and variegated shales. (Stanton thinks equivalent to Laramie of Denver Basin. Knowlton thinks is Fort Union.)	
Lennep sandstone, 250–460 feet: Dark-colored sandstone with intercalated shales. Few fossils. Not definitely correlated with Fox Hills sandstone.	
Bearpaw shale.	
Judith River formation.	
Claggett formation.	
Eagle sandstone. Livingston flora nearly through this sandstone.	
Colorado.	
Kootenai (Lower Cretaceous).	
Jurassic.	

The following notes give the substance of Stone and Calvert's remarks, though not a literal quotation.

In the upper valley of Musselshell River and north of the Crazy Mountains the basal Cretaceous rocks belong to the Kootenai formation, which rests conformably on the Morrison formation. The Kootenai is 235 feet thick, is composed of shale and sandstone, and is not coal bearing. It is overlain conformably by Colorado shale, about 1,300 feet thick, prevailingly dark colored and carrying marine invertebrates.

The four formations of the Montana group, Eagle, Claggett, Judith River, and Bearpaw, are found here. The Eagle is mainly massive sandstone, about 200 feet thick, and in some places carries coal which usually is unworkable. The Eagle is a conspicuous ledge or ridge maker. The Claggett is composed of dark shales and white to light-brown sandstones of marine and brackish-water origin, from 400 to 800 feet thick, and is overlain by the Judith River formation, which has about the same range in thickness. The Judith River is prevailingly of fresh-water origin, carries thin beds of coal, and has fossil shells, bones, and wood.

Above the fresh-water Judith River is the upper marine Cretaceous shale, 700 to 1,000 feet thick, known as the Bearpaw shale. This shale is commonly dark-colored and has fossiliferous limy nodules. The Cretaceous section is normal to the top of the Bearpaw. Resting on these marine shales and evidently of a transitional nature is about 300 feet of dark-colored fresh and brackish water shale and sandstone. The stratigraphic relation of these beds is like that of the Fox Hills sandstone. but enough fossils have not yet been obtained to make the correlation positive. These beds are more or less tuffaceous.

There is some question as to the age of the overlying Lance formation, which is 1,000 to 2,400 feet thick and composed of light-colored fresh-water sandstone and shale. The paleobotanic collections are ascribed by Knowlton to the Fort Union, but the vertebrate and invertebrate fossils point to Cretaceous age for the same beds. There is no doubt that they should be in part correlated with the "Ceratops beds," but whether the latter are Cretaceous or Tertiary is as yet unsettled.

Resting conformably on the Lance formation is another series of tuffaceous sandstones and shales. The beds are about 2,200 feet thick at the north end of the Crazy Mountains and 460 feet on Fish Creek northeast of the mountains. They are of Fort Union age and will be described in future papers as the Lebo andesitic member of the Fort Union formation.

The youngest consolidated strata in the Crazy Mountains are the massive sandstones and shales of the Fort Union formation. They are of fresh-water origin and are shown to be Tertiary both by plant and by animal remains. The thickness is unknown but exceeds 4,000 feet.

At the north end of the Crazy Mountains the Upper Cretaceous formations gradually lose their distinctive lithologic characteristics, and all from the Eagle to the massive sandstones of the Fort Union become merged into a single series of tuffaceous beds several thousand feet thick and constituting a single lithologic unit. On the west side of the Crazy Mountains, therefore, the Eagle sandstone is overlain conformably by a great series of sediments more or less andesitic in composition and varying in age from lower Montana to Tertiary. These in turn are overlain by the Fort Union.

The Kootenai (Lower Cretaceous) and Colorado formations extend northwestward from the fields described and have been traced around the Big Belt Mountains, according to Fisher,[332b] who says (see also Chapter XIV, pp. 621–623):

> The Colorado shale rests with apparent conformity upon the underlying Kootenai and is overlain conformably by the Eagle sandstone, the lowest member of the Montana group. Although conformable relations appear to exist between the Kootenai and Colorado formations in this region, the Dakota, which occupies a position between these two formations in other localities, is, as previously stated, believed not to be present. If this is true, there is a hiatus at this contact representing at least several hundred feet of beds. It is possible that Dakota time is here represented by marine sediments not easily separable from the Colorado shale.

The Upper Cretaceous section of central Montana was established by Stanton and Hatcher,[785] from whose report the following general facts are abstracted:

The Benton (or more properly the Colorado, as more than the Benton is included) consists of dark clay shales with intercalated bands of sandstone, especially in the upper portion, and frequent calcareous concretions. The fossils of the lower portion are *Inoceramus labiatus, Scaphites warreni,* and others. The upper part yields *Inoceramus umbonatus, I. exogyroides, Pholadonya papyracea, Scaphites ventricosus, Baculites asper* (?), and many other forms. The total thickness is estimated at 800 feet.

Immediately above the Colorado is the Eagle formation. At its base the Eagle consists of sandstones and shale which grade into the underlying shale, but its conspicuous member is a massive light-colored cross-bedded sandstone, more than 100 feet thick. Above this member are softer beds of sandstone together with shale and lignite. Fossils are scarce but include, of invertebrates, *Cardium speciosum, Thetis ?circularis, Mactra alta, Placenticeras whitfieldi?,* and others, and, of vertebrates, remains of the dinosaur *Ornithomimus grandis.* The thickness is probably 300 feet or more.

The Claggett formation is a body of dark clay shales, about 400 feet thick, which rests on the Eagle. In the upper part are yellow sandstone beds, and the passage into the Judith River is by gradual transition. The lower part of the Claggett contains *Gervillia borealis, Baculites ovatus, Baculites compressus,* and other characteristic Pierre forms. The sandstone beds contain a fauna which "has long been considered a typical 'Fox Hills' fauna." Stanton concludes that "faunas similar to that of the Fox Hills sandstone have a great vertical range and are likely to be found at any horizon within the Montana group where a littoral or shallow-water facies is developed."

The Judith River consists chiefly of fresh-water deposits together with layers laid down in brackish water, especially near the top. There are also local marine beds. Workable coals occur in the upper portion. The thickness is about 500 feet. Extended descriptions of the Judith River formation are given in the bulletin cited.

The Bearpaw shales are marine and succeed the prevailingly fresh-water Judith River. They are dark clays which include many calcareous concretions. The thickness is estimated at 750 feet. The commoner forms in the varied invertebrate fauna are listed in Stanton and Hatcher's report.

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The grounds for distinguishing the Eagle, Claggett, Judith River, and Bearpaw formations as divisions of the Montana group are fully stated, their correlations are discussed, and special reports on the faunas and the flora are presented.

The distribution of the Cretaceous and early Tertiary in eastern Montana is shown as determined by the special surveys of coal fields[a] and reconnaissances connecting them.

Notes relating to the development of the sequence in particular fields (Lewistown coal field, Crazy Mountains, Livingston district, and Great Falls coal field) are given elsewhere in this chapter.

For the northeast side of the Bighorn Basin, Washburne[867] determined the following section of the Cretaceous. (For Tertiary, see p. 775.)

Cretaceous rocks on northeast side of Bighorn Basin.

Series.	Group.	Formation.	Thickness (feet).	Characteristics.
Upper Cretaceous.		Laramie (?) formation.[a]	150–700	Massive sandstone with subordinate shale. Contains workable coal.
	Montana.	Bearpaw shale.	150	Dark marine shale.
		Judith River formation.	300–400	Variegated clays and soft sandstone.
		Claggett formation.	400–500	Massive fresh and brackish water sandstones and dark shale. Coal not workable.
		Eagle sandstone.	150–225	Massive fresh and brackish water sandstones, separated by carbonaceous shale. Contains workable coal.
		Colorado shale.	4, 400	Dark shale with one or two conspicuous sandstones, not divisible in this field, though more than 1,500 feet of the lower part is known to be equivalent to the Benton shale.
		Unconformity		
Lower Cretaceous (?).		Cloverly.	0–275	Bright-colored clays, with massive sandstones at the top and bottom. Coal not workable.

[a] The evidence is not sufficient to class this formation as undoubted Laramie, consequently the term is used throughout this report in a questionable sense.

In the wide basin southeast of the Bighorn Mountains near longitude 106° and latitude 43° the general section of the Cretaceous is, according to Shaw:[735a]

Cretaceous:
- Montana—upper two-thirds principally sandstone with coal; lower third dark shale with no coal.
- Colorado—mostly dark-brown shale with some brown sandstone layers, and at the top a buff to white sandstone, which may be Niobrara. Near the base is the Mowry member, a very resistant dark shale which weathers white.
- Cloverly—massive, brown, resistant sandstone, which commonly forms a pronounced hogback. Near the top there is some shale, and at the bottom a fine conglomerate.

[a] Bull. U. S. Geol. Survey No. 316, 1907; No. 341, 1909.

Of the formations Shaw writes as follows:

The coal-bearing rocks described above are unconformably overlain by Tertiary and Quaternary formations. The White River, a Tertiary formation of white sandy clay and conglomerate, covers a considerable area in the southeastern part of the field. It is spread over parts of all the older formations, and is even found high up in the mountains. The so-called Chalk Buttes, 3 miles southwest of Douglas, are also composed of Tertiary rocks, and the outcrop of similar rocks extends westward for 25 miles along the foot of the mountains.

L 13–14. SOUTH AND NORTH DAKOTA.

A representative section of the Cretaceous of the Great Plains northeast of the Black Hills is given by Darton.[245]

Generalized section [of Cretaceous] for the Belle Fourche quadrangle, South Dakota.

System.	Series.	Formation name.	Character of rocks.
Cretaceous.	Upper Cretaceous.	Fox Hills sandstone.	Sandstone, light colored and slabby below, massive and yellowish to pinkish above.
		Pierre shale.	Limestone concretions that give rise to "tepee buttes." Dark-gray shale with numerous concretions.
		Niobrara formation.	Soft impure limestone or chalk and limy shale with thin limestone masses composed of *Ostrea congesta*.
		Carlile shale.	Gray fissile shale with numerous ferruginous limestone concretions. Thin sandstone near bottom.
		Greenhorn limestone.	Impure gray slabby limestone with shale intercalations.
		Graneros shale.	Gray fissile shale with scattered concretions. Thin bed of sandy limestone near middle and bentonite near base. Mowry shale member, composed of hard gray shale and fine-grained sandstone, weathering light gray and containing numerous fish scales. Local bed of sandstone. Dark fissile shale with concretions and thin sandstone layers near base.
		Dakota sandstone.	Gray to brown sandstone, mostly massive below, slabby above.
	Lower Cretaceous.	Fuson formation.	Gray to purple sandy shale and thin sandstones.
		Lakota sandstone.	Gray to buff sandstone, massive to flaggy, mostly hard.
Cretaceous or Jurassic.		Morrison shale.	Massive sandy shale, greenish gray to maroon.

Leonard [532] recognizes in the Upper Cretaceous of North Dakota the Laramie, Montana (Fox Hills and Pierre), Colorado (Niobrara and Benton), and Dakota. He describes the strata in detail, but they present no special peculiarities.

In a later discussion of this area [533] Leonard refers the Laramie of his previous report to the Lance and Fort Union formations and says concerning the strata of the Lance formation that "they have the same stratigraphic position as the Laramie formation, with which they correspond in whole or in part."

M 9–10. VANCOUVER ISLAND.

The Cretaceous of Vancouver Island forms three areas—the Nanaimo, Comox, and Quatsino, named from southeast to northwest. There are local differences of stratigraphy among the basins, but in general the terrane closely resembles that of Queen Charlotte Island, except that the two lower formations of that island are lacking on Vancouver. Dawson [256b] states:

In the northern part of Vancouver Island the Cretaceous which still remains appears to consist of outliers of a distinct and older basin and may probably be regarded as having been originally continuous with that developed in the Queen Charlotte Islands. The Cretaceous rocks of Quatsino Sound have so far afforded the best sections, and in these we appear to find the three higher members of the Cretaceous section of the Queen Charlotte Islands, as it exists in the vicinity of Skidegate Inlet. * * * In comparing these with the corresponding rocks of the Queen Charlotte Islands it is probable that the thickness of the Quatsino beds is somewhat less and that the conditions met with in the lower or coal-bearing portion of the series are more distinctly littoral at Quatsino, sandstones and conglomeratic layers being relatively more important. The Cretaceous rocks which extend along the northeast shore of Vancouver Island, from Port McNeill to Beaver Harbor, may in part represent the lowest or coal-bearing portion of the Quatsino section. A few fossil plants obtained from Beaver Harbor are Middle Cretaceous and possibly referable to a horizon near that of the lowest beds at Quatsino, but are regarded by Sir William Dawson as distinctly newer than these, though possibly older than much larger collections since made at Port McNeill, which have not yet been worked up in detail, the Nanaimo and Comox Cretaceous floras. It is thus evident that we have not merely a single horizon to deal with along this part of the northeast coast. No trace of the lower subdivisions represented at Skidegate (D and E) has yet been found on Vancouver Island.

The relations of the Cretaceous rocks of the Queen Charlotte Islands and those of the northern part of Vancouver Island, as now understood, may be expressed as below, in tabular form:

	Queen Charlotte Islands.	Northern part of Vancouver Island.
Upper Cretaceous.	A. Upper shales and sandstones, 1,500 feet.	A. Port McNeill beds (?). Upper shales.
Middle Cretaceous.	B. Coarse conglomerates, 200 feet. C. Lower shales and sandstones, with coal, 5,000 feet. D. Agglomerates, 3,500 feet. E. Lower sandstones, 1,000 feet?	B. Coarse conglomerates. C. Lower sandstones and shales with coal. D. Wanting. E. Wanting.

In the course of the examination of the Cretaceous rocks of the northern part of Vancouver Island, it has been found that these rest unconformably on a rough and irregular denudation surface of the older rocks. * * * Owing to this circumstance the higher Cretaceous beds successively overlap the older rocks, and as the areas of these beds which have escaped subsequent denudation are probably to a great extent those which have filled the deeper portions of the hollows, it follows that the actual outcropping edges of the beds rarely give a complete section of the entire thickness of the formation.

In 1873 Richardson [671] made a report on the Nanaimo ana Comox fields, which contains numerous detailed sections of the Cretaceous strata. Dawson [259] summarizes the facts as follows:

The rocks accompanying the coals are sandstones, conglomerates, and shales, being largely of the character of littoral formations but also containing, particularly in the shaly members of the series, truly marine fossils. They hold also in some layers abundance of fossil plants, and in appearance and degree of induration much resemble the older Carboniferous rocks of some parts of eastern America. Coals of a workable character have been found only in the lower part of the Cretaceous series, which is represented with closely similar characters in the Comox and Nanaimo areas. The somewhat variable character of the Cretaceous measures as a whole is, however, shown by the fact that Mr. Richardson found it necessary to adopt a different scheme of subdivisions for the two areas, notwithstanding their general correspondence. The sections at Comox and Nanaimo are as follows, in descending order:

Comox.		Nanaimo.	
	Feet.		*Feet.*
Upper conglomerates	320	Sandstones, conglomerates and shales	3,290
Upper shales	776		
Middle conglomerates	1,100		
Middle shales	76		
Lower conglomerates	900	Shales	660
Lower shales	1,000	Productive coal measures	1,316
Productive coal measures	739		
	4,911		5,266

The age of the productive coal measures of Nanaimo and Comox is approximately that of the Chico group of California, in which, however, in its typical locality, coals are not found.

M 11. CANADIAN ROCKIES, ALBERTA AND BRITISH COLUMBIA.

George M. Dawson [255b] classified and described the Cretaceous of the Canadian Rockies as follows:

The sections representing the upper part of the Cretaceous rocks of the mountains are, unfortunately, very unsatisfactory, the best being that of the Northwest Branch. * * * The volcanic beds are there followed by dark shales which afford a few fossils referred to the Benton group and are estimated to attain a minimum thickness of 1,400 feet. Above these are sandstones and shales, generally of pale tints and possibly several hundred or a thousand feet in thickness, which are supposed to represent the Belly River series of the plains to the eastward. A concealed area beyond these is presumed to be underlain by the Pierre shales, and still higher in the section are beds referable to the base of the Laramie, with characteristic fossils. The thickness of the Laramie at this place is indeterminate but must be considerable. * * *

A provincial general representation of the Cretaceous beds of the mountains of this region, as compared with those of the plain to the east, may be given as follows, in descending:

	Rocky Mountains.		Foothills and plains.	
		Feet.		*Feet.*
Laramie.			Porcupine Hill beds	2,500
			Willow Creek beds	450
	St. Mary River beds (base)	Not known.	St. Mary River beds	2,800
Cretaceous.	Fox Hill and Pierre	Not known.	Fox Hill and Pierre	830
	Belly River series	Not known.	Belly River series	910
	Benton and (Niobrara?)	1,400	"Lower dark shales"	800
	Volcanic rocks (greatest thickness)	2,200		
	Dakota and upper part of Kootanie series to coal-bearing horizon	2,750		
	Lower part of Kootanie series	7,600		
		13,350		8,290

T. W. Stanton comments as follows on the foregoing section:

The lower part of the strata Dawson referred to the Kootenai in this region doubtless includes some marine Jurassic. (See Whiteaves, Description of a species of Cardioceras from the Crows Nest coal fields: Ottawa Naturalist, vol. 17, 1903, pp. 65–67.) This Jurassic ammonite is one of the fossils mentioned by McElroy as occurring in the lower beds of the Kootenai below the coal and plant-bearing horizon (Rept. Geol. Survey Canada, vol. 13, 1900, p. 91A).

McConnell's description [559a] supplements that given by Dawson:

The Cretaceous is essentially a clastic formation and contains beds ranging through every degree of coarseness, from fine-grained fissile shales to heavy conglomerates.

* * * * * * * * *

The lower part of the series consists mainly of beds and bands of flaggy sandstone, alternating with dark shales. The shales are usually somewhat arenaceous and pass gradually, by the addition of more sandy material, into pure sandstones. They are also occasionally carbonaceous and in a number of places inclose coal seams, some of which are workable. The sandstone occurs characteristically in somewhat thick beds and is usually coarse grained and soft, but harder quartzitic beds are not altogether absent. It weathers to a dull red color. The bands of sandstone are little persistent and if traced along their strike for any distance are found to break up into subordinate beds, separated by thin shaly partings, or to pass altogether into shales. The upper part of the section contains some conglomerate, in addition to the shales and sandstone. This occurs in massive beds, measuring up to 150 feet in thickness, and is composed of rounded siliceous pebbles, with some shaly and calcareous grains, embedded in a hard siliceous matrix. The pebbles are usually small, seldom exceeding an inch in diameter, and the rock passes insensibly into sandstone. The section here is more arenaceous than is usually the case, and there is reason to believe that it occupies a comparatively high position in the series and that the lower part contains a greater proportion of shales. The Cascade River section, a few miles farther north, which is undoubtedly lower, shows no conglomerate, and the sandstones are also of less importance, and in nearly every case where beds of Cretaceous age overlie the Banff limestone in an undisturbed condition, showing that the base of the formation is present, they consist almost entirely of dark shales.

* * * * * * * * *

The following fossils were collected near the base of a small Cretaceous outlier situated 3 miles north of the east end of Devil's (Minnewanka) Lake: *Oxytoma mucronata, Trigonia intermedia, Trigonoarca tumida,*[a] all three characteristic of the Queen Charlotte Island series, and species of Terebratula, Ostrea, Camptonectes, Lima, Cyprina, ammonites, and belemnites.

A small collection, obtained from the shales faulted under the Cambrian limestones at the gap of the south fork of Ghost River, includes amongst others, such Benton species as *Scaphites ventricosus* and possibly *S. warreni,* and an Inoceramus like *I. undabundus.*

McEvoy [564] gives a detailed section of 4,736 feet of Cretaceous beds in the Crows Nest Pass basin near Morrisey and notes 1,000 feet or more of shaly limestone and calcareous shales below the measured section, as well as 4,000 to 5,000 feet of soft shale and sandstone above it. He concludes that the total thickness of Cretaceous strata in the Crows Nest Pass basin is 12,000 to 13,000 feet.

M 12. NORTHWESTERN MONTANA.

In northwestern Montana, at the eastern base of the Rocky Mountains, Cretaceous strata form the valley floors and foothills. In a reconnaissance survey in 1901 Willis [940a] distinguished Dakota, Benton, and Laramie.

[a] "Most probably Jurassic" [Fernie shale].—T. W. Stanton. See also statement by D. B. Dowling in Bull. Geol. Soc. America, vol. 17, 1906, p. 298.

Laramie sandstone [a]: Sandstone, hard, gray, cross-bedded, and soft, shaly, interbedded, carrying layers of oyster shells and containing plant remains.
Benton shale: Shale, dark bluish gray, very fissile, fossiliferous, with occasional beds of sandstone, medium grained, brown, and thin limestone layers.
Dakota sandstone: Sandstone, yellow and brownish, and shale, arenaceous, with plant remains and fresh-water shells.

A recent reconnaissance [b] by M. R. Campbell and C. A. Fisher shows that the Colorado is exposed in a broad strip extending from the Big Belt Mountains north by west, possibly to or into Alberta. This strip is flanked on both sides by the Eagle sandstone and higher formations of the Montana group, including the Judith River.

M-N 11-14. PLAINS OF ALBERTA, SASKATCHEWAN, AND MANITOBA.

Dawson's classification of the Cretaceous strata of the southwestern part of the Great Plains in Canada is given on page 693 in comparison with that of the Cretaceous in the Rocky Mountains. The Athabaska and Peace River sections are described on pages 699–700.

The standard section of the Upper Cretaceous of Canada was established by Dawson [254] in a study of the region between the base of the Rocky Mountains and the meridian of 110° 45′, near Medicine Hat, on the South Saskatchewan. Dawson's classification is as follows:

	Feet.
Laramie:	
Porcupine Hill beds: Sandstones, frequently thick bedded and generally comparatively soft, with intercalated grayish and blackish shales and shaly clays. Fresh water	2,500
Willow Creek beds: Soft sandstones, shales, clays, and sandy clays, generally with pronounced reddish or purplish tint. Fresh water	450
St. Mary River beds: Sandstones, shales, and shaly clays in frequent alternations, and generally well bedded. Fresh water except near base	2,800
Cretaceous:	
Fox Hill sandstones: In some parts of the district well defined as a massive yellowish sandstone, but inconstant, and apparently often represented by a series of brackish-water transition beds between the Laramie and the Pierre	80
Pierre shales: Neutral gray or brownish to nearly black shales, include a zone of pale soft sandstone in the northeastern part of district, and frequent intercalations of harder sandstones near the mountains. Marine	750
Belly River series: Composed of an upper or "pale" and lower or "yellowish" portions and consisting of alternations of sandstones, sandy clays, shales, and clays	910
Lower dark shales: Gray to nearly black shales, frequently with arenaceous shales	800

Details of occurrence and local character of each of these formations are given in the subsequent pages of Dawson's report and he states his interpretation of the geologic history.[254a]

The region east of that examined by Dawson, lying between the meridians of 106° and 110° 50′, was studied by McConnell,[558] who recognized Belly River, Pierre, and Fox Hill, overlain conformably by the Laramie, and the latter overlain unconformably by Miocene.

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[a] "The 'Laramie' of this section is probably Judith River or older. The distinction between Laramie and Judith River was not generally recognized when these fossils were examined."—T. W. Stanton.

[b] Data contributed from manuscript records of the United States Geological Survey.

On the North Saskatchewan and its tributaries Tyrrell[816] distinguished the following beds:

	Feet.
Laramie:	
Paskapoo series: Gray and brownish weathering lamellar or massive sandstones and olive sandy shales. This is an exclusively fresh-water deposit	5,700
Edmonton series: Soft whitish sandstones and white or gray, often arenaceous clays, with bands and nodules of clay ironstone and numerous seams of lignite. These are of brackish-water origin and correspond to the lowest portion of the St. Mary River series of Dr. Dawson's report (Geol. Survey, Rept. for 1882-84, p. 114c)	700
Fox Hill and Pierre: Brownish-weathering sandstones and dark-gray clay shales	600
Belly River series: Soft whitish sandstones and arenaceous clays, changing toward the east to light-brownish and yellowish sandstones and sandy shales; bottom not seen.	

In the foothills evidence was found of the presence of rocks of the age of the Benton shales, which immediately underlie the sandstones of the Belly River series, but our knowledge of them is as yet too imperfect to allow of our treating of them in any way, and we can therefore simply record their occurrence.

No intrusive rocks occur anywhere throughout the district, and below the top of the Laramie there is no evidence of any unconformity between the different formations, although in some cases the extreme irregularity of the bedding gives the strata very much the appearance of having been laid down unconformably one on the other.

[The Belly River series is represented by] white or light-gray clays and soft clayey sandstones, interbedded with bands and nodules of clay ironstone. These nodules are often highly calcareous, breaking with a smooth, sharp fracture. Toward the center, on a freshly broken surface, they are of a clear slate-gray color; around are darker and darker layers, till the outer one, which is very dark brown, almost black.

As has already been pointed out in the reports of Dr. Dawson and Mr. McConnell, this series, if followed toward the east, is found to lose gradually its clayey character and to consist of purer and much more massive sandstones, generally of a yellowish color.

The Fox Hill and Pierre are described by Tyrrell as consisting of—

dark or light gray, very friable clay shales, weathering down into a soft tenacious clay, interbedded with bands of coarse-grained yellow sandstone. Unlike the beds both above and below, it is of purely marine origin, having been laid down in a sea of varying though generally very considerable depth.

The thickness of the formation, wherever it could be measured, was found to be from 600 to 700 feet.

* * * * * * * * *

It is quite impossible here to separate the Fox Hill sandstone from the Pierre shales, as they are completely interbedded from the top to the bottom of the group. In descending Battle River this is particularly noticeable, as at the top of the group yellow sandstones are met with containing *Placenticeras placenta*, teredo burrows, etc., and at the bottom a sandstone quite undistinguishable from that above is seen holding precisely the same fossils. In the southern part of the district, nodules of clay ironstone are common throughout the shale, and fossils are plentiful, both in the nodules and in thin bands of included sandstone, but to the northward, fossils become much more rare and new species begin to appear, which are not known to the south.

The fossils found in the district, so far as known at the time of the report, are listed by Tyrrell to the number of 32 species.

No workable beds of coal occur in this group within the district, though in the shales on the top of the high ridge to the north of the Neutral Hills a thin band of carbonaceous shale is seen over a considerable area, and at Egg Creek, near the North Saskatchewan, there is a thin seam of coal of fine quality.

For an account of the Edmonton and Paskapoo series, see Chapter XVI (pp. 781–782).

In the eastern portion (M–N 13–14) of the area under consideration the classification of the Cretaceous differs from that given for the western portion (M–N 11–12) in the recognition, by Tyrrell,[817b] of Dakota, Niobrara, and Benton. Tyrrell gives the following systematic account in a report which contains also many local details:

The Dakota sandstone formation, resting unconformably on the limestones of the Devonian, is composed of white or reddish sandstones, either cemented by a calcareous matrix or often quite incoherent, being then an even-grained white quartzose sand. It grades up into a light-green and rather hard sandstone, commonly interstratified with thin bands of shale.

Very few fossils have been found in this sandstone, and those that have been found are confined to the greenish upper beds.

Overlying the Dakota sandstones, the Benton formation occurs as a band of dark-gray, almost black shale, holding a considerable quantity of carbonaceous material. This shale is evenly bedded and breaks down readily into thin flakes, on which account it generally forms sloping banks. With the dark shales are associated thin beds of white, soft, sweet-tasting magnesian clay.

It is generally quite destitute of fossils, but in a few places undeterminable fragments of oysters and Inocerami have been collected from the shale.

* * * * * * * * *

The Niobrara formation conformably overlies and is an upward extension of the Benton. The rock, however, instead of being a soft fissile shale, with little or no admixture of calcareous material, is a lighter-gray calcareous shale or marl, sometimes varying to a band of moderately hard limestone. This is especially the case at the top of the terrane, where a band of grayish chalky limestone is generally met with. This band is often highly charged with pyrite.

A very characteristic feature of the formation is the presence of a large number of Foraminifera, among which *Globigerina cretacea* is often very conspicuous and in great abundance.[a]

The terrane varies considerably in thickness. In the Manitoba Oil Co.'s bore on Vermilion River it appears to have a thickness of 130 feet. On North Pine Creek its total thickness is less than 400 feet and probably is not more than 200 feet. On Bell River it is probably less than 250 feet. In the Swan River valley, near Thunder Hill, it would seem to have a thickness of 540 feet, but it is quite possible that the upper beds represent a foraminiferous horizon in the overlying Pierre formation.

This terrane is known to extend southward through the western portion of the province of Manitoba, having been recognized in the valleys of the Assiniboine and other streams near the face of the Manitoba escarpment and in the borings from the deep wells at Morden and Deloraine. It is doubtless continuous with the Niobrara shales and limestones, originally described by Messrs. Meek and Hayden, from the banks of the Missouri River in Nebraska. Northwest of the area now described a fragment of typical Niobrara rock was collected from Carrot River, about west longitude 103°, by Mr. A. L. Russell, beyond which it has not been traced, and its exact correlation with the beds on Athabasca River is not yet known.

* * * * * * * * *

Grading upward from the top of the Niobrara formation the Pierre shales occupy the summits of all the higher lands of the Riding, Duck, and Porcupine mountains. In the Riding Mountain and farther south this formation naturally separates itself into an upper and a lower subdivision, which the writer has elsewhere called the Millwood and the Odanah series.[b]

* * * * * * * * *

Farther west the Pierre is highly fossiliferous, but in northwestern Manitoba fossils are very scarce, and of those recorded in the following list[a] the Radiolaria are from a bed of shale on

[a] For list see the work cited.—B W

[b] Tyrrell, J B., The Cretaceous of Manitoba: Am. Jour. Sci., vol. 40, 3d ser , 1890, pp 227–232.

Bell River, and the remainder are from ironstone nodules from the west bank of the Assiniboine Valley at Millwood, a short distance south of the present map.

The total thickness of the Pierre in northwestern Manitoba is 800 feet or more. The Millwood series, as seen in the valleys on the northern face of riding Mountain, has a thickness of between 450 and 500 feet, while about 300 feet of the overlying Odanah series is there also seen, reaching to near the summit of the mountains and being immediately overlain by the drift deposits. The top of the Odanah series is not seen.

O 4-5. ALASKA PENINSULA.

Atwood [42b] in a report on the mineral resources of southwestern Alaska discusses the Jurassic and Cretaceous of the peninsula, stating in regard to the Upper Cretaceous:

Upper Cretaceous sediments are exposed in the mountains northwest of Chignik Bay and west of Chignik Lake. They are also present in the Herendeen Bay district. They * * * consist of sandstones, shales, conglomerates, a little limestone, seams of bituminous coal, and some lignite. Upper Cretaceous fossils were procured by Paige [a] from the coal measures in the Herendeen Bay field and by the present writer from the several other localities above mentioned in this district and in the region of Chignik Bay.

(See also Chapter XIII, p. 574.)

O 8. SOUTHEASTERN ALASKA.

See Chapter XIV (pp. 632–633).

O 10-12. NORTHERN BRITISH COLUMBIA AND ALBERTA.

The northern portion of the great Cretaceous area of the plains has been examined on Liard, Peace, and Athabaska rivers and their tributaries. McConnell [560b] describes the structural relations in the eastern foothills and out on the plains and concludes:

The Cretaceous section along the Liard shows two great shale and sandstone series separated by a heavy band of sandstones and conglomerates. The lower shales, from the imperfect fossil evidence at hand and also from their lithologic character, may be referred tentatively to the horizon of the Queen Charlotte Islands, or Kootanie formation, the upper shales to that of the Benton, while the intervening conglomeratic band probably represents the Dakota. The lithological succession of the Cretaceous beds here is almost identical with that which obtains in other parts of the Cordilleran belt north of the international boundary and on the Queen Charlotte Islands and shows that similar conditions of deposition prevailed at the same time over this whole area.

The Cretaceous rocks cross the Liard with a width of over a hundred miles and north of the river enter a bay in the mountains, the extent of which to the northwestward is not known; southward they are connected with the great Cretaceous basin in the plains.

South of the Liard the next section examined is that of Peace River, which was seen by Selwyn [725] and McConnell.[562] Dawson [253a] observed the Cretaceous rocks more fully in a parallel section on Pine River, a tributary of the Peace near longitude 121° and utilized Selwyn's notes in the following discussion:

Cretaceous beds in the vicinity of the [Rocky] Mountains appear to be composed almost exclusively of sandstones and conglomerates and with little exception maintain this character

[a] Paige, Sidney, The Herendeen Bay coal field: Bull. U. S. Geol. Survey No. 284, 1906, p. 103.

on the Pine River as far as the Middle Forks. * * * The sandstones are generally brownish in color, contain little calcareous matter, and are often quite coarse in grain. They are usually regularly bedded, and broad surfaces are frequently ripple marked. In the coarser grits and conglomerates the constituent fragments are found to be almost entirely of cherty material like that occurring in the more resistant of the limestone beds about the summit of the pass. * * * From sections exposed in the nearly bare hillsides of Pine River, the thickness of the series must be at least 2,000 feet and may be much more. * * *

While there is no means of arriving at the precise age of most parts of the sandstone series of the upper Pine River, I see no reason to doubt that it forms the coarse littoral portion of the Cretaceous rocks which spread so widely to the eastward. It seems probable, as more fully detailed elsewhere, that fine shaly materials become increasingly abundant in receding from the mountains, and that the rocks eventually resolve themselves into the subdivisions described below. * * *

1. Upper sandstones and shales with lignite coals (Wapiti River sandstones).
2. Upper dark shales (Smoky River shales).
3. Lower sandstones and shales with lignite and true coals (Dunvegan sandstones).
4. Lower dark shales (Fort St. John shales).

The preceding paragraphs refer particularly to the Cretaceous of the eastern foothills of the Rocky Mountains. The typical development of Cretaceous strata in the northern plains of the Athabaska and Peace River region differs from that of the foothills. It has been well described by McConnell,[561a] who says:

The Cretaceous section in the Peace-Athabaska country includes beds ranging in age from the Laramie to the Dakota, but the lithological succession of the various divisions differs from that which obtains on the Great Plains and also varies in different parts of the district. This feature of the formation, together with the further fact that most of the fossils collected are new to science and therefore useless for the purpose of correlating the beds here with known horizons elsewhere, makes it difficult to classify the different terranes in a satisfactory manner and also renders necessary the provisional use of some new names. The following illustration shows the succession of the various divisions of the Cretaceous on the two rivers, and also their ages, so far as the stratigraphical and paleontological evidence at hand admits:

Athabaska River section.		*Peace River section.*
Laramie.	Laramie.	Wapiti River sandstone.
Foxhill sandstone. La Biche shales (upper part).	Montana.	Foxhill sandstone. Smoky River shales.
Unrepresented.		Dunvegan sandstone.
La Biche shales (lower part). Pelican sandstone. Pelican shale. Grand Rapids sandstone. Clearwater shale.	Colorado.	Fort St. John shales. Peace River sandstones. Loon River shales.
Tar sands.	Dakota.	Unrepresented.

For an account of the stratigraphy, with notes on the faunas and correlation, McConnell's report should be consulted, but the following summary indicates the nature of the formations enumerated in the preceding table:

The Laramie is an alternation of yellowish and grayish flaggy and massive sandstones with grayish and dark clays and shales. It carries thin ironstone bands and lignite and is at least 1,000 feet thick in the plateaus south of Lesser Slave Lake. No determinable fossils were obtained in it.

The Montana comprises 50 feet of alternating sandstone and shale (Foxhill) and 700 feet of shale, the upper part of the La Biche shales. "The exact junction between the Montana and the Colorado was not definitely ascertained, owing to the scarcity of fossils and to the fact that the La Biche shales pass downward from the Montana into the Colorado without any structural break or lithologic change of any kind."

The Smoky River shales of the Peace River section are the equivalents of the upper part of the La Biche shales of the Athabaska section. They are dark-grayish to bluish-black shales, 200 feet thick, with bands of ironstone. The fossils belong to a typical "Pierre and Foxhill fauna."

The Dunvegan is a littoral formation which is lacking in the east and thickens westward from 100 feet on Smoky River to 600 feet at Dunvegan and 2,000 feet at Table Mountain, on Peace River. It consists of sandstone and arenaceous shales and carries fresh-water, brackish-water, and marine fossils, evidence of estuarine conditions and deposition on an oscillating surface. It occupies the stratigraphic position of the Belly River series of Assiniboia and Alberta, but the Belly River does not contain any marine fossils. The fauna of the Dunvegan is said to be like that of the Bear River formation of Wyoming, inasmuch as it contains "two of the most characteristic species of the Bear River, *Corbula pyriformis* and *Corbicula durkeii*," but Stanton[a] does not consider the likeness established by these species. The Dunvegan overlies the Colorado, whereas the Bear River underlies it.

The beds of the Peace River section which are assigned to the Colorado comprise about 1,500 feet of shale and sandstone, constituting three named formations. The Fort St. John is 700 feet thick, the Peace River is a lens which thins out eastward, and the Loon River is about 400 feet thick. The Loon River apparently rests directly on the Devonian.

In the parallel Athabaska section the corresponding formations that make up the Colorado are 930 feet in thickness. Compared with the Peace River section the divisions are stratigraphically equivalent as follows: La Biche (lower part) = Fort St. John; Pelican sandstone and shale and Grand Rapids sandstone = Peace River sandstones; Clearwater shale = Loon River shale.

McConnell says: [561c]

> The Tar sands underlying the Clearwater are assigned to the Dakota on lithologic and stratigraphic evidence, as no fossils were found in them. They rest on Devonian limestones and occur in the same position as the sands of undoubted Dakota age, which outcrop along the eastern edge of the Cretaceous in Manitoba and south of the international boundary in Minnesota. They consist of an almost homogeneous mass of tar-cemented sands, ranging in texture from a coarse silt to a grit, and vary in thickness where fully exposed from 140 to 220 feet.

P 8. LEWES RIVER, YUKON PROVINCE.

Rocks of Cretaceous age, both igneous and sedimentary, are described by Dawson [258] as occurring along the Lewes and other valleys of the inner Coast Ranges. He says:

> Besides the Triassic rocks previously referred to, the Mesozoic period is represented also by strata of Cretaceous and Laramie age. These rocks are distinctively more recent in appearance than and rest quite unconformably on all the older formations, though they have since been to some extent involved in their flexures. On the lower part of the Lewes, below the mouth of the Little Salmon, these rocks are cut across by the river for a distance of at least 35 miles. Some

[a] Personal statement.

fossil mollusks and plants have been obtained from this area, from which it would appear to include beds referable to the Middle or Lower Cretaceous[a] and to the Laramie period, and it is not improbable that the series is a consecutive one between these limits, as the total thickness represented must be very great. * * * The rocks comprise, in their lower portion, coarse conglomerates, graywacke sandstones, yellowish and gray quartzose sandstones, and dark calcareous slates. The upper portion, in which Laramie plants are found, consists chiefly of rather soft sandstones, shales, and clays, generally of pale colors. Evidence of contemporaneous volcanic action is observable in both parts of the series, and the higher beds include lignite coal of good quality.

Some miles farther up the Lewes, midway between the Little and Big Salmon rivers, peculiar green graywacke sandstones and green, highly calcareous conglomerates occur, which are provisionally referred, though with some doubt, to the Cretaceous. They are at least newer than the Paleozoic rocks, being composed of fragments of those and of granites.[b]

Conglomerates and sandstones similar to the last are again found near the lower end of Lake Labarge, on the east side, and are associated with black calcareous slates, which recur in several places along the same side of the lake, farther up, and from which a few fossils have been obtained. These seem to show that the beds are on or near the horizon of series C, of the Queen Charlotte Islands, which is of Middle Cretaceous age, approximately equivalent to the Gault.[a]

On the Upper Pelly River, 43 miles below Hoole Canyon, a single low outcrop of hard dark shales, containing fossil plants of Cretaceous or Laramie age, was found, but in the absence of further exposures along the river in that vicinity nothing can be said of the extent of this area, except that it must be quite limited in width. Again, on the Stikine River, between Glenora and Telegraph Creek, there are local occurrences of conglomerates and soft sandstones which may be regarded as probably Cretaceous, though no paleontological evidence is forthcoming.[b]

The position of these last-noted areas, as well as that of those along the Lewes River, occurring as they do in a zone of country immediately within the line of the Coast Ranges, is analogous to that held by Cretaceous rocks on the Skeena and in other localities still further southward in British Columbia. Further investigation will probably show that the rocks of this age occur in many additional places, and occupy somewhat extensive areas in this belt of country. In the vicinity of the Lewes, particularly, it is noted that the plane of the original base of the Cretaceous, now thrown into a number of folds, is about that of the present surface of the country, and these rocks may therefore be expected to recur frequently in the form of troughs or basins, more or less strictly limited and only to be discovered in detail by thorough examination. The loose material brought down by the Big Salmon River appears to indicate the existence of a considerable development of these rocks not far up the valley of that stream.

P-Q 4. LOWER YUKON, ALASKA.

The large area mapped as Cretaceous on the lower Yukon includes the Nulato sandstone, and the strata probably range in age from Lower Cretaceous to upper Eocene, according to Brooks,[101r] who says:

Cretaceous rocks outcrop almost without break on the lower Yukon from the mouth of the Melozi River to the head of the delta and northward into the basin of the Koyukuk River. In this part of the Yukon Valley Dall made the first geologic observations in the interior of Alaska over 40 years ago. In his summary of Alaskan geology,[c] made many years after, he assigned some coal-bearing beds to the Kenai (Eocene) and reported that they were succeeded by marine fossil-bearing sandstone. Spurr[d] corroborated Dall's observations and, accepting Eocene as the age of the underlying coal-bearing beds, assigned the succeeding strata to the

[a] In the opinion of T. W. Stanton these strata are probably of Jurassic age.—B. W.

[b] In the opinion of A. H. Brooks these strata are probably of Kenai (Eocene) age.—B. W.

[c] Dall, W. H., and Harris, G. D., Correlation papers—Neocene: Bull. U. S. Geol. Survey No. 84, 1892, pp. 347-348.

[d] Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, p. 196.

Miocene under the name Nulato sandstone. This conclusion seemed to be further supported by fossils from sandstone which were determined as Miocene. The stratigraphic position of the coal-bearing beds of the Yukon will be considered below, but it will be noted that so-called Kenai of the Yukon embraces beds as divergent in age as the Upper Cretaceous and the upper Eocene. The stratigraphic work of Collier [a] in 1902, followed by that of Hollick in 1903 and the studies of their collections by Stanton and Knowlton, have yielded ample proof of the Upper Cretaceous age of both the Nulato sandstone and the underlying coal-bearing beds. * * * Near Nulato there seems to be exposed a conformable series, consisting of sandstones, shales, and conglomerates, which represent continuous sedimentation from the middle of the Cretaceous to the Upper Eocene.

Schrader's Koyukuk report [b] makes mention of Lower Cretaceous fossils in an impure limestone, associated with volcanic rocks, which outcrop near the sixty-sixth parallel, and to the south of these of an impure limestone which carried Upper Cretaceous fossils, but assigned the Nulato sandstone to the Miocene.

Collier [163] gives the following description and tabular arrangement of the Cretaceous and Tertiary of the region:

The Upper Cretaceous is represented near Nulato by sandstones, conglomerates, and dark-colored shales, which outcrop along the river at intervals for about 100 miles. These have in part yielded a marine invertebrate fauna of Upper Cretaceous age, as determined by Stanton. Fossil plants were found in the same general horizon and were assigned by Dr. Knowlton to the Upper Cretaceous. It is evident, therefore, that these beds include both marine and fresh-water deposits. The fresh-water beds carry coals of commercial importance. The Cretaceous beds have undergone considerable deformation but are not metamorphosed and, in fact, are only slightly indurated.

The succeeding horizon is made up chiefly of sandstone and conglomerate, with some shale. It is called the Kenai series and is of upper Eocene age. These beds usually carry abundant plant remains, which show them to be of fresh-water origin. The Kenai series has been named from its typical occurrence on Kenai Peninsula and has been identified in various other parts of Alaska. It occurs in isolated areas on the Yukon near the boundary and near Rampart and is more extensively developed near Nulato. On the upper river it unconformably overlies various horizons below the Upper Cretaceous, but near Nulato its relation to the Upper Cretaceous seems to be one of conformity. The Kenai beds are, as a rule, little disturbed, but in some localities they have suffered considerable deformation. The Kenai is the great coal-bearing horizon of Alaska. Its coals are usually characterized by the presence of fossil resin, or amber.

Provisional tabular statement of Yukon stratigraphy.

Age.	Formation name.	Contact relations.	Lithologic character.
Recent	Alluvium		Flood-plain deposits.
Pleistocene?	Yukon silts	Unconformity	Fresh-water silts, sands, and gravels.
Post-Eocene Tertiary	Twelvemile beds; Palisade conglomerate.	(?)	Sands, clays, and gravels.
Upper Eocene	Kenai series	(?)	Fresh-water sandstones, shales, and conglomerates.
Upper Cretaceous		Conformity?	Fresh-water and marine sandstones, shales, arkoses, and conglomerates.
Lower Cretaceous		(?)	Fresh-water calcareous sandstones.
Do		(?)	Marine black, slaty shales, and thin-bedded limestones.
Permian		Unconformity	Marine, massive, white limestones, heavy conglomerates, and gray shales.

[a] Bull. U. S. Geol. Survey No. 213, 1903.
[b] Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, pp. 476–477.

Q 7. UPPER YUKON, ALASKA.

In 1905 Prindle and Hess [641] reported the occurrence of a Cretaceous sandstone in the Rampart region. More recently Prindle [640] has revisited this locality and found fossils assigned to the Upper Cretaceous. The rock in which this fauna occurs is a black carbonaceous sandy argillite. Granitic rocks cut these beds, showing a later intrusion of acidic rocks than was previously known. The areas are too small to show on the map.

(See also Q 7, Chapter XIV, pp. 635–636.)

Q 8. NORTHERN YUKON TERRITORY.

According to Camsell,[128c] Peel River, which flows northward from the Rocky Mountains in Yukon Territory to the Mackenzie Delta, emerges from a lower canyon, cut across folded slates of supposed Devonian age, and thence to a tributary called the Snake—

> cuts a deep valley 500 to 700 feet in soft shales and sandstones of Cretaceous age. A section of the bank * * * shows about 200 feet of yellow and red shales, which toward the base are interbedded with layers of sandstone, resting on massive sandstone 50 feet in thickness. * * * Farther downstream the banks consist principally of sandstone, with thin beds of shale interposed between sandstone beds. In parts the sandstone contains concretions, many of which are 10 feet in diameter. Apparently the river in this portion cuts through a low anticline. * * * The Snake River has a deep and narrow valley cut into soft gray argillaceous sandstones, which lie horizontally or dip at a low angle to the east. The sandstone is massive, but the beds are separated from each other by thin seams of a harder red-weathering sandstone, which contains many fossils of ammonites. * * * South of Snake River is a range of hills whose highest points are 2,000 feet above the river. This range is built up of hard gray sandstone, very similar to the sandstone of the Snake River valley, only a little more indurated and approaching a quartzite.

The fossils collected in the sandstone of Snake River have been referred by Whiteaves to the Cretaceous period. The list of forms is: Panopœa or Pleuromya?, Thracia, Tellina?, Inoceramus, Desmoceras? possibly *D. affine* cf. *D. liardense* W.

Q-R 8–10. MACKENZIE BASIN.

Dawson [257d] refers to Richardson's observations on the lower Mackenzie and along the Arctic coast eastward, in accordance with which Cretaceous rocks are indicated in this region. McConnell [560c] made a reconnaissance of the Mackenzie and Porcupine basins, and regarding the area here in question says:

> The plains bordering the lower part of the Liard and the upper part of the Mackenzie rest on Devonian limestones and shales, and the Cretaceous rocks were not detected in descending the latter stream until the Dahadinni River, in latitude 64° north, was reached. They consist here of a couple of hundred feet of dark-gray shales and sandstones. They are exposed along the valley for 10 or 12 miles, and are then concealed by the bowlder clay, but probably continue under the latter as far as the Tertiary basin at the mouth of Bear River, a distance of 50 miles. The Cretaceous beds here occupy a depression between two high ranges of limestone mountains and can not have a greater width than 10 or 15 miles. They have been separated from the Cretaceous beds which form the western shores of Great Bear Lake by the elevation of the Mount Clark range.
>
> Forty miles below Bear River the Cretaceous beds reappear on the banks of the Mackenzie, and with the exception of one break of a couple of miles where they have been removed by

denudation, underlie the valley all the way to the Ramparts, a distance of 90 miles. The fossils obtained both from this area and from the one above Bear River consist of fragments of ammonites and Inocerami, too imperfect for specific determination.

A hundred and twenty miles below the Ramparts the Mackenzie enters a third Cretaceous area, and the largest one on the river. Cretaceous beds appear in the banks a short distance below old Fort Good Hope and extend down the Mackenzie to the head of its delta and westward across the Rocky Mountains and down the Porcupine to about longitude 139° west. They consist on the Mackenzie of coarse shales interstratified with some sandstones and fine-grained conglomerates; in the mountains of several thousand feet of barren sandstones and quartzites underlain by dark shales; and on the Porcupine of the same two series underlain by a great thickness of alternating shales, sandstones, and conglomerates, holding *Aucella mosquensis* var. *concentrica*. The intermediate dark shales are probably of Benton age, while the lower division, so far as the fossil evidence goes, represents the Queen Charlotte Island formation and the Dakota.

Cretaceous shales holding Aucella and passing upward into fine-grained conglomerates occur on the Yukon for many miles above and below the mouth of the Tatonduc and were traced by Ogilvie up the latter stream for some distance. They have been greatly disturbed and are folded up in broad bands with the underlying Paleozoic limestones.

These rocks are described in greater detail by Brooks and Kindle.[103]

The area of Cretaceous west of Great Bear Lake is briefly described by J. M. Bell.[64] The rocks are shales and sandstones which lie in nearly horizontal attitude. On Bear River the strata dip very gently downstream and consist of dark ferruginous and arenaceous shales overlain by thin-bedded and jointed sandstones. No fossils were collected and the correlation as Cretaceous depends on stratigraphic and lithologic comparison.

The paleontology of this area is discussed by F. B. Meek.[585]

R 5. NORTHERN ALASKA, ARCTIC SLOPE.

(See Chapter XIV, p. 636.)

R 22. WEST COAST OF GREENLAND.

The Nugsoak Peninsula and Disco Island, on the west coast of Greenland, present sections of late Lower Cretaceous and of Upper Cretaceous littoral strata. The coast of the Cretaceous sea was apparently not far from the present seacoast, the more easterly exposures of the sediments carrying plant fossils without marine remains and being coarse clastic rocks, whereas the strata farther west are marine clays. The latest account of these strata is that given by White and Schuchert,[902] whose conclusions are in part as follows:

The Cretaceous and Tertiary rocks in the region described lie everywhere unconformably upon a hilly basement of old crystallines, chiefly gneiss and diorite (Kærsut, Pagtorfik, Ekorfat), or upon early Cretaceous or pre-Cretaceous (?) basalts (Niakornat, Alinaitsunguak, Atanikerdluk). The greatest altitude of the sedimentary terranes is at Atanikerdluk, 3,400 feet above sea level. The old basalts are highly altered and usually occur as breccias (Niakornat, Alinaitsunguak).

The prevailing easterly dips of the Lower Cretaceous along the north side of Nugsoak Peninsula, in which the strata should dip westerly, since it is in that direction that the higher and younger beds appear, may be in part explained by fault compensation, as illustrated at Ujarartorsuak. A certain degree of irregularity of dip, the variable and often strong coastward dips as well as the low altitude of the Tertiary at its eastern border on the south side of the peninsula (Atanikerdluk), are probably due to inequality in the post-Tertiary epeirogenic movements

The sediments appear to have been derived from the east, since the light-colored sandstones and conglomerates are most abundant on that side of the sedimentary belt (Kock, Kæ sut), where marine fossils appear to be wanting. At one of the eastern localities (Ujarartorsuak) fresh-water shells occur with plants. To the west dark homogeneous shales with abundant remains of marine animals predominate.

Sedimentation appears to have been continuous in some portion of this region throughout Cretaceous and early Tertiary times, since no marked unconformities or unmistakable evidence of interruption of deposition have been seen. In certain sections, however, there appears to be, either in a variable thickness of the series or a slight difference of attitude, evidence of movements or erosion prior to the imposition of the Tertiary basalt cap, though these may be only local or of minor extent. But in many well-exposed sections there is no local trace of sedimentary discontinuity between the Mesozoic and Tertiary.

The entire thickness of the clastic deposits is probably over 3,500 feet. They are divided by Heer into four series, on the basis of their vegetable contents. Of the lowest of these, the Kome series, developed on the north coast of the peninsula, a thickness of probably not over 700 feet is exposed above tide. The discovery of additional dicotyledons in the Kome series, from which hitherto only *Populus primæva* was known and which was regarded as Urgonian in age by Heer, casts a serious doubt on the reference of those beds to so low a stage in the Lower Cretaceous. The flora as a whole is, however, to be compared with that of the Virginian Potomac formation, with some, perhaps the upper portion, of which the Kome series is probably synchronous.

The Atane series, hitherto not positively known on the north shore of Nugsuak Peninsula, is clearly present at Ujarartorsuak with characteristic Atane plants. Farther west, at Kook Angnertunek and Niakornat, the dark homogeneous shale series probably represents both the Atane and Patoot members of the Upper Cretaceous, since of the marine organisms found here some are identical with those occurring at Ata and Patoot, the typical localities for the two divisions of the Upper Cretaceous. The marine invertebrates from the Atane series, which Heer correlated by means of fossil plants with the Cenomanian of Europe, strongly indicate that the series is to be correlated with the Fort Pierre and Fox Hills or Montana formation of the western United States. Paleobotanically the Atane series is so closely related to the Vineyard series of Marthas Vineyard, the Amboy clays of the Raritan region of New Jersey, or the uppermost Potomac of Alabama as to furnish strong reason for the belief that the middle of Heer's groups is the Greenland contemporary of the Amboy clays. The Patoot series, which appears lithologically and stratigraphically to be inseparable from the Atane series, contains at the same time many plants common in the upper part of the Amboy clays, with others allied more closely to the higher Cretaceous floras, such as that of the Laramie. The Patoot series may perhaps be safely interpreted as constituting a paleontological as well as sedimentary transition from the Atane series to the Tertiary. The thickness of the Atane and Patoot series (Senonian) is not less than 1,300 feet and may considerably exceed this.

Chapter XVI.

EARLIER TERTIARY (EOCENE AND OLIGOCENE).

Color, orange and light orange, in ruling and dots, and orange brown.

Symbol, 5, 5a, 5b, 5b1, 5c, 5d.

Distribution: Throughout the Atlantic and Gulf Coastal Plain, Mississippi embayment, Central America, the West Indies, Jamaica, Colombia, and along the Pacific coast to Alaska; also in the interior western United States and Canada and in Greenland.

Content: Marine Eocene and Oligocene of Central America, the West Indies, and Pacific coast to Alaska (5), including the coal-bearing formations of Puget Sound (Puget group) and Alaska (Kenai formation); marine Eocene and Oligocene of the Atlantic and Gulf coast plains, the Mississippi embayment, Jamaica, and Greenland (5b and 5d); continental Eocene (Puerco, Fort Union, Wasatch, Green River, Bridger, and Uinta formations) of the Interior (5b1); continental Oligocene (White River group, including Chadron and Brule formations) of the Great Plains (5c); earliest Tertiary or latest Cretaceous of the Interior (Shoshone group, Denver and Arapahoe and equivalents in Colorado; "Upper Laramie," Lance formation, and "Ceratops beds" or "Somber beds," in Wyoming, Montana, and the Dakotas), Edmonton of Alberta, "Upper Laramie" of Canadian reports, and in Colombia the Guaduas or Cerro de Oro formation (5a).

Earlier Tertiary areas.

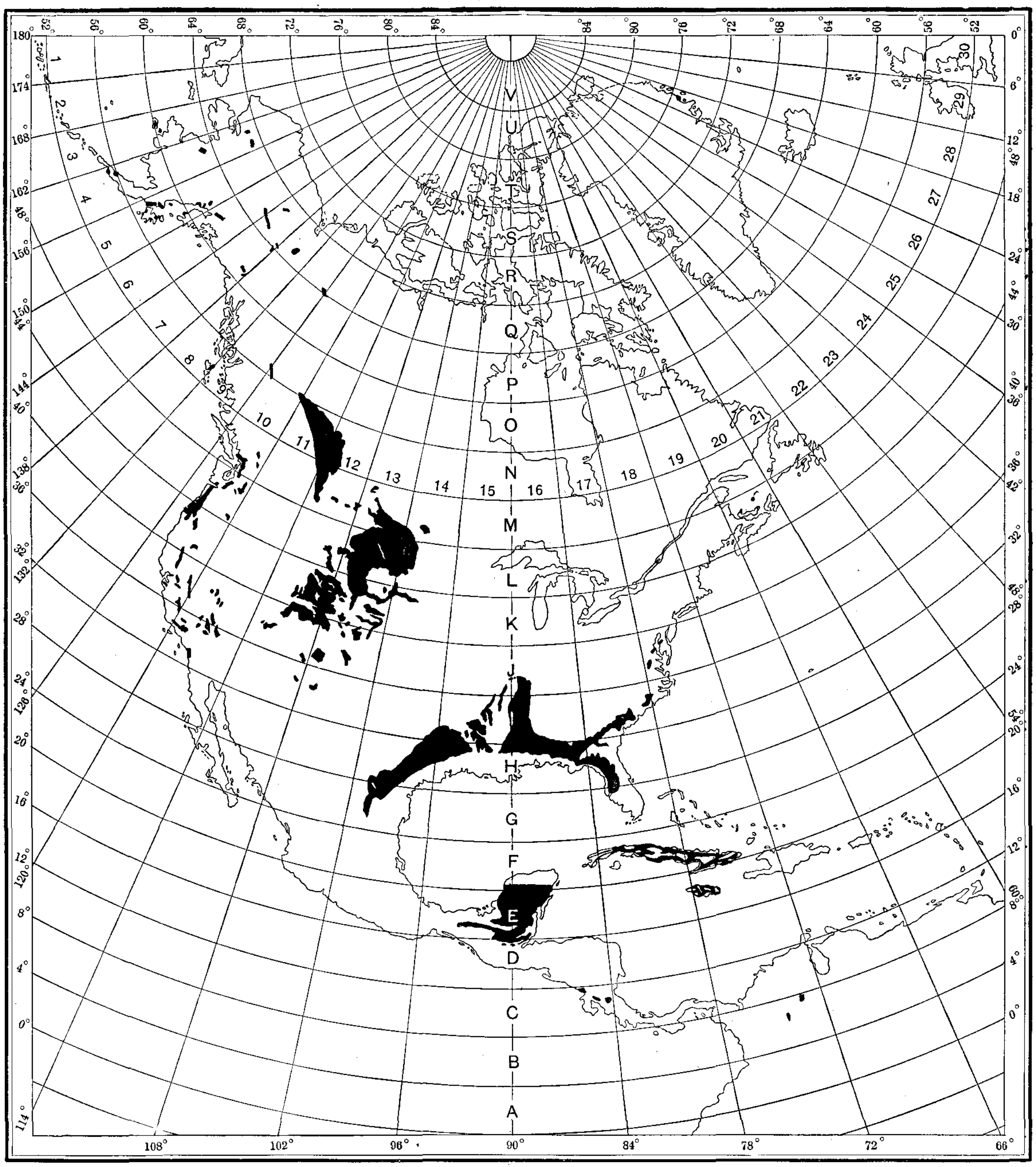

FIGURE 18.—Sketch map showing the distribution of earlier Tertiary rocks represented on the geologic map of North America and the key to references in the text. Eocene and Oligocene mapped separately where their extent is known.

B 18. COLOMBIA.

A formation which has been assigned with doubt to the Cretaceous or Tertiary is described by Hettner [437a] as the Guaduas formation of the Cordillera of Bogota. This was recognized by Sievers in the Cordillera de Merida in Venezuela and there entitled the Cerro de Oro series. It consists of bright-colored, especially red, yellow, or violet clays that contain particles of brown iron ore and interbedded layers of coarse sandstone which is mostly red or dirty white and which in places becomes conglomeratic. The lower portion of this formation or the upper part of the underlying Guadalupe (Upper Cretaceous) belongs to the coal-bearing strata of Colombia. No other fossils than imperfect remains of plants have been found with the coal. Karsten was of the opinion that this formation was unconformable upon the Guadalupe and therefore considered it to be Tertiary. Hettner, however, regards the unconformity as apparent rather than real, and as he could not find any sharp boundary between the two divisions, he doubted the Tertiary age of the Guaduas formation, thinking it more likely Cretaceous.

B–C 19. VENEZUELA.

Sievers,[741b] in describing the Cordillera de Merida, places provisionally in the early Tertiary a division which he calls the Cerro de Oro terrane. He says:

> In Tachira, as well as elsewhere in various places in the Cordillera, massive deposits of very varied constitution lie above the limestone of Albien age. In various places one may observe coal beds occurring between shaly calcareous and sandy formations, and in two places petroleum occurs in these deposits. It is probable that the thickness varies from place to place and that it may often be impossible to establish a particular sequence of strata, especially as the formation has undergone great tectonic disturbance. However, I had the good fortune to discover at least in one place a thickness of 800 meters in which the relations of this formation were clearly presented.

The section as measured by Sievers and given in great detail shows an alternation of thin sandstone, shale, and carbonaceous layers and is compared with the Caroni series of Wall in the Island of Trinidad. Sulphur occurs as a characteristic constituent of many of the sandstones.

Regarding the age of the formation, Sievers has no definite data, as he found no fossils. The Caroni series of Wall was placed in the Miocene on fossil evidence, and Sievers regards the Cerro de Oro terrane as probably equivalent to it. On the other hand, he is not sure that it should be separated from the Cretaceous, and in the absence of fossils its age remains undetermined.

C 16. NICARAGUA.

Hayes [427] states that the Tertiary rocks along the line of the proposed Nicaragua Canal are the oldest certainly known in that section and comprise two formations, the Brito and Machuca.

The [Brito] formation presents considerable variety in its lithological composition, but it has not yet been sufficiently studied to permit of its subdivision, even if this may be eventually possible. Much the larger mass of the formation consists of somewhat calcareous nonfissile shale. When fresh this is bluish gray and weathers to a yellowish or brownish color. Distributed through the shale are numerous beds of sandstone. These are also somewhat calcareous and doubtless contain a considerable proportion of volcanic ash. The sandstone beds vary in thickness from a few inches to 2 or 3 feet and occur singly or in groups. * * * These sandstones, like the shales, are blue when entirely fresh but are always weathered at the surface to some shade of yellow or brown. * * * They occur most abundantly near the Pacific coast and are well exposed in the headland northwest of the Rio Grande Valley at Brito. The beds here have a general though somewhat variable dip to the southwest, hence the higher portions of the formation make the cliffs along the Pacific. This seems also to be its most variable portion. In addition to the shales, which constitute its greatest bulk to the eastward, it here contains also beds of sandstone, conglomerate, and coarse breccia on the one hand, and on the other marly beds and lenses of pure limestone. Forming a part of the headland south of Brito is a bed of limestone something over a hundred feet in thickness. Small outcrops of this bed, or one very similar, have been noted at several other localities to the eastward in the Divide Hills. Its limited extent is due in part to erosion, since the dip of the bed would carry it above the tops of most of the hills to the eastward, but it is doubtful if its original extension was very great. Several of the limestone outcrops noted are probably small lenses in the shale and not connected with the more continuous bed at Brito. A portion of this limestone has a peculiar concretionary structure, some of the concretions attaining a diameter of an inch and a half, while other portions of the bed are oolitic. Immediately west of this exposure of limestone, forming a group of islets nearly covered by high tide, is a very coarse volcanic conglomerate or breccia. The larger fragments are a foot or more in diameter and quite angular, and from this extreme they grade downward to small pebbles, some of which are well rounded. The present relations indicate that the conglomerate is the stratigraphical equivalent of the limestone, replacing it within a few yards. In some places the two rocks are seen to merge, the limestone containing numerous angular fragments of volcanic rock. At other points along the coast both north and south of Brito, similar conglomerates occur. Their bedding is extremely irregular, and they afford evidence of having been formed rapidly and near the source from which their constituents were derived. While it is possible that the source of this material may have been to the eastward, it seems much more likely that it came from volcanic vents to the southwest, from volcanoes which have been entirely removed by the waves of the Pacific. * * *

The exposures of the Brito formation are so infrequent and the dips are so variable that no satisfactory measure of the thickness of the formation can be obtained. Taking the observed dips between the Pacific coast and the lake shore the thickness exposed is estimated at about 10,000 feet. This of course is not the total thickness of the formation, since the bottom is not exposed at the axis of the anticline. Also the formation has undoubtedly suffered an unknown but considerable diminution in thickness by erosion, and there are no data for determining the thickness of strata which have been removed from the highest beds now observed. * * *

The greater part of the Brito formation is apparently barren of organic remains. The only locations at which fossils have been found are on or near the Pacific coast. This, however, may be due to the fact that the rock exposures are not elsewhere of such a character as to facilitate the discovery of fossils, and the latter may possibly be more generally distributed than present knowledge would indicate. The fossils are confined almost wholly to the limestones and marly beds. They consist of corals, molluscans and foraminiferal remains. The latter are especially abundant. The rather meager collections have been submitted to Dr. Dall for determination. He pronounces them Oligocene and probably identical with the foraminiferal beds described by Hill from the Caribbean coast at Panama. One of the most abundant forms is a small nummulite, *Orbitoides*, probably *forbesei*, which is characteristic of the lower Oligocene. The molluscan remains were collected on the Pacific coast about 75 miles northwest of Brito in what was supposed to be a higher portion of the same formation. Dr. Dall states that these have the upper Oligocene aspect, though there are not enough of them to be conclusive. He thus confirms the view entertained in the field that successively higher beds in the Brito formation are exposed along the coast toward the northwest.

In addition to the fossils on which is based the above conclusion concerning the age of the Brito formation, it also contains rather abundant plant remains. They are in the form of driftwood and coal, and as yet no remains sufficiently well preserved for identification have been discovered. Associated with the coarser sandstones are numerous blocks of wood, whose rounded forms suggest that they are fragments of drift which were incorporated with the sand and gravel while it was accumulating. In some cases they still contain a large proportion of their original carbon, and in others this has been more or less perfectly replaced by silica or iron pyrites. The coal occurs associated with the finer sediments, and although a careful search was made, the thickest seam observed was under half an inch. While sufficient carbonaceous matter is sometimes disseminated through the shales to give them a black color, no indications were found pointing to the existence of workable coal deposits in the region examined.

Coal in workable quantity has been reported from the region southwest of the lake, between the lake shore and the Costa Rican volcanoes. The exact locality is on the Rio Hacienda, 12 miles from its mouth. It was not visited and no samples of the coal were seen, so that the report lacks verification. There appears to be no reason, however, why conditions favorable for coal accumulation should not have prevailed in some portions of this region during the deposition of the Brito beds. * * *

[The Machuca formation] appears to consist chiefly of calcareous shales with which sandstones are interbedded. The constituents of the rocks are largely igneous in their origin, but there are no coarse conglomerates or breccias such as occur in the Brito. Also no pure limestones or distinctly marly beds have been discovered, although the examination of the formation has not been sufficiently exhaustive to enable one to say that such beds do not occur. * * *

No fossils have as yet been found in the Machuca formation which are sufficiently well preserved for specific determination. At Cruzita, 1 mile below Machuca, the core from the diamond-drill hole in the bed of the river contains numerous indistinct organic forms. The rock is described by Dr. Ransome as an andesitic tuff containing fragments of limestone. The organic forms are revealed by the weathering of the rock with the removal of the soluble limestone, and they are also shown in the thin section under the microscope. While they can not be identified, they strongly suggest the forms which occur so abundantly in portions of the Brito formation. The beds in which they occur are evidently derived in large part from fresh volcanic tuff, though the latter was not so abundant as to prevent the growth of organisms in the sea in which it was being deposited. In the absence of conclusive fossil evidence, therefore, the age of the Machuca formation, so far as it may be determined, rests upon other and less satisfactory evidence. It is believed to be nearly or quite contemporaneous with the Brito formation—that is, Oligocene (Tertiary). The grounds on which this conclusion is based are briefly as follows: (1) There is a general similarity in lithologic composition and appearance between the two formations. (2) Both have suffered about the same amount of deformation, elevation, and erosion since they were deposited. The value of this fact for correlation depends upon the proximity of the areas which they occupy and the evidence that the recent geologic conditions have been similar in both. (3) Both formations bear about the same relation to a group of igneous rocks which was in part contemporary with them and in part subsequently invaded their beds. The differences in composition of these intrusive rocks are not greater than differences in igneous rocks within the same area which are known to be nearly or quite contemporaneous. (4) Finally, as pointed out above, it is possible and even probable that the two formations are nearly or quite continuous through the southern part of the upper San Juan Valley.

C 17. PANAMA.

Howe [465] states, in a report on the geology of the Canal Zone:

The central portion of the isthmus along the canal line consists of rocks of igneous origin. They are the oldest rocks of the region and have been observed at the surface in the central area, between Mamei and Empire and northeast of the city of Panama. Diamond-drill borings have indicated their presence also at other points, and it is believed that they underlie at greater or less depth the whole territory included in the Canal Zone.

To the northwest younger rocks of sedimentary origin occur, resting on the older igneous mass and gently inclined toward the Caribbean Sea, so that in passing from the interior toward Colon successively younger beds are encountered. Their well-defined stratification and the abundant fossil remains of marine organisms indicate that these rocks were formed by the deposition of gravel, sand, and mud on the sea bottom, or in tidal estuaries where the materials gradually hardened into rock. Nearly the same conditions prevail on the Pacific side, where, in addition to the older igneous and sedimentary rocks, younger igneous rocks occur.

Dikes and large crosscutting masses of a basaltic nature have invaded all of the older sedimentary rocks; they occur in greatest abundance in the central and southern parts of the Zone and are believed to represent the last phase of active volcanism in the neighborhood.

From its very characteristic occurrence in the vicinity of Obispo, this name has been given to the formation about to be described that occupies a large part of the central region and consists of andesitic breccias and associated lava flows. * * *

The Obispo breccias, which are believed to constitute a large part of the formation, are of variable texture, usually being composed of angular fragments an inch or more in diameter. No evidence was found that they were laid down or sorted by the action of running water. The fragments consist of andesite of a variety of textures and show slight differences in composition. The majority of the fragments appear to consist of pyroxene andesite, although a fair percentage of hornblende andesites are present. The color of the breccia on fresh exposures is a dark blue or green. The rock near the surface has been altered to a red clay.

At a few places, notably in the vicinity of Empire, lava flows of massive andesite were found associated with the breccias. The actual relation of the flows to the breccias is not clearly shown, but it is believed that they were contemporaneous and that quiet outpourings of lava alternated with the explosive eruptions that produced the breccias. The massive rock is of essentially the same composition as that composing many of the fragments in the breccias, but in most cases is too far decomposed to admit of exact determinations. * * *

Judging from the extremely unconformable relations that exist between the Obispo formation and the younger rocks, it seems clear that following the eruption of the breccias the region was thoroughly dissected by the erosive action of streams. The interval between the close of the andesitic eruptions and the beginning of the next recorded epoch was of unknown extent, and the original surfaces of the Obispo rocks were completely obliterated before the next succeeding formation—the Bohio—was deposited. * * *

Probably the oldest sedimentary formation represented in the Zone is that which has its most characteristic outcrops in the vicinity of Bohio.

Near the railroad station is a cliff, from which building stone has been quarried and which rises 50 feet or so from the level of the flat on which the town is built. The rock here is of a very even texture and at first glance strongly suggests a fine-grained volcanic breccia. It is of a peculiar brownish color, unlike that of the Obispo breccia; the fragments are apparently angular and usually less than 1 inch in diameter. One of the most striking features of this rock, shown in deep borings as well as at surface outcrops, is its alteration; it mashes under a blow of the hammer and yet has not the appearance of being greatly decomposed, except at or very near the surface. The alteration seems to have been to serpentine or some related mineral instead of kaolin, as is usually the case with the other rocks, especially those of the Obispo formation.

Across the river, at the old lock site south of Bohio and east of Pena Blanca, quite a different phase of this formation is exposed; it consists of alternating layers of sandstones and coarse conglomerates all clearly water transported and deposited. Many of the bowlders are a foot or more in diameter; they are of andesites for the most part, but not a few are of a lighter-colored porphyritic rock with abundant hornblende crystals. The finer layers and the cementing material are very like the rock occurring at the Bohio quarries. Cross-bedding is common and fine material often occurs in lenses in the grits and conglomerates. The prevailing strike is N. 25° E., and the dip to the northwest at an angle of about 14°.

The identity of these conglomerates and the more even-textured breccia-like rock is not at all evident in the field, but many borings made in the vicinity show a gradual transition southward from the even-textured breccias of Bohio to the conglomeratic facies at Pena Blanca.

The boring made at kilometer 24 (hole 24–b) is of interest, since it shows carbonaceous sandstones in the middle part and fossils in the lower part of the core.

Further study of this formation to the southeast and by means of borings has shown that it is of variable character, in some places clearly sedimentary and water sorted, both fine grained and conglomeratic; in other places the appearance is more that of a volcanic breccia, possibly water-laid but not water transported. * * *

In general the formation may be described as a probable fluviatile deposit characterized by sudden changes and transitions, the composition of the materials being fairly uniform. It is not improbable that volcanic eruptions may have been taking place during the period in which the formation was deposited and the material forming the breccia-like portion attributed directly to such a source.

The fossils previously referred to that were found in the core taken from hole 24–b occur at elevations of from 30 to 40 feet below sea level. They include, in addition to vegetable matter, certain fossils indicating probable Eocene age. At about 2 miles to the west, at a locality known as Vamos Vamos, on the left bank of the French canal, are outcrops of a limy shale with large calcareous concretions resembling bowlders in a conglomerate; both the shale and concretions contain numerous fossils which Dr. William H. Dall regards as of undoubted Eocene age. Outcrops of similar rock containing the same fossils occur about 6 miles to the northwest on the left bank of the canal in the vicinity of Gatun.

The rocks at Vamos Vamos and in the vicinity of Gatun are finer grained than those of the Bohio formation and consist of shales and fine sandstones.

The fossil evidence shows with certainty that the beds near Gatun and at Vamos Vamos and Bohio are of the same age, and it is believed that they are to be regarded strictly as part of one formation, the occurrence at Bohio representing a littoral facies, while those farther to the northwest were deposited in deeper water.

In the excavations made by the French between Bohio and Pena Blanca, and also at the base of a little hill at the west end of the village of Bohio, there are outcrops of a white calcareous sandstone or marl containing some volcanic material in the form of crystals of feldspar and fine specks of a ferromagnesian mineral. In places it is extremely rich in the remains of Foraminifera, especially *Orbitoides fortisi,* and may seem to consist altogether of the shells of these minute organisms. * * *

The Foraminifera of the Pena Blanca rocks, and especially the species *Orbitoides fortisi,* are characteristic of the Lower Oligocene. From their position between two well-determined occurrences of Eocene rocks it is believed that they are clearly younger than the Bohio formation and rest upon these rocks unconformably.

Directly above a conglomerate that occurs near the railroad station at Gatun is a brownish impure calcareous clay or argillaceous sandstone, apparently containing much débris of volcanic rocks and numerous fragments of shells. Many perfect fossils are to be found, but the extremely crumbling nature of the rock makes it almost impossible to obtain good specimens. Such as were collected have been determined by Dr. Dall as of probable Oligocene age and newer than the foraminiferal beds of Pena Blanca, and the rocks are to be regarded as near the base of the succeeding Oligocene formations that occur at numerous places between Gatun and the bay, notably at the Mindi Hills and at the Monkey Hills.

The conglomerate under these sandstones contains many fossils that are the same as those of the Bohio and Vamos Vamos beds, but it is believed that the conglomerate represents the base of the Gatun formation and that the Eocene fossils present were derived from the older rocks and so do not indicate the true age of the conglomerate.

Soft sandstones of a dirty greenish-gray color, derived from igneous rocks with a calcareous and clayey cement, are the most abundant rocks of the Gatun formation. Associated with them are shales, impure marls, greensands, and, at certain horizons, fine white tuffs composed of pumice, probably of the composition of a rhyolite. * * * The rocks are all well consolidated, though in a few rare cases sandy layers are found which crumble on exposure to the air. These are the beds that have been referred to frequently as "indurated clays." The term is a misleading one, since true clays make up but a small part of the formation. Induration is a term applied to the process by which sandstones or argillaceous rocks are converted into quartzites or slates by heat or mineralized solutions accompanying the intrusion of igneous rocks. None of these conditions existed in the vicinity of Gatun. The rocks are of sedimentary origin and were deposited on the sea bottom at some distance from the shore in the form of sands and clays. Their subsequent hardening into rock is the result of simple cementation by calcareous solutions contained in the sea water and through pressure. Certain beds are harder than others, since the nature of their constituents favored more complete consolidation. The beds, however, are not to be regarded as unconsolidated. They are all "rock," though in some instances soft enough to be loosened with a pick.

These beds extend northward with little change in lithologic character to the Monkey Hills in the vicinity of Colon. Fossils collected in the more northerly localities indicate that the beds in this region are still younger than those at Gatun. No sharp breaks have been observed, however, and it is believed that practically continuous sedimentation took place from the time the Gatun beds were deposited until the close of later sedimentation.

The rocks belonging to the Culebra formation have been exposed by excavation from Las Cascadas to Pedro Miguel along the line of the canal, the best exposures being in the vicinity of Culebra.

The formation consists of a series of soft shales, with sandy, conglomeratic, and calcareous layers abundant. Limestones, as at Empire, Las Cascadas, and in the railroad cut between these two places, are also indicated at several points by borings. Of these the occurrences at Empire (Camacho) are undoubtedly the most massive, the others being present apparently as lenses in the shales and sandstones. Although some thick beds of very homogeneous pure clay shales occur, most of the formation is richly carbonaceous, and at a number of places in the cut lenslike seams of lignite have been found and remains of trees and plants are abundant.

The age of the Culebra formation can not be fixed with absolute certainty. Fossils collected at a number of points between Las Cascadas and Pedro Miguel were not sufficiently characteristic to determine the age of the beds, but at the lock site at Pedro Miguel collections were made at two points less than 100 yards apart that supply more definite information. The fossils from the more northerly point, 30 feet vertically above the other horizon, are regarded by Dall as representing the Oligocene, probably a reef deposit. The material from the lower and more southerly locality is pronounced Eocene by Dall. From the prevailing southerly dip of the beds in the region the fossils from the two localities were believed in the field to belong to the same horizon. The lack of continuous outcrops, however, makes it impossible to assert positively that this is so. The only fossils collected by Hill from the Culebra formation came from the Empire limestone. Only the foraminiferal portion seems to have been determined, and these are regarded by Bagg as probably Eocene. The fossiliferous beds near Pedro Miguel are undoubtedly at or very near the top of the formation, since the dip carries them below the surface a short distance to the south, and borings at kilometer 59, slightly to the north, show the usual Culebra formation extending to an unknown depth below. The Eocene and Oligocene ages of the beds at the two localities at Pedro Miguel seem certain. In any event there can be little doubt of the Eocene age of the Culebra formation as a whole and its probable correlation with the Bohio and Vamos Vamos beds. The occurrence of an Oligocene fauna directly above the characteristic Eocene at Pedro Miguel is comparable to the sudden change that takes place at Gatun from the Eocene of the Vamos Vamos beds to the Oligocene of the Gatun formation.

The thickness of the Culebra formation has been variously estimated at from 400 to 500 feet. A boring made at kilometer 55 of the canal (hole 31) extends 40 feet below sea level, starting at 167 feet above the sea; 207 feet of Culebra beds are here indicated, while possibly 175 feet might be added as representing the part already excavated at the cut, giving a thickness of nearly 400 feet, with the bottom not yet shown.

C 20. TRINIDAD.

Wall and Sawkins [863b] distinguished the Newer Parian group in Trinidad as Tertiary and recognized five divisions. They say:

The Newer Parian group comprises a considerable succession of limestones, calcareous sands, shales, loose ferruginous sands, conglomerates, clays, and marls, which seem sufficiently related to one another by fossiliferous contents to form one group, of which the organic remains present a certain analogy with the Miocene fauna.

For distinct classification, five divisions or series are admitted, in naming which the same principle of locality already employed, and so convenient in provisional nomenclature, will be again adopted. These divisions are—

A. The Nariva series.
B. The Naparima marl.
C. The Tamana or calcareous series.
D. The Caroni or carbonaceous series.
E. The Moruga or arenaceous series.

The Nariva series consists of clays, with shales and extremely rare yellowish limestones, and forms the substrata to the well-known red soils. * * * The strata are traversed by bands of highly ferruginous matter parallel with the stratification.

The geological importance of these beds is very subordinate; they possess, probably, but a slight thickness and seem to constitute merely the inferior portion of the following division. Their relations to the Older Parian group were not ascertained, and generally, from the absence of proper sections, but little information has been obtained respecting this series. * * *

The Naparima marl includes a series of strata composed of marls, conglomerates, and calcareous sand.

The mineral matter of these marls is in a state of fine division and varies from a basis of clay, with 10 to 50 per cent of carbonate of lime, to a basis of siliceous substance, consisting of the shields of Infusoriæ, and an average content of 20 per cent carbonate of lime. The clay marl contains sometimes a much smaller proportion of Infusoriæ.

There is generally a small proportion of carbonate of magnesia, and in some cases even 30 per cent, almost sufficient to combine with the carbonate of lime to form true dolomite. * * * These strata have usually a highly conchoidal fracture, especially the more argillaceous marls.

The conglomerates are formed of rounded pebbles of indurated sandstone, and varieties of jasper from the Older Parian, with cement. They do not exceed 8 or 10 feet thick and are sometimes bounded by sands containing shelly fragments and a variety of calcareous matter.

Limestones occur interstratified in the marl, in rather thin beds, and of oolitic or even subcrystalline texture. Corals are of common occurrence, especially a species of Orbicella. * * *

The Tamana calcareous series consists of the massive limestone of Tamana, L'Ebranche, and Montserrat, which varies from white to yellow in color and from granular to crystalline in texture. These strata have experienced a very complete change of structure, the particles being entirely rearranged, which is most beautifully exemplified in the obliteration of the fossil corals, whose exterior surfaces are well preserved, but toward the interior all organized texture gradually fades into the crystalline mass.

This is the most definite stratum of the whole island, and can be traced, with only two or three interruptions, from near the western to the eastern coasts. There is only one common coral (a species of Orbicella) which also occurs in the limestones of the Naparima marl. The stratification being usually obliterated, the dip can be but rarely determined and is always found to be to the northwest, at an angle varying from 30° to 70°. The thickness can not be less than several hundred feet.

The beds of conglomerate are composed partly of rounded pebbles of indurated sandstone and jasperized clays from the Older Parian, and partly of quartzose detrital from the northern hills (Caribbean group). The cementing matter is ferruginous, calcareous, or siliceous. These conglomerates are generally highly consolidated.

Calcareous sand and sandstone form a marked feature in this succession of strata. The former are loose, with a certain, usually small admixture of calcareous, often shelly matter, and occasionally traversed by layers of hard calcareous sandstone. The latter consist of grains of sand, with calcareous cement, which is frequently fine organic débris or larger shelly fragments, and form hard beds of a few inches to 20 or 30 feet in thickness. Both these varieties of strata contain abundance of marine shells and have supplied the larger proportion of the animal fossils collected in the island.

The remaining strata of the series consist of sands and clays, more or less fossiliferous, but not consolidated.

The sequence of strata is exposed in the cliffs at Manzanilla. The thickness, including the crystalline limestone, may be about 2,000 feet. * * *

The crystalline limestone seems to form one of the lowest members, over which are calcareous sandstones, conglomerates, and calcareous sand, above which are fossiliferous clays and sands. * * *

The Caroni or carbonaceous series is exposed in a complete section in the cliffs between Manzanilla and the Oropuche. Two divisions may be introduced—the lower or noncarbonaceous and the upper or carbonaceous. The former consists of shales, generally dark gray; dark, often black fossiliferous clays; a few thin beds of sand, frequently sulphurous, and associated with a small number of pebbles from the Caribbean and Older Parian groups; and in the upper part of highly laminated but unfossiliferous hard calcareous sandstone. The superior division contains strata composed of sand, with small pebbles of the usual varieties, shelly fragments, and calcareous cementing matter. The rock of Point Noir is an illustration of this.

Of shales there are all varieties, from light-colored to dark carbonaceous. The clays are frequently carbonaceous and sulphurous.

Beds of massive yellow but pulverulent sand generally overlie the larger seams of coal, with only a few feet of shale intervening.

Subordinate layers of calcareous sandstone, usually only a few inches thick, occur in places. The seams of Tertiary coal associated with the preceding strata form an important item. They are numerous and vary from a mere carbonaceous film to over 4½ feet in thickness. * * *

The lower strata of the upper division contains shells similar to those at Manzanilla, but the superior beds are characterized by large shells, which are believed to be confined to that portion of the series. A few dicotyledonous leaves occur in the nodules of calcareous sand or clay. * * *

The Moruga or arenaceous series is an extensive series of strata, usually of a loose sandy nature. These are well exposed in cliffs all along the southern shore and offer some characteristics quite peculiar to themselves and others which are possessed in common with the Caroni division. Thick strata of massive sand, generally loose and pulverulent, are the most prevalent beds, and, indeed, sand may be said to be in great excess. Granular sulphur is very generally disseminated in these strata, having been observed from Canary round Point Icaque to Oropuche. Shales are also numerous, but clays of rarer occurrence.

Calcareous sandstone is extensively diffused in beds not exceeding 6 to 8 feet thick, and often only a few inches, and, being very hard, resists the destructive action of the sea, running out in parallel lines on the beach often beyond low water, and forming quite a characteristic feature of this line of coast. The cementing calcareous matter seems to have been comminuted organic detritus, but in some cases the original nature of the deposit was fossiliferous sand, the indistinct impressions of the shells remaining, but their calcareous substance being entirely removed and reprecipitated as cementing matter round the grains of sand, thus binding the whole into one compact mass. * * *

Layers of carbonaceous matter occur, but by no means so commonly as in the Caroni series. The vegetable structure is usually very distinct, but occasionally obliterated. The principal seam of lignitic shale is near Point Moruga. It occupies a vertical position and is 20 feet wide, containing several layers of lignite not exceeding 10 inches but much inclined to be bunchy. These carboniferous beds are all more or less mixed with shaly matter, rendering them impure. At Erin and Irois the beds of lignite are less inclinded and the ligneous texture still more apparent.

Strata which will be named porcellanite occur especially at Erin, Points Cedros and Rouge, part of Point Brea, to a small extent at Moruga, and adjacent to the large seam of coal at Punta Paloma (Caroni series). By the above term it is intended to imply strata of semi to perfectly indurated and compact structure, presenting a great variety of colors, among which brick-red is predominant. They are fissured and jointed into almost cubical masses, these joints being frequently lined with vesicular slag. An alternation of colors in thin laminæ frequently prevails. Some specimens are semivitrified, forming porcelain jaspers, and the fracture is frequently conchoidal.

The peculiarities of these strata are most fully developed in the central portion, diminishing in intensity upward and downward, and finally graduating into the adjacent shales or sands. The thickness has not been noticed over 70 to 80 feet.

This structure has been induced by the heat developed in the combustion of carbonaceous matter, for not only are there remnants of the original stratum with its unconsumed carbon, but this porcellanite is identically the same with the substances produced immediately above or below seams of coal which have accidentally taken fire and burnt for a length of time. The unconsumed portions are associated with granules of sulphur. Perhaps the decomposition of pyrites (extensively disseminated in this series) generated sufficient heat to occasion the ignition of the carbonaceous matter of the seams of lignite, and the cracks or fissures might permit so much air to penetrate as would support a slow combustion. That this combustion originated within the altered portions is evident from the circumstance of the adjacent lignitic beds being unaffected, which could not have been the case had the heat been transmitted from below. * * *

Natural asphalt, a well-known product of Trinidad, is extensively disseminated in this series. * * *

No sections sufficiently extensive occur from which to deduce any very positive order of succession; as far as could be ascertained, there seemed to be a great repetition of sands and shales of very similar characters.

The data for estimating the thickness are very uncertain; conclusions founded on the inclined positions give at least 3,000 to 4,000 feet.

E 17-18. JAMAICA.

Hill's classification of the rocks of Jamaica is given in Chapter XV (pp. 639-642). From his account [443b] we take the following description of the deposits assigned to the early Tertiary:

The Richmond beds constitute the upper subdivision of the Blue Mountain series. Their arrangement and composition, consisting of shallow marine deposits of worked-over and water-assorted terrigenous material, indicate a succession of more quiet sedimental conditions than those which marked the preceding epoch.

The rocks are mostly black bituminous laminated clays and ferruginous sandstones with occasional beds of loose conglomerate. They occur in uniform alternations of thin, regular, and evenly bedded strata, varying from an inch to a foot or more in thickness. They are dull blue-black on fresh exposure, but undergo excessive oxidation and hence are ordinarily of dark-brown ferruginous colors. In general texture, arrangement, color, and stratification they resemble the Eo-Lignitic (lower Eocene) beds of the southern United States. The clays contain many small flakes of carbonized vegetal matter, and silicified wood has been found in the gravel. The gravel is mostly derived from the antecedent beds of the lower division of the Blue Mountain series. The so-called "sandstones" are composed of cemented grains of waterworn hornblende andesite derived from the underlying igneous rocks, and the shales are the same material more finely triturated and mixed with vegetal matter. The conglomerates consist of rounded pebbles of various dimensions and in places attain a thickness of 50 feet. They are almost entirely of the same material as those of the lower subdivision. Rounded fragments of the Rudistean limestone also occur in them. * * * In addition to these rocks of the conglomerate, former observers have noted, from the bluff at Port Maria, specimens of gneiss and crytalline slates, "rocks of which no trace either in situ or otherwise have hitherto been found in Jamaica; also a fine-grained granite to which nothing analogous has been noted on the island. * * * In this unique collection are many instances of rocks which have totally disappeared from the surface of Jamaica but which must have existed during former epochs, either in the formations of this country or in adjacent lands that have been destroyed." [a]

At the same locality, as also noted in the Jamaican reports,[a] the ordinary sandstone is rapidly transformed in its seaward extension into a promiscuous assemblage of large pebbles 6 or 8 inches in diameter. This fact indicates that some of this material came from the area to the north, now occupied by the sea. In this same bed of conglomerate were found the Eocene corals described by Duncan, and a few species of mollusks. * * *

The Richmond formation outcrops in many places a short distance back of the sea along the north coasts of the parishes of St. Ann and Trelawney. It is well exposed beneath the Cambridge beds south of Cambridge, along the highway on the west side of Great River, as seen by the writer. It also occurs on the south side of the Blue Mountain Ridge in St. Andrews and St. Thomas. According to Sawkins, in the latter parish at Blue Mountain Valley it consists of "alternate bands of red clay, yellow sandstone, and light-gray shales, 1,000 to 1,200 feet in thickness."

In general, this formation underlies nearly all the later rocks, and, in our opinion, prior to the Montpelier subsidence it occupied an area as large or larger than that of the island of to-day.

From data presented in the paleontological chapter of this work the age of these beds is undoubtedly old Eocene, although it is impossible to draw an exact line between these beds and those of the lower division which we have termed Cretaceous, and they are no doubt stratigraphically continuous.

The uniform alternations of the Richmond beds indicate that they were rapidly deposited over a considerable shallow area of deposition; since much of this area was the present locus

[a] Jamaican Reports, p. 130. (Entitled "Reports on the geology of Jamaica, or Part II of the West Indian Survey," by James G. Sawkins, with contributions by others.)

of the island, it is difficult to infer the situation of the near-by land from which the material was derived; some of it may have come from the old nucleus of Blue Mountain Ridge, but in our opinion this was not of sufficient size to afford all the material. These facts, together with the presence of foreign material, are at least strongly suggestive of the occurrence of land areas during this epoch, concerning the locality of which present knowledge is wholly wanting.

The Cambridge formation is named after the typical locality of its occurrence at Cambridge, between Ipswich and Montpelier, in the parish of St. James, in the northwestern portion of the island, near the junction of the boundaries of St. James, Hanover, and Westmoreland.

In places the Richmond beds grade up into irregular alternations of impure clay, marls, and yellow limestones, which, in general, occupy a transitional position between the obviously land-derived beds of the Blue Mountain series and the ocean-derived limestones of the Oceanic series. Argillaceous calcareous marls appear in the upper part of the Richmond beds, become successively more and more frequent, and finally dominate. These are accompanied by thin beds of impure blue limestone of a segregational character, oxidizing yellow on weathering and alternating with the marls which gradually increase in thickness and relative proportion until they preponderate. Finally these yellow limestones become more purely calcareous in ascending series as the sediments become clearer and freer from land-derived material, until they finally pass into the purer White limestones.

As he was not able to correlate certain divisions of the Cambridge formation precisely with one another, Hill distinguished them under the names of Catadupa and Chapelton beds. After describing these different occurrences, he continues:[443c]

There are several paleontologic. and stratigraphic features of the Cambridge beds which are peculiar and will require more extensive field work for final explanation. We have reason to believe that the beds are not connected but occur in broken patches, which, at least in their lower portion, like the Cretaceous beds, represent sporadic colonies of lime-making organisms, which found temporary foothold at intervals during a period of turbulent deposition generally unfavorable to a large development of marginal life. These deductions are based upon the fact that in no two localities are the sequence of sediments or association of species identical, while in others the beds do not appear between the Richmond and the Montpelier. Furthermore, the fossiliferous horizons of the Lower Cambridge are so like some of the Cretaceous that the one has been frequently mistaken for the other. The mixture of Cretaceous Rudistes and Eocene corals and Mollusca at Catadupa, as seen by us, and of Orbitoides and Rudistes in Portland, as noted by Barrett, indicates a transgression of Cretaceous life into the Eocene and further denotes the anomalous nature of this formation.

These beds, while showing sedimentary relations to the Richmond, undoubtedly represent a transitional step in the deepening which later produced the Montpelier formation. In some places it seems perfectly conformable beneath the latter, while again, as shown by Brown and seen in several places by us, they are unconformable. These apparently irreconcilable conditions can probably be explained upon the hypothesis that the island was undergoing subsidence during the Cambridge epoch, although parts of it were then dry land, which was still further covered by the Montpelier beds during the succeeding epoch. As shown in another chapter, the age of these beds, although containing a remarkable mixture of Cretaceous and Tertiary fossils, is undoubtedly Eocene, and with the Richmond beds they constitute the Eocene system in Jamaica.

Of the White limestones, Hill distinguished two series, the Oceanic and Coast series. He says:[443d]

The transitional Cambridge beds grade up into rocks of organic oceanic origin. These are the White limestone formation of the official Jamaican reports. They have no genetic relationship with the rocks of the Blue Mountain series and differ from them in every physical and chemical aspect.

The interpretation of the white limestones has been one of the greatest problems of Jamaican geology. There have been so many diverse opinions concerning their age and sequence that it is almost impossible to obtain from current literature any approximation of their true relations and significance. The difficulties can be readily seen by any one who reads the conflicting and apparently involved conclusions in the Jamaican reports. The fragmentary descriptions of their local occurrence are frequently well written, but through lack of correlation and erroneous deduction they fail to clear up the sequence and age of the beds. * * *

The truth is, the white limestones of the Jamaican sequence represent several distinct formations and ages, from Vicksburg to recent inclusive, but that the greater portion of it, as I shall show, is of old Oligocene age. There are even some white limestones in the Cretaceous in Clarendon which are almost lithologically indistinguishable from those of the Tertiary. In recent years English geologists have observed the discrepancies of previous interpretations of the white limestone and suggested, from specimens of the material sent them, that at least an upper and lower division might be distinguished. Our investigations will show that not two but several subdivisions can be made, and that the rocks hitherto classified under this general head really belong to several distinct formations of two great series, the Oceanic and the Coastal, the former constituting most of the rocks of this character and occupying large areas of the interior upland, while the latter are confined to a narrow belt along the coast.

The older white limestone formations, constituting the greater mass of these rocks, are found in the upland area of the island and are all of Tertiary age. More exactly speaking, they are of the Vicksburg stage, which is placed in the Eocene by some writers and in the Oligocene by others. The later white limestone formations—including the Coast limestone of the Jamaican reports, which we shall describe as the Falmouth formation, and the Hospital Point limestone of Montego Bay—are of Pliocene, Pleistocene, and recent age.

There has also been much vagueness concerning the origin of these rocks, accompanied by an opinion on the part of many that they are of coral-reef origin. * * *

Not the least important result of our researches will be a demonstration that the larger thicknesses of these limestones are neither of molluscan, coralline, or reef-rock origin, but are foraminiferal oceanic deposits and other offshore calcareous oceanic muds composed of organic detritus laid down at depths below that at which reef rocks were formed and in periods of eologic time prior to the appearance of the modern reef-building species in the sequence. * * *

The upland white limestones or Oceanic series, as we shall call the Tertiary formations under discussion to distinguish them from the later deposits of the Coastal series, consist of white limestones of varying texture and hardness, and probably aggregate 2,000 feet in thickness. These present a perplexing series of surface and interstitial changes under the influences of solution and oxidation, as explained in their detailed descriptions, which render their study a difficult task. They consist of deeper-water organic deposits and are free from coral-reef rock, littoral shell agglomerates (such as coquina, cantera, and caleche), beach wash, eolian débris, or other clastic formations which characterize the rocks of the Coastal series. They contain few macroscopic fossils by which their age can be independently determined, but this is fixed by their microscopic fossils and their position between including fossiliferous horizons—the underlying Cambridge beds and the overlying Bowden gravels and marls.

In general, the Oceanic series occupies most of the plateau region, which practically includes all the island under 3,000 feet in altitude outside of the Blue Mountain district, except its immediate coastal borders. In the mountainous region of eastern Jamaica these rocks occur as a high piedmontal peripheral border around that end of the island. In the western half of the island the beds of the Oceanic series completely cover the old Blue Mountain series and occupy the higher summits of that portion of the island.

Owing to the elevation of the plateau region which took place after the deposition of these beds, and the subsequent contraction of its oceanic borders by erosion and subsidence, the coastward extension of the rocks is truncated and partially embedded near the littoral by the still later formations of the Coastal series, which are deposited unconformably against them.

The detailed subclassification of the Oceanic series comprises not only the Catadupa and Chapelton beds of the Cambridge formation, but also the Montpelier, Moneague, and Cobre formations. Of the Montpelier Hill [443e] says, quoting Charles B. Brown:

It consists of thin beds of white limestone, interbedded with a soft white chalky marl, the limestone beds invariably containing nodules of flint. The limestones are chiefly soft but seldom compact or crystalline; they form thin beds, which vary from a few inches to 4 feet in thickness and are much disturbed, so as to dip in almost every direction over small areas. The marl beds, being interstratified with these, of course show the same disturbance and dips and are similar to them in thickness. The flints and chert contained in the limestone beds lie usually in flattened nodular masses in lines of stratification and are rarely in beds themselves. They are not connected continuously but are in long, hollow flat masses, and have all the appearances of having been deposited around or in the substance of some organic form which was embedded in the limestone. These flints are chiefly of brownish-pink, brown, and gray colors. At Knockalva and other places in the vicinity the limestone contains small veins of silica, and also has become so thoroughly impregnated with that substance as to be completely changed into a siliceous limestone.[a]

Microscopic examinations show that the calcareous beds consist of organic oceanic material and are composed of the shells of Foraminifera, occasional sponge spicules, and fine crystals and amorphous particles of carbonate of lime, like those usually found in all chalky oceanic deposits. No terrigenous material whatever has been found in any specimens examined. The Montpelier beds are singularly free from molluscan or other visible fossils, except a large species of Orbitoides in its lower beds. Nummulinæ have also been found. * * *

The thickness of the Montpelier formation is difficult to determine, owing to lack of continuous exposures. Our observations have led to the conclusion that they do not exceed 1,000 feet. Everywhere these beds show great disturbance, but not to the degree of the Blue Mountain series, usually consisting of more open folds.

The Montpelier beds are the deepest sediments preserved in the geological structure of Jamaica and represent the culmination of the great subsidence initiated in the Cambridge epoch. Judging from the rapid transition between the littoral Cambridge formations and the chalks of the Montpelier formation, this subsidence must have been rapid in geologic time.

The age of the Montpelier beds most probably corresponds to that of the late Eocene (old classification) now called the early Oligocene, agreeing approximately with the position of the Vicksburg stage of our American Tertiary. This inference is based upon the position of the beds above the undoubted lower Eocene of the Cambridge formation and below the undoubted late Oligocene of the Bowden formation, together with the occurrence of *Orbitoides mantelli.*

In regard to the Moneague formation Hill [443f] states:

The Montpelier beds grade up into more massive limestones, white in color, firmer in texture, often semicrystalline, sometimes containing casts of fossil mollusks and solitary corals, and occurring in well-defined bands of stratification from 1 to 5 feet in thickness. More massive texture and regular bedding especially distinguish this formation from the other white limestones of the island, such as the chalky rocks of the underlying Montpelier and the irregular lumpy texture of the overlying Cobre formations. These rocks contain many cavernous molds of Mollusca and single corals, indicating that a considerable amount of shell débris may have accompanied their original deposition. The fossils obtained near Ewarton, Retreat, and Cinnamon Hill, in a firm limestone matrix, were mostly poorly preserved molds of corals and mollusks, which the paleontologists could not determine. * * *

[a] The description above given refers to Brown's lower division of the white limestone (our Montpelier beds); the upper beds (our Brownstown beds) are more compact and massive and contain fewer interstratified marls.

From their usual association with and occurrence above the Montpelier beds, there is little doubt that they were continuously deposited with the latter and possibly may represent shallowing but nevertheless deep-water beds after the culmination of the Montpelier subsidence. Our knowledge of the upper contact of these beds is very deficient. In Clarendon and St. Elizabeth they clearly occur below the Cobre and Porus (Bowden) formations.

The name Cobre formation is applied to a local occurrence of white limestone exposed in the canyon of the Cobre. Hill says that from the Bog Walk section it is evident that the Cobre formation lies stratigraphically above the supposed Moneague beds at Ewarton and below the May Pen formation. Its relations with the Bowden beds are not established. It apparently occupies an intermediate position between the Moneague and the Bowden.

For description of the later Tertiary formations, see Chapter XVII (pp. 799–801).

E–F 15–16. CHIAPAS, GUATEMALA, TABASCO, AND YUCATAN.

The peninsula of Yucatan is mapped in accordance with an interpretation of the map given by Sapper,[694c] who characterizes the Tertiary of the States of Tabasco and Chiapas as follows:

> The major part of the Tertiary terranes consists of marls and shales with sandstones and conglomerates as well as limestones which are, however, of minor importance.

The fossils which Sapper cites from these formations are Pecten, Ostrea, Nummulites, Elypeaster, and different Glossophora (?), lamellibranchs, and corals.

Sapper regards these fossils as representing the upper Miocene or some of them as coming from a lower horizon. Dall thinks it probable that they represent the Oligocene. Sapper further cites certain remains of plants and Foraminifera which were determined by Schwager to be of Tertiary age.

Heilprin [433a] describes in the following terms the limestone of the Sierra de Yucatan, a range of hills which runs in a northwest-southeast line from Ticul in the direction of Peto:

> The rock formation of the Sierra de Yucatan differs in many particulars from that of the basal plain. The surface rock, forming the crest and the slopes on either side—presumably an anticlinal structure—is a fairly compact red or reddish limestone, which seems to rest at nearly all places, as we had occasion to observe in the Caves of Calcehtok and Loltun, on a semicrystalline white or gray marble or on an exceedingly fine grained cream limestone, somewhat resembling in texture true lithographic stone. A brecciated limestone, containing fragments of the last-mentioned rock, occurs at intervals along the base of the hills, and we also found it among the rocks used in the construction of the buildings (now ruins) of Labna. I am not absolutely certain as to the age or even as to the general nature of the red rock. The brecciated masses are almost undoubtedly of marine origin, and they give evidence of the encroaches of the sea after the underlying rock had not only been formed but been converted into its present semicrystalline condition. In other words, the present range of hills probably by that time already existed. It is, however, less clear that the red or reddish rock which extends away from the base of the hills but forms their slopes is of marine origin. Its universality would seem to indicate that it was of this nature, but at many places where I examined it, on and off the crests of the hills, it bore suspicious marks of being a disintegration product, which had subsequently undergone cementation. The only fossil that I found in it, on any surface exposure, was a Helix (probably identical with a species now living in the same region), which was obtained from near the summit of the pass between Ticul and Santa Elena, at an

absolute elevation of perhaps 300 feet. It occurred in a thoroughly hard rock, but this circumstance is in itself no proof of actual antiquity, since in a purely calcareous region such as this one rock cementation is a rapid process, as we had occasion to observe in the terrestrial (fossiliferous) limestone now forming near a quarry about 2 miles south of Ticul. In the red rock which in the cave of Calcehtok overlies the gray limestone I found the impression of a single gastropod, which I should unhesitatingly refer to a terrestrial form and to a genus of Pupidæ close to Macroceramus, if indeed it is not Macroceramus itself. I could find no vestiges of marine mollusks, but yet they may well occur in other parts of the rock and it would, perhaps, not be safe to conclude that the entire red rock is of terrestrial origin, or that it represents a single type of formation.

No doubt attaches to the heavily bedded gray and white limestones and marbles which are so well exhibited in some of the deeper caves, such as that of Calcehtok, for example. The mouth of this cave, according to a rough approximation, is some 200 feet above the sea. At a depth of some 50 feet the red limestone appears in a solid mass, and beneath it we reach the crystalline limestones, which are disposed in layers of 10 to 15 feet thickness. Fossils are not abundant in this rock, and Col. Glenn, who had explored this cave on a previous occasion, was of the opinion that no fossils were to be found in it. After considerable search, however, we discovered a few in an indifferent state of preservation, and still later some whose characters were sufficiently defined to permit us to determine their relationship. Among these are a Pecten, with little doubt *Pecten nucleus*, the cast of a large Marginella, apparently the living *Marginella labiata*, a Potamides or Cerithidea, the impression of the apex of a large Oliva (of the type of *Oliva literata*), and a single impression of *Venus cancellata*. While the above forms are barely sufficient to determine the exact age of the formation in which they occur, whether Pliocene or Miocene, I am inclined to believe that it is rather the former, the mountain rock—semicrystalline or highly compact and but scantily fossiliferous—being a compressional alteration of the much less compact and highly fossiliferous rock of the basal plains. But whether Pliocene or Miocene, I think it can be all but positively assumed that it is not older than Miocene, although it has been asserted that it represented the Oligocene or Vicksburgian period.[a]

F 17-18. CUBA.

T. W. Vaughan has contributed to this work the following notes on the early Tertiary of Cuba:

The only rocks that we positively know to be of Eocene age in the island occur in the Province of Santiago, not far from the city of Santiago, where they are associated with manganese ores. This information is furnished by William H. Dall, who determined some fossils collected by Clarence King. Associated with the manganese ores in this province are foraminiferal limestones and foraminiferal marls, which appear to be of Eocene age and are tentatively referred to that epoch. It is probable that the limestones occurring along the northern foot of the Sierra Maestra from Los Negros to Cabo Cruz are also Eocene. Eocene limestones are reported from the Province of Santa Clara, particularly near Cienfuegos, from the Province of Matanzas, near the city of Matanzas, and from the vicinity of Havana. The data on which the age of these rocks has been determined for these three provinces seem doubtful, the doubt for the vicinity of Havana being so strong that the formations in that area are referred to the late Oligocene.

North of the city of Pinar del Rio and along the Rio Santa Fe, just south of the village of San Jose, sandstones underlie the upper Oligocene limestones. No paleontologic data by which the age of this formation could be determined were procured, but it may be of Eocene age.

A yellowish marl composed of the remains of Radiolaria has been described by several authors as occurring in Baracoa. This material underlies the upper Oligocene and is probably of early Oligocene age.

Limestones and marls of late Oligocene age constitute by far the most widespread geologic formation in Cuba. They extend uninterruptedly from the Province of Pinar del Rio to the

[a] Agassiz, Alexander, Three cruises of the *Blake*, vol. 1, p. 69.

Province of Santiago. The most westerly locality at which rocks of this age were observed was in the Province of Pinar del Rio, some 4 miles north of the city of that name, on the road to Viñales. Lithologically the material is either soft limestone or calcareous marl. There is a quarry in yellowish upper Oligocene limestone at the town of Consolacion del Sur, from which a fair collection of fossils was obtained through the kindness of the alcalde of that town. Limestones and marls, with a few beds of calcareous sands, occur over large areas in the vicinity of Havana, extending from the city toward the west, south, and east.

Limestones and marls of the same age, with conglomerates, occupy extensive areas around Matanzas and east of that city. The gorge of Yumuri River is cut through rocks of this age and exposes an excellent section. At this place the river runs nearly east and west through a narrow canyon 500 to 600 feet wide. From its bottom the vertical distance to the top of the highest level through which it is cut is some 450 feet. The gorge itself is about 200 feet in depth. The rocks dip at an angle of about 27° SE., the thickness here exposed being estimated at 600 to 700 feet. The whole section, except the lowest 100 feet, at the west end of the gorge, is composed of limestone, more or less impure, with a few beds of sandstones and conglomerates near the top of the section. Characteristic upper Oligocene fossils are abundant. The writer did not collect any upper Oligocene fossils in the Province of Santa Clara but has reason to believe that limestones of this age are extensively developed in its northern and southern portions.

Upper Oligocene yellowish calcareous marl or limestone are found in the vicinity of Nuevitas; also at Baracoa, where they immediately underlie the Pleistocene coastal soborruco. There is a very great development of marls and limestones, containing large numbers of reef corals, in and around the city of Santiago. The terraces in this city, excepting the lowest soborruco, have been cut into upper Oligocene formations. Upper Oligocene limestones have also an extensive development in the vicinity of Manzanillo.

G–H 14, H–I 15. TEXAS, LOUISIANA, AND ARKANSAS.

The following discussion of the early Tertiary of Texas, Louisiana, and Arkansas has been compiled by T. W. Vaughan from the literature, from unpublished manuscript or notes of Alexander Deussen, C. H. Gordon, and A. F. Crider, and from the results of his own researches.

Space will not permit detailed descriptions or geologic sections, and for further information the reader should consult the publications listed in the bibliography (pp. 840–865) under Nos. 297, 299, 370, 401, 406, 407, 408, 430, 485, 486, 487, 488, 633, 832, 833, 838. Additional references are given on page 731, and many of these publications contain still other citations.

GENERAL SECTION.

The same division of the Eocene into Midway, Wilcox, Claiborne, and Jackson can be made in the Coastal Plain area west of Mississippi River as east of that stream (see p. 731); for the Oligocene, however, a different classification is necessary, as the Vicksburg is not so far west as Red River, and the Apalachicola group is not known in the western area, the sediments stratigraphically equivalent to the Apalachicola being of estuarine or littoral character, similar to those across southern Mississippi. In the table opposite page 724 the section for Arkansas and Louisiana is modified from the one published by A. C. Veatch[838a] and that for Texas east of Guadalupe River has been furnished by Alexander Deussen.

EOCENE.

Midway group.—The Midway group is extensively developed from Arkansas southwestward across Texas to the Rio Grande. Usually the group has not been subdivided, and the name is therefore applied in a formational sense. However, future studies may lead to subdivision and the adoption of several proposed names for local manifestations. There is a general unconformity by erosion between the Midway and the underlying Cretaceous, but it is usually concealed or inconspicuous because of the similarity of the Eocene and Cretaceous sediments. In northeastern Arkansas the Midway overlaps the Cretaceous, and rests upon a Paleozoic floor.

Stephenson and Crider, in an unpublished manuscript, state:

"In Pulaski County, Ark., the strata of the Midway formation, where most completely developed, are separable, according to Harris,[a] in ascending order into (*a*) white, compact sand (2 feet); (*b*) ledge of calcareous sandstone ($2\frac{3}{4}$ feet); (*c*) the 'Turritella limestone' (8 feet); (*d*) the 'Ostrea [Gryphæa] limestone' (3 feet); (*e*) the 'Enclimatoceras limestone' ($1\frac{1}{2}$ feet). In general, the 'Turritella limestone' in Arkansas consists of layers of hard light-gray to blue limestone interbedded with layers of sand, and this division is the one most often seen in outcrops. The formation is easily separable both lithologically and paleontologically from the underlying Paleozoic rocks and the overlying younger formations."

According to Harris and to Stephenson and Crider, the northernmost Midway outcrop is near Newark, in Independence County, Ark., whence it has been traced southward, more or less continuously, along the edge of the Paleozoic rocks to a point near Rockport on Onoshata River, Hot Springs County. North of the locality near Newark it has not been recognized on the surface or in well borings. In southern Missouri the group may be represented by the Porters Creek clay. From Olyphant, Jackson County, to Russell, White County, the Midway outcrops in numerous places along the St. Louis, Iron Mountain & Southern Railway and on the terrace-like elevation which extends almost unbroken from Russell to Olyphant. It occurs in Pulaski and Lonoke counties. The best exposures in Arkansas are between Little Rock and Malvern. It outcrops in Little Rock near the point where the Hot Springs wagon road crosses the St. Louis, Iron Mountain & Southern Railway and may be traced almost continuously from this place westward to Malvern. Outcrops of the Midway are not known in Arkansas southwest of Hot Springs County.

In Louisiana two outcrops of the Midway are known, one on the road from Marthaville to Many, at Rocky Spring Church, in Sabine Parish, and the other at King's salt works, in southwestern Bienville Parish. These outcrops have been brought to the surface by anticlinal folding. The material in both localities is calcareous.[408a] Harris [407e] says regarding a third probable outcrop:

"Farther to the south in the Sabine uplift territory—for example, along the Texas & Pacific Railway for over a mile in the vicinity of Marthaville—*Ostrea thirsæ*,[b] a very characteristic fossil of the basal Wilcox formation, occurs in great abundance. As the strata in that vicinity dip to the south, though but slightly, it is evident that Midway beds must occur at the surface over a considerable area to the north. Their geographic distribution has not yet been worked out."

In Texas the basal contact of the Midway has been positively identified at only two localities—on Brazos River $1\frac{1}{2}$ miles above the Falls-Milam county line [403a] and on Frio River.[832e] At the former locality no erosion unconformity can be seen, notwithstanding the great faunal change; at the latter locality there is evidence of such an unconformity. Deussen, in an unpublished manuscript, says that northeast of Brazos River "at the base of this formation are usually found bluish micaceous clays or clayey sands with occasional light-yellowish fossiliferous limestone layers of marine origin. These are succeeded by sandy ledges, resting on which are generally found black selenitic clays. The outcrop constitutes the Eastern Marginal Prairies and occupies a narrow belt extending approximately north and south in Van Zandt, Kaufman, Henderson, Navarro, Freestone, Limestone, Falls, Robertson, and Bastrop counties. Much of the exposure is obscured by materials of later age. This formation in northeast Texas averages about 260 feet in thickness. The dip varies between 1° and 5° SE."

Southwest of Bastrop County the Midway has not yet been definitely traced in Texas, but evidence obtained by Vaughan along Frio River and the Rio Grande indicates that it extends into Mexico. On Frio River,[832e] 5 miles due north of the southern boundary of Uvalde County,

[a] Harris, G. G., Ann. Rept. Arkansas Geol. Survey, 1892, vol. 2, pp. 28, 29.

[b] Through a slip of the pen, *Ostrea sellæformis* in the original.—T. W. V.

Section of older Tertiary formations in Arkansas, Louisiana, and eastern Texas.

System.	Series.	Group.	Arkansas and Louisiana. Formation.	Thickness (feet).	Character.		Eastern Texas. Formation.	Thickness (feet).	Character.
Tertiary.	Oligocene.		Fleming clay.	260	Green calcareous clays, with a few brackish-water fossils.		Fleming clay.	100–400	Gray, white, and bluish-white bedded calcareous clays, with numerous small concretions of lime; occasional lenses of sand.
			Catahoula formation.	1,000–1,200	Near-shore deposits; sandstones, occasionally quartzitic, and green clays, with fresh-water shells and land plants.		Catahoula sandstone.	100–300	Hard blue semiquartzitic sandstones.
			Vicksburg limestone.	100–200	Limestones and calcareous, somewhat lignitiferous clays, containing marine shells.				
	Eocene.[a]		Jackson formation.	200–550	Highly fossiliferous shallow-water marine sandy calcareous clay.		Jackson formation.		Calcareous blue clays of marine origi[illegible]eloped in Sabine, San Augustine, and Angelina counties only. Farther w[illegible]s interval is occupied by the Catahoula sandstone, which passes progressive[illegible]er in the column until it includes rocks of Claiborne age.
								50–60	A very persistent series of gray fossiliferous sandstones, the Wellborn beds of Kennedy, forms the base.
		Claiborne group.	Cockfield formation.	300–390	Lignitiferous sands, and clays, with plants and occasional beds of marine shells.	Undifferentiated Eocene.[a] Landward these formations merge into lignitiferous sands and clays without distinctive marine fossils.	Yegua formation.	500–600	Green calcareous clays with concretions of selenite; occasional lenses of sand and lignite; possibly also occasional lenses of fossiliferous clays.
			St. Maurice formation.	200–500	Fossiliferous sandy clay, containing shallow-water marine shells.		Cook Mountain formation.		Lenticular masses of yellow sand and clay; occasional lenses of green calcareous glauconitic fossiliferous marl; occasional fossiliferous calcareous concretions, beds of limonite and lignite.
							Mount Selman formation.	200–400	Red ferruginous indurated and probably altered green sand, lenses of lignite and clay, beds and concretions of limonite.
			Wilcox formation.	400–500	Lignitiferous sands and clays, with land plants.		Wilcox formation.	100–200	Palustrine phase, consisting of white porous, loose, water-bearing sands (the Queen City beds of Kennedy). More or less contemporaneous.
								500–800	Lignitic beds, consisting of lenticular masses of sand, clay, and lignite. Clays are leaf bearing and in places carry crocodile teeth; large concretions, some 20 to 30 feet in diameter, of hard, flintlike sandstone are especially characteristic.
									Marine phase, consisting of calcareous glauconitic fossiliferous marl, alternating with beds of sand, clay, and lignite. Exposed only on Sabine River; does not outcrop in the central Coastal Plain region, the Wilcox being there represented by the palustrine phase only, into which the marine phase grades.
			Midway formation.	20–260	Limestone and black calcareous clays.		Midway formation.	100–200	Palustrine deposits consisting of lenticular masses of sand, clay, and possibly lignite, with indurated fossiliferous concretions. This member simulates in composition the basal member of the overlying Wilcox formation.
								100–200	Black and blue fossiliferous shales, etc. of distinctly marine origin.
Cretaceous.	Gulf series (Upper Cretaceous).				Beds separated by a pronounced break in the fauna, which is concurrent with an erosion unconformity now traced from the Carolinas across Texas.				

[a] The Jackson, Claiborne, and Wilcox, which are fossiliferous and distinct in central Louisiana, grade toward the north into lignitiferous beds containing no distinct fossils. In northern Louisiana and southern Arkansas the fossiliferous Jackson limits this lignitiferous complex above. Still farther north, however, the Jackson also grows lignitiferous and merges with the rest. The Midway, likewise, in the upper embayment region shows a decidedly lignitiferous tendency and may in places merge with the lignitiferous time equivalents of the other Eocene beds.

no limestone was found, but there is a yellowish or bluish sandstone, usually rather soft, containing Midway fossils. The Midway also occurs along the Rio Grande, near the Webb-Maverick county line, above the mouth of San Ambrosia Creek.[832c] The material consists of dark-brownish or yellow clays and soft sandstones. The thickness was not determined.

According to Dumble [298] the main divisions of the Texas Eocene extend into Mexico.

Wilcox formation.—The following statement regarding this formation in Arkansas and Louisiana is modified from that of A. C. Veatch.[838d]

Overlying the limestones and calcareous clays of the Midway formation is the Wilcox formation, a series of dark, finely laminated sands and clays containing much vegetable matter, either scattered through the mass or accumulated in lignite beds, and a few layers containing marine shells. It commonly differs from the underlying Midway in the presence of lignitic material and fossil leaves and when containing marine fossils is readily distinguished from both the Midway and the overlying Claiborne. Toward the coast, where it is overlain by the very calcareous, argillaceous, fossiliferous St. Maurice formation of the Claiborne group, its upper limit can be fixed with exactness, but farther inland, where estuarine and swamp conditions persisted until Jackson time, no separation is possible except on a purely paleontologic basis. On the whole, the formation is predominantly sandy. Veatch closes his description as follows:

"The Sabine [Wilcox] formation and its equivalent beds in the undifferentiated Eocene underlie the whole of Louisiana, except the limited areas occupied by the outcrops of the Cretaceous and Midway domes, and all of Arkansas south and east of the Cretaceous and Midway outcrops. Its thickness, as shown by carefully constructed sections in which local irregularities are reduced to their proper minor importance, ranges from 300 feet in northern Bossier Parish to from 800 to 900 feet near Nachitoches and on Sabine River."

From an unpublished manuscript by Deussen the following description of the Wilcox formation in eastern Texas is taken:

"In eastern Texas the Wilcox formation comprises a series of beds of palustrine and littoral origin, carrying deposits of lignite and glauconitic, fossiliferous, nonlignitiferous beds of marine origin. This formation consists chiefly of a great mass of lenticular beds of sand, concretion and leaf bearing sandstones and clays, sandy clays, and lignites, all of palustrine origin. Cross-bedded sands and sandstones also occur. In places the sand is indurated into a hard sandstone that is locally useful for building purposes. Thick lenses of lignite of good grade, irregularly distributed, give to the formation great economic value. Plant remains indicative of the shallow-water origin of these beds occur at a number of places. The lignitic and palustrine deposits apparently grade seaward into glauconitic and fossiliferous marls of marine origin. The great thickness of these shallow-water sediments—500 to 600 feet—is indicative of subsidence contemporaneous with deposition. It is otherwise impossible to account for this thickness. Along Sabine River close to the southern margin of the outcrop of the formation glauconitic beds of marine origin occur, which carry characteristic Wilcox fossils.

"The rocks of this formation outcrop over a wide belt of country, occurring in large portions of Robertson, Limestone, Leon, Freestone, Navarro, Anderson, Henderson, Van Zandt, Smith, Gregg, Harrison, Rusk, Shelby, Panola, and Sabine counties, occupying a position to the east and south of the Midway exposures. Where they are not covered by deposits of later age they almost invariably give rise to sandy soils easily eroded. The sandy outcrop constitutes a portion of the east Texas timber belt.

"In northeastern Texas, in the counties of Cass, Marion, Harrison, Panola, Gregg, Smith, and Upshur, the Wilcox formation is generally seen to underlie a red sandstone which carries casts of *Venericardia planicosta* and appears to be an altered greensand. This red sandstone is provisionally referred to the Mount Selman formation of the Claiborne group.

"The uppermost beds of the Wilcox formation in this portion of the State consist of a series of laminated or thinly stratified white and red sands and sandy clays, in many places merging into one another. They do not carry any lignite, so far as we are aware, nor have they yielded thus far any organic remains. These deposits are so distinctive in this portion of the State that they have sometimes been described as a separate formation, to which the name Queen City has been applied by Kennedy.[a]

"The lower beds of the Wilcox in northeastern Texas, which are seen to underlie the beds above described, are similar in all respects to the deposits occurring on the Brazos."

West of the Colorado River the Wilcox or its representatives have not been definitely traced, but the studies of Penrose, Vaughan, and Dumble have proved that it is extensively developed along the Rio Grande. Vaughan [832b] has shown that on the Rio Grande 3½ miles above the mouth of San Ambrosia Creek, Maverick County, sandstones and thinly bedded lignitic sands carrying Midway fossils underlie coarser sands outcropping in the vicinity of the Chupadero ranch and extending thence northeastward through Carrizo Springs and Batesville. These sands are the Carrizo sands of Owen [625] and are probably the lower portion of the Wilcox. They are at least 150 feet thick. They are overlain by about 300 feet of fine-grained micaceous sandstones, which are succeeded by alternating beds of clay, shales, and sandstones, at least 400 feet thick, and these in turn by clays, sandstones, and lignite beds 190 feet thick.[832d] Dumble [297b] reports: "About 35 feet above the San Pedro seam [Santo Tomas] there is a band of shell breccia which contains a great number of fossils. Among there were *Ostrea divaricata* Lea, *Anomia ephippoides* Gabb, *Corbula texana* Gabb, and many others." These fossils belong to the Claiborne group and occur between the two coal seams in this mine, or the last division of the section described above belongs to the Claiborne. The Wilcox along the Rio Grande is probably at least 850 feet thick.

Claiborne group.—In central Louisiana the Claiborne group is divisible into a lower fossiliferous formation, the St. Maurice, and an upper formation, the Cockfield, which contains no marine fossils. The St. Maurice formation is much more calcareous, glauconitic, and clayey than the underlying Wilcox formation and where typically developed contains no lignitic nor lignitiferous matter, though to the north it changes to lignitiferous sands and clays and merges into the undifferentiated Eocene.

The thickness of the St. Maurice formation is 250 to 300 feet in the region about Monroe, but increases to over 500 feet at Winnfield. On Sabine River the thickness, calculated from dip observations, is 550 feet.[836] In a well recently put down near Robinsons Ferry, Tex., at a depth of 1,250 feet fossils were obtained that W. H. Dall regards as Claiborne, indicating that the thickness is as much as 700 feet.

Harris [407c] says: "The Claiborne group borders the Sabine uplift. It is represented only by patches in Gregg, Marion, and Cass counties, Tex, and Caddo and Bossier parishes, La., where it has been for the most part carried away by long-continued erosion. It spreads out extensively in Rusk and Nacogdoches counties, Tex., and Bienville and Winn parishes, La., where the dip is slight, but it narrows down in Sabine Parish, where a steep dip carries it beneath the later Tertiary deposits."

The northwestern area of the St. Maurice formation referred to in the following note of Harris [407d] probably represents the Mount Selman formation of Texas.

"In the Caddo field, as already defined, marine Claiborne fossils have been found in but one locality, by the roadside about one-fourth of a mile east or east-southeast of the railway station at Vivian. Here, as at Roberta, Bolinger, and Plaindealing, in Bossier Parish, and in Ouachita County, Ark., the fossils are in the form of casts in very ferruginous indurated layers. From their appearance, which is very different from that of the fossil species so abundant and characteristic of the Claiborne from Bienville Parish to Nacogdoches County on the south, it is inferred that either these northern forms existed under considerably different conditions from their southern relatives or they represent a somewhat older type of life. It is possible that the Sabine uplift was more or less manifest in early Eocene or perhaps even late Cretaceous time. Desoto Parish, La., as well as Shelby, Panola, and Harrison counties, Tex., may have constituted an island in Claiborne time. The ferruginous, more or less brackish waters to the north of the island would naturally contain a very different fauna from that flourishing in the pure sea water to the south."

[a] Kennedy, William, Proc. Acad. Nat. Sci. Philadelphia, 1895, pp. 135, 136.

The Cockfield formation comprises lignitiferous sands and clays which occur in central Louisiana between the St. Maurice and Jackson formations and is extremely similar in lithologic character to the Wilcox formation, with which it was at first confused. It contains no marine mollusks and is characterized by thin, impure lignite beds and clays which in many places contain plant remains in an excellent state of preservation. It is identical in appearance with the lignitiferous complex to the north (undifferentiated Eocene), of which it forms a part, and can be definitely differentiated only when fixed between fossiliferous Claiborne and Jackson strata or by paleontologic data. (Modified from A. C. Veatch.)

Of the Claiborne group in eastern Texas Deussen has the following to say in an unpublished manuscript:

"In eastern Texas the Claiborne group comprises three formations—the Mount Selman, Cook Mountain, and Yegua—which are lithologically and genetically distinct.

"The Mount Selman formation consists chiefly of dark-green and brown sands and sandstones, with thin seams and concretions of limonite. The fossils are not plentiful and usually occur in the form of casts. This formation has been given the name Mount Selman from its typical exposure at that place in Cherokee County.[a] These highly ferruginous sands with casts of fossils and beds of iron ore of economic value occupy extensive areas in Anderson, Henderson, Cherokee, Rusk, Gregg, Harrison, Marion, Morris, and Cass counties.

"The formation overlying the Mount Selman has been named Cook Mountain, from Cook Mountain,[b] Houston County. At the base of this formation occur beds of greensand, greensand marl, and iron ore, all highly fossiliferous and of marine origin; in the medial portion lignites, lignitic clays, and sands of palustrine origin are found; at the top occurs another series of fossiliferous greensands, greensand marls, and iron ores of marine origin. The thickness along Brazos River is at least 400 feet. The outcrop appears in Robertson, Brazos, Leon, Houston, Anderson, Cherokee, Nacogdoches, San Augustine, and Sabine counties.

The lignitiferous unit stratigraphically and conformably overlying the Cook Mountain formation, was recognized by Dumble[c] in 1892 as a separate formation, and he applied to it the name Yegua. It consists of clays, sands, and lignites of palustrine and marine origin. The clays are characterized by the presence of fragments and concretions of selenite. The thickness of the formation varies from 375 to 750 feet. The outcrop appears in Sabine, San Augustine, Angelina, Trinity, Houston, Madison, Grimes, and Brazos counties.

"On the Brazos beds belonging to the Yegua formation are exposed between the mouth of the Little Brazos and a point southwest of Wellborn, in Brazos County. The beds as exposed in this section consist entirely of palustrine and lignitiferous deposits, barren of marine fossils. On Sabine River beds belonging to this formation are exposed from a point 3 miles below Columbus to a point a short distance below Robertson's Ferry, in Sabine County. The beds here are typical palustrine deposits."

The details of the Claiborne group have not as yet been studied between Guadalupe River and Rio Grande. Dumble's work along the latter stream has shown that representatives of the marine Claiborne outcrop from Santo Tomas, 30 miles above Lando, to the vicinity of Roma. The material consists of lignite beds near the base, soft sandstone, and clays, which are more or less calcareous,[297a] and greensands. The thickness of the marine Claiborne in this region is not known.

Jackson formation.—The Jackson formation in Louisiana immediately overlies the Cockfield and represents a return to marine conditions, being composed of calcareous gray fossiliferous sands and clays, which in places contain large calcareous concretions. It extends farther up the Mississippi embayment than any other formation bearing marine fossils except the Midway. Its most northern outcrop is in Crowleys Ridge, near Forrest City, St. Francis County, Ark. To the south of this locality the formation underlies an extensive area southward from

[a] Kennedy, Third Ann. Rept. Geol. Survey Texas, 1892, pp. 52–54.

[b] Idem, pp. 54–57.

[c] Dumble, E. T., Report on the brown coal and lignite of Texas, character, formation, occurrence, and field uses: Rept. Geol. Survey Texas, 1892, pp. 148–154.

Pine Bluff in Jefferson County to the Louisiana line.[401b, 406a] It is concealed in northern Louisiana over a large area by the swamp deposits of Ouachita River, but again comes to the surface in southern Caldwell Parish and thence occupies a belt of territory that crosses Red River at Montgomery and Sabine River just below Robinson's Ferry, Sabine County.

According to A. C. Veatch[838e] the Eocene beds, which in central Louisiana, Mississippi, and Alabama are fossiliferous, all become lignitiferous in the upper portion of the embayment. The marine fossils of the Wilcox, St. Maurice, and Jackson epochs each extend farther northward than those of the preceding epochs, but in each case the beds bearing marine fossils grade into lignitiferous clays and sands containing no distinctive marine fossils.

Veatch says: "The first name given to this lignitiferous group, which can not be separated except on structural grounds, was the Lagrange. This included all the Eocene beds in Tennessee above the Midway and was afterward quite logically extended by its author, Prof. J. M. Safford, State geologist of Tennessee, to include the lignitiferous sands and clays of Crowleys Ridge,[a] which are of lower Jackson age and are the stratigraphic equivalents of the beds in the upper Chickasaw Bluffs. This formation grows more sandy to the north, where at Memphis essentially continuous sand beds 800 feet thick have been penetrated." [b]

The following is taken from an unpublished manuscript by Deussen:

"The Jackson formation in eastern Texas lies stratigraphically and conformably above the Yegua and beneath the Catahoula. It consists of a series of calcareous, fossiliferous clays of marine origin with large limestone concretions. It outcrops in the region between Trinity and Sabine rivers, in Sabine, San Augustine, and Angelina counties. Along the Sabine the formation is estimated to be 250 feet thick. It thins rapidly westward and disappears completely between Trinity and Brazos rivers. The formation is characterized by such fossils as *Umbrella planulata* Conrad, *Levifusus branneri* Harris, and *Trochocyatus lunulitiformis* var. *montgomeriensis* Vaughan.

"On Sabine River 1 mile below Robertson's Ferry, in Sabine County, highly fossiliferous calcareous clays and marls carrying large limestone concretions outcrop and carry characteristic Jackson fossils. The following species occur here: *Mitra millingtoni* Conrad, *Hipponyx americanus* Conrad, *Calyptræa trochiformis* Lamarck, *Ostrea trigonalis* Conrad, *Arca (Scapharca) rhomboidella* Lea, *Crassatellites flexurus* Conrad, *Cardium (Protocardia) nicolletti* Conrad, *Dione securiformis* Conrad, *Corbula wailesiana* Harris.

"The Jackson formation extends from Angelina River in Texas eastward across Louisiana into Mississippi. In Texas the time equivalents of the formation have been traced as far west as the Brazos. The equivalents in the region of the Brazos, however, are not lithologically similar to the Jackson formation and therefore do not belong to the Jackson but are here a part of the lithologic unit next to be described, namely, the Catahoula sandstone."

The Jackson has not been recognized in southwestern Texas, although more thorough investigation may discover it in that region.

OLIGOCENE.

Vicksburg limestone.—This formation is known west of Mississippi River only in a small area in northern Catahoula Parish, La. The material is yellow calcareous clay and yellow limestone, which contains typical fossils.[830]

In Louisiana and eastern Texas the Oligocene deposits are divided into two formations—a lower one, the Catahoula sandstone, which in east-central Texas also comprises the uppermost Eocene and which consists of semiquartzitic sandstones and sands with some clay and carries a few plant remains, and an upper one, the Fleming clay, which consists of calcareous clays with nodules of lime and occasional crystals of gypsum.

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[a] Report of John Lundie on waterworks system of Memphis, Tenn., 1896, p. 16.

[b] Safford, J. M., Bull. State Board of Health, vol. 5, pt. 7, Feb. 20, 1890, pp. 98-106; Ann. Rept. Geol. Survey Arkansas for 1889, vol. 2, 1891, pp. 28-29.

Catahoula sandstone.—This formation is thus described by Veatch:[838f]

"Overlying the fossiliferous Vicksburg clays and limestones is a series of sandstones and greenish clays which are generally [very] different, lithologically, from any of the older beds of the Tertiary series in Louisiana and Arkansas. The sandstones which are the characteristic feature of this formation range in thickness from a few inches to 50 or 60 feet, and thicknesses of as much as 140 feet have been reported.[a] These sand beds are often cemented by silica into very hard quartzites, but such occurrences are essentially local, and the quartzitic beds pass laterally in very short distances into soft sandstones or even unconsolidated sands. These sandstones and quartzitic layers have resisted erosion more than the underlying clays and unconsolidated sands of the Eocene and so have formed a line of rocky hills, the Kisatchie Wold, extending across Louisiana, into Texas on the one hand and into Mississippi on the other.

"These beds contain no indications of marine life, but land plants are abundant and fresh-water shells have been found in several places. The change from the conditions existing in the Vicksburg is very marked and indicates an elevation during which the region where the oceanic conditions were favorable for the growth of marine life was considerably south of the present outcrop of the formation.

"These beds were observed at Grand Gulf, on Mississippi River, in Claiborne County, Miss., by Wailes, the first State geologist of Mississippi, who referred to them as the Grand Gulf sandstones.[b] Later Hilgard[c] used the name 'Grand Gulf group' to include the beds exposed in southern Mississippi between the Vicksburg and the relatively recent coastal clays (Port Hudson), and the name has been used with varying shades of meaning by different authors since that time.[d]

"In view of this confusion and in order to furnish a name not likely to be misunderstood, the name Catahoula formation is used in this paper as a synonym for the 'typical Grand Gulf' or the 'Grand Gulf proper.' This new name is from Catahoula Parish, La., which is directly across the Mississippi Valley from Grand Gulf and where there are many outcrops which are lithologically and stratigraphically counterparts of the beds of the old type locality. From this place the beds have been traced eastward through Mississippi into Alabama, where they apparently grade into a series of fossiliferous sands and calcareous clays known as the 'Chattahoochee group.' To the west they extend in a very pronounced line across Louisiana into eastern Texas.[e] The thickness of this formation, as shown by comparative cross sections based on wells at Alexandria and Boyce and on dip observations on Sabine River,[f] is about 1,100 feet."

The Catahoula sandstone in eastern Texas is thus described by Deussen in an unpublished manuscript:

"The Catahoula sandstone lies stratigraphically and conformably above the Jackson formation in eastern Texas and above the Yegua in central and southwestern Texas. It lies stratigraphically and conformably beneath the Fleming clay. It consists of a series of gray and blue sandstones, interbedded with brown, gray, and green clays, gray sands, and a few deposits of lignite. The sandstones in places carry marine fossils; in other places they carry casts of palm leaves, reeds, and great quantities of silicified and opalized wood. A characteristic feature is the occurrence locally of very hard blue quartzites, which, owing to their superior hardness, resist weathering better than the adjacent materials and appear topographically in the form of hills. These quartzites pass laterally in very short distances into soft sandstones and unconsolidated sands.

[a] Kennedy, William, Third Ann. Rept. Geol. Survey Texas, 1892, p. 63.

[b] Wailes, B. C. L., Agriculture and geology of Mississippi, 1857, pp. 216–219.

[c] Hilgard, E. W., Report on agriculture and geology of Mississippi, 1860, pp. 147–154.

[d] In this connection see the following: Smith, E. A., and Aldrich, T. H., Science, new ser., vol. 15, 1902, pp. 835–837; idem, vol. 18, 1903, pp. 20–26. Dall, W. H., idem, vol. 16, 1902, p. 947; idem, vol. 18, 1903, pp. 83-85. Hilgard, E. W., idem, vol. 18, 1903, pp. 180–182.

[e] Dumble, E. T., Science, new ser., vol. 16, 1902, pp. 670–671.

[f] Rept. Geol. Survey Louisiana, 1902, pp. 120, 132–135, Pl. XXXVII.

"The formation ranges in thickness from 500 to 800 feet. The outcrop appears as a belt extending across the area in an east-west direction, about 15 miles in width, and including portions of Sabine, Newton, San Augustine, Jasper, Angelina, Tyler, Trinity, Polk, Walker, San Jacinto, Montgomery, Grimes, and Brazos counties."

Deussen states that great confusion has existed regarding the age and correlation of this unit and, after reviewing the literature relating to it, continues:

"As here interpreted, the Catahoula sandstone is a lithologic and stratigraphic unit which transgresses several biologic zones. Stated differently, it is conceived to be of different ages and to have been laid down at different periods in the different regions of its occurrence. In southwest Texas it is of Claiborne age, and this kind of deposition seems to have begun in this area as early as Claiborne time. In central Texas, in the region of the Brazos, it is largely of Jackson age. In eastern Texas it is largely of Vicksburg age. According to Matson, the vertical transgression continues across Louisiana into Mississippi where the formation is of post-Vicksburg age. This kind of deposition, begun in southwest Texas in Claiborne time, gradually shifted eastward, and prevailed in Mississippi as late as middle Oligocene time. If this interpretation is correct it precludes the possibility of an unconformity between deposits of Eocene and Oligocene age in the Coastal Plain; no evidence of such unconformity has been found. It also explains the apparent absence of the Vicksburg limestone in eastern Texas. Upper Eocene deposits are not absent in eastern Texas and there is no hiatus in the sedimentary series there. The assumption by Hilgard, Hopkins, and Loughridge that the 'Grand Gulf group' of Hilgard was stratigraphically continuous across Mississippi, Louisiana, and Texas is thus demonstrated to have been correct, if this interpretation is valid, but they were in error in regard to the age of the materials in Texas. On the other hand, Dumble's determination of the age of his 'Fayette beds' (the Catahoula here recognized) is demonstrated to have been correct for southwest Texas, but if the view here maintained has force he is in error in assuming that the formation in east Texas is of the same age as in southwest Texas."

Fleming clay.—Veatch[838g] says: "The Fleming clay, which was so named by Kennedy in 1892[a] from Fleming siding on the Missouri, Kansas & Texas Railway near the line between Tyler and Polk counties, Tex., consists of green or bluish-green calcareous clays, differing from the underlying Catahoula beds in the presence of numerous small white calcareous nodules and the absence of the characteristic Catahoula sandstone layers. Near its base it often contains a bed of bright-red clay which forms a convenient line of parting.

"Although these deposits represent less truly littoral sediments than the Catahoula beds, extended search has failed to reveal any marine remains except near Burkville, Newton County, Tex., where a brackish-water Oligocene fauna[b] has been found in a local development of limestone 3 to 4 inches thick. William Kennedy[c] reports a number of lower Claiborne (Eocene) species from this locality, but the collection made by the writer in 1902, which was by far the largest made at this point, showed none of the species listed by Kennedy. Dr. T. Wayland Vaughan later visited the outcrop and states that the fragmentary material which he was able to obtain was regarded by both himself and Dr. W. H. Dall as having a decidedly Oligocene aspect."

This formation in Louisiana outcrops in a belt of country extending from Alexandria, on Red River, westward to Burr's Ferry, on Sabine River, south of the outcrop of the Catahoula sandstone. Deussen says:

"This formation consists of grayish sandy clays with small nodules of lime, thin beds of sandstone, and bluish and greenish-gray sand with nodules of lime. The occurrence of the nodules of lime is a characteristic feature. The formation is from 200 to 500 feet in thickness. The outcrop appears as a belt of country varying in width from 2 to 7 miles, lying south of the Catahoula outcrop and extending east and west across Newton, Jasper, Tyler, Polk, San Jacinto, Walker, and Grimes counties.

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[a] Kennedy, William, Third Ann. Rept. Geol. Survey Texas, 1892, pp. 62–63.

[b] Veatch, A. C., Rept. Geol. Survey Louisiana, 1902, p. 136; Maury, C. J., Bull. Am. Paleontology No. 15, vol. 3 1902, p. 80.

[c] Bull. U. S. Geol. Survey No. 212, 1903, p. 53.

"Much the same interpretation must be given to this formation as has been given to the Catahoula, for it appears that these clays, like the Catahoula sandstone, transgress several biologic zones."

Oligocene strata have not been recognized in southwestern Texas but may be present there.

G 17, H 16–17, I 15–17, J 16. SOUTH ATLANTIC AND EASTERN GULF COASTAL PLAIN AND NORTH END OF MISSISSIPPI EMBAYMENT.

The following discussion (pp. 731–745) has been compiled by T. W. Vaughan from the literature and from the unpublished results of G. C. Matson and E. W. Berry in western Florida, southern Alabama, and Mississippi, of E. W. Berry in western Tennessee and Kentucky, and of his own researches.

As the space allotted to this subject is limited, it is not possible to present detailed descriptions of the several formations or to give geologic sections of specific localities or lists of the important fossils. Further information will be found in the publications listed in the bibliography (pp. 840–865) under Nos. 141, 178, 179, 212, 214, 369, 403, 404, 405, 438, 557, 580, 583, 693, 737, 744, 751, 831, 835, 843. Many of these publications contain still other citations.

A series of reports on the Atlantic and Gulf Coastal Plain of the United States is in preparation in cooperation between the United States Geological Survey and the respective State surveys. These reports will present as complete discussions of the different geologic formations, the geologic structure, etc., as present information will permit.

GENERAL CLASSIFICATION.

For the Eocene formations a classification into four groups has been adopted in the Gulf and South Atlantic Coastal Plain region. The type sections of the three lower groups occur in Alabama along Alabama and Tombigbee rivers, and that of the highest is in Mississippi. These groups are the Midway, Wilcox, Claiborne, and Jackson. The marine Oligocene is divided into two groups—a lower, the Vicksburg, and an upper, the Apalachicola. The former takes its name from Vicksburg, Miss., the latter from Apalachicola River, Florida. The non-marine Oligocene of southern Alabama, Mississippi, Louisiana, and Texas has received no group name. The Catahoula sandstone and the Fleming clay of Louisiana and Texas, which are mostly of upper Oligocene age, are described on pages 729–730.

Each stratigraphic group will be described in ascending order, its distribution and variations being indicated.

EOCENE.

Midway group.[403]—This group takes its name from Midway Landing, on Alabama River, in Alabama, where it is divided into three formations.[749] The lowest, the Clayton limestone, rests unconformably on the Upper Cretaceous. It is an impure limestone 25 feet thick in western Alabama along Tombigbee River, but it increases in thickness to the east and along Chattahoochee River includes fully 200 feet of alternating calcareous sands and limestone. The Clayton limestone is overlain by the Sucarnochee clay, which on Tombigbee River is a series of black or dark-brown clays at least 100 feet thick. At Black Bluff, on Tombigbee River, these clays contain a few fossils but except in the lowermost strata are almost devoid of lime. Toward the east, however, they become more calcareous, and in Wilcox County, east of Alabama River, they form the basis of some fine black prairie lands. This formation has not been traced east of Wilcox County. The Naheola formation, which conformably overlies the Sucarnochee clay along Tombigbee and Alabama rivers, is composed of 150 feet or more of gray sandy glauconitic clays, containing many marine fossils. It does not extend so far eastward as Chattahoochee River.

The Midway group has been identified along Chattahoochee River between Alabama and Georgia, in the vicinity of Fort Gaines, whence it extends as a narrow belt, only a few miles wide, in a northeast direction to Montezuma, on Flint River, and a short distance beyond into Houston County.[a] As the group in Georgia has not been subdivided into formations, it is termed the Midway formation in this State. It is separated from the Upper Cretaceous by small erosion unconformities, but at no place has there been found good evidence of any profound physical break between the two. According to Veatch, "the formation is mainly a marine deposit consisting of sands, clays, and marl or limestone. The sand is varicolored, generally loose or friable, and contains lenticular layers of white clay. A characteristic of the lower part of the formation is a rather wide distribution of limonite in thin crusts in the sand and sandy clay and in the form of hollow concretions having black, polished botryoidal interiors. The limestone is fossiliferous and in general highly arenaceous, but in a few places it is sufficiently pure for use in the manufacture of lime. Friable marls, made up of glauconitic quartz sand, clay, and shells occur, and also laminated black clay and fuller's earth. The limestone is conspicuous at several localities and is the phase of greatest stratigraphic importance because it is abundantly fossiliferous, but sand and clay probably make up the greater part of the deposit. The thickness of the Midway on Chattahoochee River was estimated as 218 feet by Langdon.[b] The thickness to the northeast is probably greater, and although it can not be accurately estimated, it is probably as much as 400 feet."

There are no known exposures of the Midway formation east of Houston County in Georgia, nor are there any in South Carolina east of Santee River. Sloan[744a] has described an occurrence in the vicinity of Georgetown, at Perkins Bluff on Black River, of 16 feet of buhr rock, silicified black shale, and compact red sands, immediately and unconformably overlying the Peedee (Cretaceous). Species of Midway fossils were obtained from the material at this locality. This is Sloan's Black Mingo formation, and he has also referred to it other outcrops along Black and Sampit rivers.

West of Alabama the Clayton limestone, the lowest formation of the Midway group, extends into Mississippi, where it is represented by a series of hard crystalline limestones and calcareous sandy marls. The limestone of this formation was referred by Hilgard to the Ripley (Cretaceous), but later investigation by Harris and others has, on paleontologic evidence, placed it in the Midway. The limestone has a maximum thickness of 20 feet near the town of Ripley. It is overlain by 20 to 30 feet of reddish to yellow sandy marl containing lime carbonate and is slightly fossiliferous. The reddish color is due to a large amount of iron oxide. The Clayton outcrop forms a narrow strip of territory from 2 to 6 miles wide, lying just west of the Ripley (uppermost Cretaceous) area. The line of the New Orleans, Mobile & Chicago Railroad approximately follows the outcrop from Middleton, Tenn., to Houston, Miss., where the outcrop turns in a southeasterly direction west of Starksville and Macon and passes into Alabama southeast of Scooba.[c]

In Mississippi the calcareous sandy marls of the upper Clayton are overlain by 75 to 100 feet of gray nonfossiliferous clay, which forms the well-known "Flatwoods" area, extending from Tennessee into Alabama. To this clay Crider applied the name Porters Creek clay, originally used by Safford in Tennessee. It corresponds approximately to the Sucarnochee and Naheola formations of the Alabama section.

The Midway group is represented in Tennessee by the Porters Creek formation as described by Glenn.[369] Harris presents in his monograph on the Midway, already cited, definite evidence that the Porters Creek clay of Safford included Midway. According to Glenn, the Porters Creek formation rests unconformably on the Ripley (Cretaceous). He says:[369b]

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[a] The Tertiary descriptions for Georgia are based on a manuscript furnished by Otto Veatch, who has since published a report by himself and L. W. Stephenson.[843] The paleontologic determinations and correlations were made by T. W. Vaughan.

[b] Smith, E. A., Johnson, L. C., and Langdon, D. W., Report on the geology of the Coastal Plain of Alabama: Geol. Survey Alabama, 1894, p. 369.

[c] Descriptions of the Tertiary formations of Mississippi are modified from A. F. Crider's "Geology and mineral resources of Mississippi" (Bull. U. S. Geol. Survey No. 283, 1906) and A. F. Crider and L. C. Johnson's "Summary of the underground water resources of Mississippi" (Water-Supply Paper U. S. Geol. Survey No. 159, 1906).

"The formation is composed mainly of a fine-grained clay that is very dark gray or in places almost black when wet, but which becomes a light gray on drying. It is familiarly known in the region as soapstone. Interbedded with this clay are sometimes found, especially in the lower part of the formation, beds of fine micaceous silty sands, which are usually indurated to soft sandstones. The lower part of the formation also contains interbedded with the gray clay and micaceous sand beds of greensand that may contain enough calcareous matter to cement certain layers into pure limestone. The calcareous matter has doubtless been derived from marine shells, the hollow impressions of which are abundant in some of the more calcareous beds. Such beds have been found near the base of the Porters Creek formation at intervals from a point just east of Middleton, Tenn., nearly to Paducah, Ky."

The thickness of the formation is about 175 feet, and Glenn states that it "outcrops immediately west of Ripley in a belt about 8 miles wide in southern Tennessee, but averages only about 4 miles in width across the State. In Kentucky it widens out again, reaching 10 or 12 miles in northern Calloway County. The outcrop narrows much as it curves westward beyond Paducah and is concealed by the alluvial deposits of Ohio River before crossing the Illinois. In Illinois it is known to outcrop only along the bank of the Ohio, at Caledonia Landing, and for some distance to the north toward Grand Chain. The exposures are for the most part poor, however, and its identification is made partly by a few indistinct fossil casts but mainly by the presence of greensand, which is absent from the Ripley below and the Lagrange above but which is found in the lower part of the Porters Creek. Farther west, across southern Illinois, its outcrop is obscured by either the Lafayette gravels and the loess or by the alluvial deposits of the Cache and Mississippi River bottoms."

Shepard[737a] states that the Porters Creek formation "has been identified in Missouri wells at but one point. It was reached in the Morehouse well at a depth of 248 feet, where it consisted of 197 feet of bluish gumbo."

Wilcox group.[404, 405]—This group takes its name from Wilcox County, Ala., where unusually good exposures of it are recorded. In that State it forms the most massive of the Eocene groups, having a thickness of probably not less than 900 feet. It also presents a great variety in lithologic character and in fossil contents. In general terms the Wilcox strata are cross-bedded sands, thin-bedded or laminated sands, laminated clays, and clayey sands, with beds of lignite and lignitic matter. With these are found, interbedded at several horizons, strata containing marine and estuarine fossils. The fossil-bearing beds form the basis for the separation of this group into four formations, which Smith[749a] describes as follows:

"The lowest formation of the Wilcox group, the Nanafalia, overlies the Naheola formation of the Midway and maintains a tolerably uniform thickness of about 200 feet entirely across the State. These beds are mostly sandy but contain great numbers of the shells of a small oyster, *Gryphæa thirsæ*. Near Alabama River and for a short distance to the east a gray siliceous clay with a tendency to indurate into a tolerably firm rock resembling very closely some of the strata of the Tallahatta buhrstone of the Claiborne group, * * * is a characteristic feature of the whole section. At the base of the oyster-shell beds there are, at certain localities, other fossiliferous beds containing a great variety of forms.

"At the bottom of the Nanafalia formation there is a bed of lignite, 5 to 7 feet thick, which may be traced across the country from Tombigbee River into Pike County, where it is well exposed near Glenwood station, not far from Troy.

"The Tuscahoma formation, which overlies the Nanafalia, is about 140 feet thick and consists mainly of gray and yellow cross-bedded sands and sandy clays, generally poor in fossils except at one horizon, which is typically exposed at the locality from which the name is taken and at Gregg's and Bell's landings on Alabama River.

"Above the Tuscahoma is the Bashi formation, which averages perhaps 80 feet in thickness. It is composed of the sands and sandy clays common in the Tertiary. It is distinguished by a characteristic bed of highly fossiliferous greensand with associated beds of lignite immediately below it. By these features the Bashi may be easily identified across the width of the State. The best exposure of the fossiliferous greensands of this formation is at Woods Bluff, on Tombigbee River.

"The Hatchetigbee formation, the uppermost formation of the Wilcox group, is composed of beds of brown, purple, and gray laminated sandy clays and cross-bedded sands abounding in characteristic fossils. It is about 175 feet thick in the vicinity of Tombigbee River, but it thins to the east, though otherwise maintaining its distinctive character. These beds have been named Hatchetigbee from a bluff on Tombigbee River."

The Wilcox group extends eastward into Georgia, where it has not been subdivided into formations and has a small areal distribution. It is best exposed in the bluff of Chattahoochee River at Fort Gaines and probably continues northeastward to Flint River, but it is not easily differentiated from the Midway, except at Fort Gaines. At Fort Gaines the Wilcox and Midway are separated by a distinct erosion unconformity represented by old potholes in the limestone of the Midway filled by black sandy clay of the overlying formation. Evidence of this erosion unconformity has not been observed farther east, but this may be due to the imperfection of the natural exposures of the strata. The contact with the overlying Claiborne, where observed, is generally an undulating line of small pebbles or a stratum of coarse sand, and there is no physical evidence of any considerable time interval between the deposition of the two. According to Veatch—

"Along Chattahoochee River the formation is made up of a sandy glauconitic calcareous shell marl, in places indurated, overlain by dark laminated, often lignitic sandy clays, some beds of which are consolidated into mudstone. To the east, in Randolph County, appears glauconitic clay like fuller's earth, but near Flint River the formation is chiefly sand, in which there are massive beds of white clay.

"The thickness lying between the Claiborne and Midway at Fort Gaines is about 75 feet. The maximum thickness at any place over the area of outcrop is probably not more than 150 feet. This is not in agreement with the thickness on the Chattahoochee, estimated by Langdon[a] at 402 feet, but in view of the recent determination of strata of Claiborne age[b] in the upper part of the bluff at Fort Gaines, it is not improbable that a portion of Langdon's 'Lignitic' belongs to the Claiborne formation."

No outcrops definitely known to represent the Wilcox group occur between Flint River in Georgia and Santee River in South Carolina. In the latter State, on Dr. W. S. Boyd's plantation (the old Gourdin plantation), Sloan collected from a silicified rock fossils characteristic of the Nanafalia formation of the Wilcox group. For the formation containing these fossils Sloan has proposed the name Williamsburg. It has probably been identified at Manning.

West of Alabama, in Mississippi, the Wilcox group has not been subdivided into formations and is known as the Wilcox formation. In this State it is of a more or less sandy character throughout. Crider and Johnson[179a] say:

"The coarse-grained, unconsolidated sand beds are often interbedded with seams of lignite and white and chocolate-colored clays. The clays of the upper division, as at Grenada, are very dark and may properly be called shale. In the eastern half of the area loosely bedded sands predominate. The western portion, which is a series of irregularly cross-bedded sands and sandy clays, is separated from the eastern by a more or less regular line of white and chocolate-colored clays, which are used for making stoneware.

"The thickness of the group is estimated from the width of the outcrop to be 750 to 800 feet.

"The Wilcox covers the largest territory of any formation in northern Mississippi. It occupies the entire area lying between the Porters Creek outcrop and the bluffs on the eastern rim of the Yazoo Delta as far south as Grenada. The west edge south of Grenada is a line extending southeast 6 miles east of Winona, west of Philadelphia, and southwest of Meridian."

In Tennessee, Kentucky, and southern Illinois the deposits of Wilcox age are included in the Lagrange formation of Safford, redescribed by Glenn. Harris[404] has given a résumé of the evidence on which the determinations of the Wilcox age of the strata are based. It seems

[a] Smith, E. A., Johnson, L. C., and Langdon, D. W., Report on the geology of the Coastal Plain of Alabama: Geol. Survey Alabama, 1894, p. 369.

[b] Determined by T. W. Vaughan.

probable that the Lagrange includes more than the Wilcox, probably beds of Claiborne age, and perhaps some as late as Jackson, as the formation includes all the beds between the Porters Creek clay below and the Lafayette above. The following description of the Lagrange formation is adapted from Glenn:[369]

The formation consists of interbedded sands, clays, and lignitic material. Much the larger part is sand, which is mostly fine grained, though here and there throughout the formation beds of medium or coarse sand or even gravel may be found. Such coarser beds do not seem to be continuous over any large area.

The sands exposed to view are usually strongly cross-bedded and were deposited under brackish water in a sea characterized by strong and ever varying currents. The clays of the Lagrange vary from pure, fine-grained plastic material to sandy, silty clays that are in places dark from organic matter or black from lignite. The clays of the lower part of the formation are characteristically fine grained, pure, plastic, and either very light colored or white. Chemically they are highly siliceous. The plastic siliceous clays occur as lenses embedded in the sands and outcrop in a belt along the eastern part of the Lagrange area in both Tennessee and Kentucky. Many of the beds contain great numbers of beautifully preserved leaf impressions, and numerous collections of these remains have been made. It is entirely possible or even probable that the upper part should be separated from the middle and lower parts and after very detailed work criteria may be forthcoming for this discrimination. At present it is impracticable and all the beds are lumped together, though certain facts render it probable that the upper clay is considerably younger than the plant-bearing clays in the lower part of the formation at Grand Junction, Tenn., and elsewhere. Lignitic material is found throughout the formation but is more abundant in the upper part. Glenn gives the maximum known thickness as 963 feet.

The eastern edge of the Lagrange formation extends from the southwestern part of Hardeman County, Tenn., north-northeastward through Chester, Madison, Henderson, Carroll, and Henry counties, Tenn., and southwestern Calloway, northeastern Graves, middle McCracken, and northern Ballard counties, Ky. It then passes westward into Pulaski County, Ill., not far south of Caledonia Landing. It is not possible to follow it westward across Pulaski and Alexander counties because it is concealed beneath later deposits.

Shepard [737] reports the Lagrange formation from wells in Caruthersville and Morehouse, Mo.

Claiborne group.—This group, which overlies the Wilcox, is easily divisible in Alabama into three formations, the lowest being the Tallahatta buhrstone, the middle the Lisbon formation, and the upper the Gosport sand. Smith [749b] describes the Tallahatta as follows:

"The Tallahatta buhrstone, in the western part of the State, is predominantly composed of aluminous sandstone or siliceous claystones. They vary slightly in composition but are always poor in fossils except the microscopic siliceous shells of marine diatoms and Radiolaria. To the east the percentage of clay decreases, the rocks becoming more calcareous and fossils more abundant, and in place of the silicified shell casts of the Tombigbee and Alabama drainage basins are extensive beds of shells, mostly oyster shells. The thickness of the buhrstone varies from 400 feet in the western part of the State to 200 feet in the eastern part. In the western part of Alabama and still more in Mississippi, beds of fossiliferous greensand are abundant in both the Tallahatta and in the Lisbon strata of the Claiborne. The decay of the greensands has in many places given rise to the accumulation of deposits of brown iron ore. The Tallahatta buhrstone as here defined is the equivalent of the Siliceous Claiborne of Hilgard."

The Lisbon formation lies between the Tallahatta buhrstone and the Gosport sand and consists of about 115 feet of calcareous clayey sands and sandy clays, generally fossiliferous. It is thus described by Smith.[749c]

"The lower half of these beds contains a great number and variety of well-preserved shells; in the upper half the shells of *Ostrea sellæformis* and several species of Pecten greatly preponderate over other forms. The most characteristic exposures in Alabama of these beds, which are the equivalents of Hilgard's Calcareous Claiborne, are at the Claiborne and Lisbon bluffs on the Alabama River."

The Gosport sand, according to Smith,[749c] "so far as yet known, does not appear in any other of the Gulf States but embraces the strata of the Claiborne group lying between the top of the Lisbon and the base of the St. Stephens. The beds are in general highly glauconitic sands about 30 feet in thickness at the Claiborne and Gosport bluffs and include the fossiliferous greensands which have made the name Claiborne famous and which have furnished the greater part of the Claiborne fossils described and figured by Conrad and Lea. While this division, as above mentioned, is not known in Mississippi, Louisiana, or Texas, yet its importance in Alabama, from the historical point of view and because of the great number and variety and beautiful state of preservation of its fossils, is such as to compel mention and a distinct name. This member of the Claiborne group has been observed at a number of localities in Monroe, Clarke, Choctaw, and Washington counties. The name is from Gosport, a landing on the Alabama River a few miles below the Claiborne Bluff."

In Georgia,[843] although in a general way the correlatives of the formations of the Claiborne group in Alabama may be recognized, the extension of the formational nomenclature used in that State is inappropriate, for the group is not naturally divisible into the same units. The divisions recognized are the Barnwell sand and the McBean formation, with the Congaree clay member at its base.

The McBean formation rests unconformably upon strata of Lower Cretaceous age east of Ocmulgee River, and tongues of the formation extend to the crystalline rocks of the Piedmont area. Between Flint and Chattahoochee rivers the McBean rests upon the Wilcox formation, with evidence of an erosion unconformity along Chattahoochee River in the vicinity of Fort Gaines. In eastern Georgia the formation is overlain by the Barnwell sand, the relations between the two formations being somewhat obscure. Along the northern margin of the areal occurrence of the Barnwell sand there is evidence of an unconformity of slight time importance, but farther south the sand seems to rest upon the McBean formation with conformable relations. It seems probable that near the close of McBean time there was an uplift which brought the northern margin of the area of Claiborne deposition above sea level, permitting erosion to take place along the margin of the emerged area, while deposition continued in the area which remained under water. The formation consists mainly of clays, in places having the character of fuller's earth, shell marls, sandy limestones, or calcareous glauconitic sands. The maximum exposed thickness of the formation occurs at Shell Bluff, on Savannah River, where 115 feet of strata were measured. Outcrops of the formation occur in an extremely irregular belt that extends entirely across the State and ranges from a few miles to 25 miles or more in width. East of Flint River exposures are known in Columbia, Richmond, Burke, McDuffie, Jefferson, Glascock, Washington, Baldwin, Wilkinson, Jones, Twiggs, Bibb, and Houston counties. There are also exposures on Flint River in eastern Sumter county and along Chattahoochee River from Fort Gaines southward.

The Congaree clay member in eastern Georgia rests directly upon the Lower Cretaceous, the contact being marked by conspicuous erosion unconformities. It is conformably overlain by the clays and marls of the McBean formation or by the Barnwell sand, either passing into the latter by gradation or in some exposures being separated from the former by unconformities. Lithologically the Congaree clay member consists of fuller's earth in which are small lenses and pockets of sand; in some places it contains large amounts of disseminated lignitic matter and thin beds of lignite. The thickness of this member is at least 100 feet. There are numerous outcrops of the Congaree clay member from Grovetown southwestward along the "fall line" to Bibb and Twiggs counties. It is confined to the northern part of the area of the outcrop of the McBean formation, but no sharp lines separating the member either from the marls of the McBean formation or from the overlying Barnwell sand can be drawn. Clays and fuller's earth of the same general character as the Congaree clay member also occur in the vicinity of Chattahoochee River near the northern margin of the area of outcrop of the McBean formation.

The Barnwell sand directly overlies the McBean formation and is in contact with both the marls and the Congaree clay member. Along the northern margin of the Barnwell sand area there is evidence of a local unconformity with the underlying McBean formation, but farther south the relations are conformable. The Barnwell sand is overlain by the Jackson formation, but as the exact contact between the two has nowhere been observed the nature of the contact is not known. In Burke and Screven counties the formation is overlain by the Vicksburg formation and in places questionably by the Chattahoochee and Alum Bluff formations. In the eastern part of the State the Altamaha (Lafayette?) formation probably originally covered a large part of it. The Barnwell sand consists largely of unconsolidated red and varicolored sands with some thin layers of sandstone, quartzite, silicified limestone or flint, and siliceous limonite. The sands, especially where weathered, are somewhat similar in appearance to the red residual sands of the Vicksburg formation. The maximum measured thickness of the Barnwell sand is 105 feet. East of Ocmulgee River the Barnwell sand is practically coincident in distribution with the Claiborne group as a whole. The formation overlies both the marls and the clays of the McBean formation and extends to the "fall line." It is probable that red sands between Flint and Chattahoochee rivers belong to this formation, but as yet no positive statement can be made.

In South Carolina the Claiborne group attains an extensive development, and Sloan[744d] has applied a number of names to its local phases, some of which are of considerable importance. The names he proposed are Congaree, Warley Hill, Cawcaw, Santee, Barnwell, and Mount Hope. Near Savannah River the succession of material is similar to that in Georgia At the base are silicified clays, fuller's earth, the Congaree shales of Sloan; these are overlain by glauconitic sandy marls, locally with silicified shells and buhr rock, and calcareous beds, the Cawcaw shales and marls of Sloan, which are equivalent to his Warley Hill marl, Santee marl, and Mount Hope marl of the Santee area and which are succeeded by calcareous beds containing in their lower portion large numbers of *Ostrea georgiana*, these beds in turn being overlain by red sands, the typical Barnwell buhr sand of Sloan.

In the region of Santee River the geologic section is decidedly different in some respects from that of Savannah River. The Congaree shales of Sloan can be identified, overlain by glauconitic, more or less calcareous sands (the Warley Hill of Sloan), which is overlain by a soft limestone (the Santee marl of Sloan), and this is succeeded by Sloan's Mount Hope, a limestone largely composed of Bryozoa, among which are mollusks of Claiborne age.

In Mississippi the Claiborne is divisible on lithologic grounds into three distinct formations. The lower of these is the Tallahatta buhrstone, which is overlain by the Lisbon formation, and at the top is the Cockfield formation.

According to Crider and Johnson,[179b] the Tallahatta buhrstone, "called 'siliceous Claiborne' by Hilgard, consists chiefly of glauconitic coarse-grained micaceous sandstome that is almost quartzite The estimated thickness is 350 feet. The formation outcrops in a belt of territory between the Wilcox and Lisbon beds and varies in width from 10 miles in northeastern Clarke County to 30 miles in Leake and Winston counties. The eastern line of outcrop is traceable from the Alabama line 4 miles south of Hurricane Creek post office to Eastville; thence it swings southwest nearly to Sterling, south of Meridian, thence it bends northwest past Battlefield, Philadelphia, Plattsburg, Hinze, and French Camp, 6 miles east of Winona, and west of Grenada. No trace of the Tallahatta has been found north of Yalobusha River.

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"Above the Tallahatta is a series of beds which Hilgard called 'calcareous Claiborne' and which will be termed the Lisbon formation. The series is about 150 feet thick and is composed of calcareous sands and laminated and lignitic clays. The character of the surface is little affected by the Lisbon, which is almost everywhere overlain by the Lafayette. In Alabama the area underlain by this formation is limited in extent, but in Mississippi it widens out and occupies the territory from southeastern Clarke to southern Carroll County, varying from 5 to 25 miles in width."

Hilgard[438d] has described "beds intervening between the Claiborne and Jackson groups" These beds are exposed where the Quitman and Winchester road crosses Coonupy Creek, on the banks of Chickasawhay River due west of the locality just mentioned, and at other places in the same vicinity. They also outcrop at Garlandsville, Jasper County, and extensive beds of earthy lignite underlie the marine fossiliferous Jackson at Jackson, Miss. At the latter place, "in the penitentiary well after passing through 32 feet of surface material and fossiliferous strata of the Jackson age, lignitic clays were penetrated for 418 feet, after which a bed of shells 20 feet thick, extremely rich in greensand, was passed through into water-bearing sand." The lignitic sands and clays intervening between the marine fossiliferous Jackson and the marine Claiborne occupy precisely the stratigraphic position of the Cockfield formation of Louisiana; and the use of that name is extended so as to apply to them.

Jackson group.—This group, which is called a formation where not subdivided, has its typical outcrop in the vicinity of Jackson, Miss, from which place it takes its name.

In Mississippi, according to Crider and Johnson,[179c] "the essential materials of the Jackson group are gray calcareous and lignitic clays and sands. The outcrop occupies a belt of country 10 to 30 miles wide, extending southeast and northwest across the State from Yazoo to the Alabama line north of Waynesboro The area is known as the 'central prairie.' * * *

"The Jackson has usually been described as 'marls' and clays, but recent investigations along the line of contact with the Vicksburg have shown that there are between 50 and 75 feet of yellow, gray, or white siliceous sand at the top of the Jackson. Whether from a paleontologic standpoint this should be considered Jackson or Vicksburg we are unable to say, since no fossils have been found in the sands They are regularly stratified, showing that they were deposited in a quiet sea with little or no current In places near the surface the sands are slightly cemented with iron oxide, causing some layers to resist erosion more than others."

For Alabama Smith[749d] says: "Above the Claiborne, and constituting the uppermost member of the Eocene in Alabama, is the St. Stephens limestone, equivalent in part to the Vicksburg limestone and in part to the Jackson limestone of Mississippi. In Alabama these two formations blend so completely that it has been impossible to draw clearly the line of demarcation between them, and the St. Stephens is therefore intended to include the Alabama representatives of both. Immediately overlying the Claiborne fossiliferous sands, at many points in Clarke, Choctaw, and Washington counties, is an argillaceous limestone closely resembling the Selma chalk and like it giving rise to rich black limy soils. The fossils of this bed show that it is probably of Jackson age, but the great mass of the St. Stephens formation, between 200 and 300 feet thick, consists of a limestone of a considerable degree of purity in which the ever present fossil is a nummulitic shell, *Orbitoides mantelli*. Other shells also abound, but this is characteristic."

More detailed paleontologic investigation in Alabama will probably differentiate the Jackson and Vicksburg. This opinion is borne out by some incomplete and unpublished studies of Vaughan.

Veatch states that "in Georgia the area underlain by the Jackson formation, so far as known, is very small. The largest area is in Houston, Twiggs, and Pulaski counties. There is an isolated occurrence at Rich Hill, Crawford County, one on Oconee River in Johnson County, and probably one on Chattahoochee River near Alaga, Ala.

"The formation is the uppermost Eocene exposed in Georgia and lies directly beneath the Vicksburgian Oligocene. No evidence of a time interval between the deposition of the two has been observed, and there seems to have been no interruption in the sedimentation, although there are lithologic differences. While the formation is known to overlie the Claiborne, contacts between the two formations have not been discovered. The Jackson at Rich Hill, Crawford County, rests upon lower Cretaceous strata.

"The Jackson consists mainly of white or cream-colored massive-bedded limestone, overlain by calcareous, glauconitic, or sandy laminated clay. The limestone is highly fossiliferous, and in places the rock is made up almost entirely of a friable mass of Bryozoa and shells.

"The thickness of the formation can not be determined with much accuracy, as the line of contact between it and the Claiborne or underlying formation has not been definitely located.

The formation has a low southward dip and the width of the outcrop is only a few miles, so that the total thickness probably does not exceed 150 or 200 feet."

On the South Carolina side of Savannah River, at Johnson's Landing, are exposures of silicified limestone which is replete with Bryozoa and contains a few specimens of *Pecten perplanus*. This rock may belong to the Jackson, but in this region the exposures are poor and fossils are rare and not well preserved, rendering it difficult to discriminate between Jackson, Vicksburg, and Chattahoochee.

The thick beds of soft limestone exposed along Ashley and Cooper rivers in the vicinity of Charleston, called by Sloan [744e] the Ashley-Cooper marl, are referable to the Jackson group. The marl is green-drab or gray-green and slightly plastic when wet, but is lighter in color and more pulverulent when dry. The marl along Cooper River usually contains less than 2 per cent of calcium phosphate; that along Ashley River may contain as high as 15 per cent. The formation exceeds 100 feet in thickness.

OLIGOCENE.

Vicksburg group.—This group takes its name from the city of Vicksburg, Miss., in the vicinity of which are excellent exposures, especially along the bluffs of Mississippi River. The outcrops of the group extend from Louisiana to Savannah River, except where they are intersected by stream valleys. In Mississippi it consists of a semicrystalline limestone in beds varying from 1 foot to 3 feet in thickness, alternating with beds of sandy fossiliferous marl of about the same thickness. Usually the beds of limestone near the surface are more or less affected by weathering and have therefore become soft and locally yellow, but below the zone of weathering there is in many places hard blue rock. The beautiful, well-preserved fossils of the Vicksburg are found mostly in the beds of marl. The thickness of the formation is between 65 and 75 feet in Mississippi. This formation marks the end of the marine conditions of the Tertiary in western Mississippi. Its outcrop occupies a narrow band just south of the Jackson area and extends across the State from the type outcrop at Vicksburg through Warren, Hinds, Rankin, Smith, Jasper, and Wayne counties into Alabama.

In eastern Mississippi near Hiwannee, on Chickasawhay River, the base of the Vicksburg, immediately overlying the Jackson, bears fossils of an older facies than those at Vicksburg and constitutes the Red Bluff group of Hilgard, which is composed of calcareous clays and some limestone beds.

The Vicksburg continues across southern Alabama, where it has not been differentiated from the Jackson (uppermost Eocene), the two being included in the St. Stephens limestone. It seems, however, that by more detailed studies the Vicksburg and Jackson can be discriminated. The Vicksburg part of the St. Stephens limestone consists of a limestone of a considerable degree of purity, in which the nummulitoid fossil Orbitoides is persistently present. The rock is largely a foraminiferal limestone. Other fossils are present, but this one is characteristic. In some places this limestone is hard and capable of polish, but usually it is soft and easily cut with a saw. Its thickness is between 200 and 300 feet. It outcrops across Clarke, Choctaw, and Washington counties and extends eastward into Georgia and southward and southeastward into Florida.

In Georgia the Vicksburg, according to Veatch, "consists mainly of white, massive-bedded limestone interbedded with sand and clay. The limestones are extensively silicified and in many places do not appear at all at the surface but are concealed by red coarse-grained argillaceous sand and are represented by residual flint. The limestone is generally soft but in a few places is exceptionally hard and crystalline and very fossiliferous, Orbitoides, Bryozoa, pectens, and their fragments forming nearly the whole of the rock.

"The thickness of the Vicksburg in the western part of the State, to judge from well records, is hardly more than 300 feet, and there is no evidence that it is likely to exceed this at the east.

"The Vicksburg formation in Georgia underlies a large area lying mainly west of Flint River. East of Oconee River the formation is usually concealed by later formations and in Screven and Burke counties only small areas are known."

In Florida the Vicksburg group is tentatively subdivided into three formations—the Marianna, "Peninsular," and Ocala limestones. The Marianna limestone occurs in Florida mostly west of Apalachicola River; the "Peninsular" limestone constitutes that portion of the Vicksburg group underlying the Ocala limestone in Peninsular Florida and is largely contemporaneous with the Marianna limestone. Matson and Clapp [580a] give the following description:

"The Marianna limestone is thought to be the stratigraphic equivalent of the upper part of the bluff at Vicksburg, Miss., and some of the wells in west Florida enter beds of sand and clay which probably represent older horizons, but the stratigraphic relation of the formation to these older beds can not be determined. In west Florida, where this formation is recognized, it is unconformably overlain by beds belonging to the Apalachicola group or by post-Pliocene formations.

"The Marianna and 'Peninsular' formations consist of soft, porous white or light-gray limestone, sometimes resembling marl, especially when partly decomposed. Some bands of darker-colored dense limestone are reported at various localities where these formations have been penetrated by drilling, and nodules and layers of chert are common throughout them, but chert beds are especially prominent in certain horizons. The chert beds are usually darker in color than the limestone and range in thickness from a fraction of an inch to 12 or 15 feet. In some localities as many as six or seven successive beds of chert have been encountered in a single well. In general the heavier layers are more persistent, and it is usually the chert which forms a nearly water-tight cap to the artesian-water beds in these formations. Certain horizons are abundantly fossiliferous, containing innumerable specimens of Orbitoides and shells of mollusks, such as *Pecten poulsoni*, etc. At several localities the rock is so soft that it can be cut into blocks with a saw, and upon exposure to the weather these blocks harden rapidly, making a very fair quality of building stone. Beds of sand, sometimes 10 feet or more in thickness, are reported in some of the wells which penetrate this formation. In general, these sands appear to be most numerous in the northwestern part of the State.

"The thickness of the 'Peninsular' limestone and the Marianna limestone appears to be exceedingly variable. The thickness given by Foerste, from his investigations of the Vicksburgian limestones in southwestern Georgia and the adjacent part of Florida, is 220 feet, and probably this may be regarded as the approximate measure of the thickness of the Marianna. On the basis of well borings Dr. Dall estimates the thickness to be over 350 feet at Gainesville, 212 feet at Lake Worth, and 1,068 feet at St. Augustine. From recent examinations of well borings by Drs. Vaughan and Bassler, limestone of Vicksburg age is known to have a thickness of over 225 feet at Quincy, 250 feet at Alachua, and 325 feet at Bartow. Apparently there is a marked thickening of these limestones from the exposures of Georgia and Alabama southward. Of all the estimates given above the one at Gainesville is probably the most reliable, because the well is cased to the bottom."

Rocks belonging to the Vicksburg group occur in deep wells on Key Vaca and Key West. The Ocala is described by Matson and Clapp [580b] as follows:

"The Ocala limestone lies stratigraphically between the 'Peninsular' and the beds here designated Apalachicola group. Lithologically it bears a strong resemblance to the underlying 'Peninsular' limestone, with which it also has a close faunal relation. These facts have led to the conclusion that the two formations are conformable, and it has also been suspected that the Ocala limestone represented a local phase of the 'Peninsular.' While the two formations are probably conformable, the extensive distribution of nummulites of the Ocala limestone shows that it represents a widespread change in conditions and is not to be classed as a mere local phase of the underlying beds.

"The Ocala limestone, as already noted by Johnson, is sometimes wanting, so that the overlying formations rest directly upon the 'Peninsular.' This relation was noted at several localities which will be mentioned in discussing the younger formations. At present it is sufficient to note its absence and to suggest that since the Ocala limestone does not appear to be a local phase of the 'Peninsular,' there is probably a stratigraphic break between the rocks belonging to the Vicksburg and Apalachicola groups in the central part of the peninsula.

"The Ocala limestone consists of a soft, porous light-gray to white limestone which bears a strong lithologic resemblance to the underlying 'Peninsular' limestone, but is distinguished from it by the included fossils. When slightly weathered the rock becomes light yellow and owing to its granular appearance is often regarded as sandstone. The removal of the calcareous material by the leaching action of underground water leaves a pale-yellow, more or less incoherent sand, containing a small percentage of calcium carbonate. When fresh the Ocala limestone is so soft that it is easily broken, but exposed surfaces often become hardened by the deposition of calcium carbonate from the waters which emerge along the outcrop. For this reason the rock frequently appears to be hard and firm. Its porosity and ready solubility permit the formation of numerous underground channels which are sometimes seen at the outcrop and are inferred from the presence of numerous sink holes. The rock contains an abundance of organic remains which are commonly preserved as casts. Nodules and large masses of chert are also common and in some localities a large part of the rock has been silicified." * * *

"The greatest thickness noted during the recent field investigation was in a sink hole near Ocala, where the formation is exposed to a depth of about 40 feet without reaching its base."

Apalachicola group.—The following descriptions are adapted or copied from Matson and Clapp.[580c] In Florida "the Apalachicola group includes a number of beds differing widely in lithological character, though they are recognized by their fossils as integral parts of a single group. While limestones and marls predominate, the group also includes beds of nearly pure sand and clay. The entire period of deposition appears to have been characterized by the accumulation of more or less terrigenous materials, and hence the limestones are usually rendered somewhat impure by an admixture of clay and sand. At certain times the conditions appear to have been especially favorable for the development of organic life, and some horizons, such as the Chipola marl member of the Alum Bluff formation and the 'silex bed' of the Tampa formation, contain very large faunas.

"Owing to the lithologic variations and widely separated exposures, the exact correlation of the formations of this group is dependent upon their organic remains. While the paleontological studies, especially those made by Dall, have shed much light upon the stratigraphic relations of the different beds, there are still many points which can not as yet be fully decided. For this reason it seems best to retain the names of various beds and to indicate as far as possible their known relationships. The Apalachicola group is separated into four formations—the Chattahoochee, the Hawthorne, the Tampa, and the Alum Bluff. There is, however, some reason for believing that the first three are, in part at least, synchronous, though exact equivalence is difficult to determine where outcrops are widely scattered and faunal variations are slight. The Alum Bluff formation is clearly younger than the Chattahoochee formation, upon which it rests."

The Hawthorne formation, "according to Dr. E. H. Sellards, is a light-colored soft, porous limestone. The original building-stone quarry which is located near the station of Grove Park, about 3 miles west of Hawthorne, is now abandoned and is badly overgrown, so that the thickness of this limestone can not well be determined. At the old phosphate mine, which is at least a mile southwest of the stone quarry, the rock is a phosphatic conglomerate. At many localities the limestones of the Hawthorne formation are silicified, forming bowlders and beds of chert. This is a very common condition in the rock-phosphate region, where these limestones rest directly on those belonging to the Vicksburg group.

"Beneath the phosphatic limestones of the Hawthorne formation are beds of sand, sandstone, or gravel, which are underlain by several feet of clay. The sand beds at some localities contain iron oxide which forms a coating on the grains of silica. The clays are greenish and locally sufficiently calcareous to be called a marl. The thickness of the Hawthorne formation varies greatly, the maximum amounting to approximately 95 feet. The three members of this formation with their maximum observed thicknesses, according to Dall, consist of greenish clay 70 feet, ferruginous yellow sandstone 4 feet, and phosphate rock 20 feet. The maximum thickness of the Hawthorne formation, as given by the same author, is 125 feet. However, over a large part of the peninsula, where the sole representative of the Hawthorne formation is the phosphatic or siliceous rock, the thickness is but a few feet.

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"The Chattahoochee formation consists of light-colored limestones and marls, containing some thin beds of chert, clay, and sand. The colors vary from creamy white to light gray or green on recently exposed surfaces to light yellow, brown, or more rarely pink on weathered outcrops. Lithologically there is a gradation from nearly pure limestone to sands and clays, but in general the argillaceous and siliceous limestones predominate, forming impure limestones or marls. The formation is in part composed of semicrystalline limestone, but soft, loosely coherent rock resembling an impure chalk is more common. While chert beds occur at various horizons, they are much thinner and less persistent than those of the underlying group. At times organic life appears to have been abundant and hence some layers are very fossiliferous, though the fossils are usually preserved in the form of imperfect casts and molds which have been left by the solution of the shells.

"Vaughan's observations along the Apalachicola River show that the Chattahoochee attains a considerable thickness near the type locality.

"Well borings from Quincy indicate that the thickness of the Chattahoochee formation at that locality is slightly greater than 100 feet, but here, as elsewhere, it is difficult to determine the exact thickness of formations from well samples. The maximum thickness of the formation is probably double the figure given above and it may be even as great as 250 feet."

The Tampa formation, named from the city of Tampa, has as its upper member "a well-stratified greenish clay containing some calcareous nodules and thin beds of limestone near the base. Scattered throughout the clay are many silicified corals, some of them having a diameter of 2 or 3 feet. The clay is very plastic and hence is valuable for the manufacture of brick. Beneath this clay is the light-gray to yellow limestone which was formerly called the 'Tampa limestone.' The 'silex bed' represents a silicified zone in this limestone and is therefore a zone of replacement. This is well shown by some of the fossils, which have been only partially silicified, and by the presence of more or less unaltered carbonate of lime in the original rock. Small nodules of chert occur at other horizons in the limestone, and outcrops of the rock are often denser and harder than exposures in quarries. Locally the limestone is hard enough to make a durable building stone. Fossils are abundant in some parts of the limestone, but they are largely represented by casts and molds, which have been left by the solution of the original shells. The 'silex bed' contains numerous fossils which have been wholly or partly replaced by chalcedony. Resting upon the 'silex' at some localities is a siliceous residual material which was formerly thought to be infusorial earth but is now known to be weathered material derived from the underlying rock. In such cases the action of the percolating water has removed the matrix, leaving many beautifully preserved pseudomorphs and casts of shells. These fossils are commonly composed of chalcedony which frequently exhibits the characteristic markings of the original shells.

"Beneath the limestone beds is a greenish clay which commonly contains a considerable admixture of sand. This clay is very plastic and resembles the clay which overlies the limestone. Judging from well records, the deposit is homogeneous, but there is a possibility that the sand contained in the well samples may be derived from thin sand partings in the clay bed.

"The information concerning the thickness of the Tampa formation is meager, but it is sufficient to fix the maximum thickness at more than 130 feet. The clay bed at the top of the formation has a known thickness of 15 feet. The limestone between the 'silex bed' and the upper clay is about 40 feet thick. The thickness of the 'silex bed' varies considerably, ranging from about 4 feet to more than 10 feet. Beneath the 'silex bed' is a limestone which has a known thickness of 6 feet. The clay bed at the base of the formation has been penetrated by two wells within 200 feet of each other, and the thickness varied from 41 feet to 64 feet.

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"The Alum Bluff formation consists of marl, sand, and clay, which are sometimes fairly distinct but more often interbedded. Limestones also occur in the formation, but they are not extensively developed and usually contain enough earthy material mixed with the carbonate of lime to form marls. Shell marls with a calcareous or sandy matrix are common and they often occur interbedded with nearly pure sand. In general the beds belonging to this formation are light gray, but occasionally shades of green or yellow prevail. * * *

"The typical Alum Bluff formation consists of coarse light-greenish gray to white argillaceous sands, often showing cross-bedding and usually containing more or less interbedded clay and fuller's earth. One of the most characteristic features of the sands is the presence of innumerable flakes of white mica—the 'isinglass' of the well diggers. The change from the shell marls of the Chipola marl member is by a transition zone which contains some of the same species of shells which characterize the marls. This zone also contains nodules of calcium carbonate which often inclose fossils. The upper part of the sand is usually free from shells but occasionally contains impressions of leaves and fragments of plants. Locally the Alum Bluff formation contains some clay, and near Chattahoochee it consists of greenish sticky marl.

"The fuller's earth has the appearance of a dense, hard fine-grained siliceous clay. It is thinly laminated and commonly light gray to greenish in color. Sand partings sometimes occur, but they are comparatively rare, the material usually being homogeneous. Beds of sand and clay are commonly associated with the fuller's earth, the sections consisting of interbedded sand and clay.

"The aggregate thickness of the Alum Bluff formation is at least 135 feet, but the maximum thickness of a single section is scarcely one-half that amount. It is doubtful if the total thickness is represented in any single section. The thickness of the sands of the Alum Bluff formation at the type locality is about 20 to 25 feet, but farther north, at Rock Bluff, Dall reports a maximum of 63 feet. The fuller's earth commonly occurs in beds of 2 to 10 feet in thickness associated with several feet of clay and sand or sandstone. In some places two or more beds occur in the same section, separated by beds of sand and clay. The maximum observed thickness of fuller's earth in a single section is about 15 feet, and the aggregate thickness of the associated clays and sand which appear to belong to the same horizon is not less than 20 feet."

Three members of the Alum Bluff formation have been recognized—the Chipola marl member, the Oak Grove sand member, and the Shoal River marl member.

"The Chipola marl member, named from Chipola River, forms the basal portion of the Alum Bluff formation and rests conformably upon either the Chattahoochee or the Hawthorne formation. At the type locality of the Alum Bluff formation it constitutes the basal division of that formation, but farther north it thins and permits the sandy beds of the Alum Bluff to lap over on the Chattahoochee formation.

"When fresh this member consists of a light-gray to yellow marl, containing many shells and shell fragments. The matrix is composed of calcareous clay containing a small percentage of fine sand. When weathered the marl becomes dark yellow or reddish yellow from the presence of hydrated iron oxide. The character of the deposit indicates comparatively quiet water, with conditions especially favorable for the development of organic life. In some localities this horizon is represented by a very sandy marl."

This member is not known to have a thickness of more than 15 feet and the average is probably only a few feet. The limestone belonging to it is so imperfectly known that a satisfactory estimate of its thickness is difficult to make. The maximum exposure which has been reported is about 10 feet.

The Oak Grove sand member, named from Oak Grove, on Yellow River, has been correlated on paleontologic grounds by Dall with the typical sands of the Alum Bluff formation. This member consists of fine-grained light-gray to greenish sands containing many excellently preserved shells. As it is not fully exposed at the type locality, where a thickness of only 2 feet is visible, it may attain a greater thickness. The fauna of the Oak Grove sand member is closely related to that of the Chipola marl member, but it contains large species of both Cardium and Lyropecten, which appear to foreshadow the large species of those genera occurring in the Miocene marls.

"The Shoal River marl member, which has recently been recognized by Vaughan, lies stratigraphically about 30 feet above the Oak Grove sand member. It thus forms the upper part of the Alum Bluff formation. In the section at Shell Bluff, on Shoal River, the lower sand represents the Oak Grove sand member and the upper fossiliferous marl horizon is the Shoal River marl member. Lithologically this member consists of interbedded greenish sands, clays, and marls. The color is usually greenish, oxidizing yellow, occasionally whitish or purplish, and the material varies in texture from fine clay to sand." This member is about 50 feet thick.

In Georgia, according to Veatch, "the area over which the Chattahoochee formation appears as a surface formation is small, being confined mainly to small exposures along streams and in lime sinks.

"Erosion unconformities with the underlying Vicksburg have been noted in the vicinity of Bainbridge by Pumpelly and Vaughan. The Alum Bluff formation everywhere overlies the Chattahoochee and there appears to have been a continuous deposition from the beginning of the Chattahoochee to the end of the Alum Bluff.

"The formation is, on the whole, calcareous and the rock varies from a compact pure crystalline limestone to earthy and argillaceous limestone and calcareous sand and sandstone. The strata are in places phosphatic, and the limestone at the base has been extensively silicified and contains a rich coral fauna.

"The formation has a total thickness of about 100 feet in the gorge northwest of Faceville, Decatur County. No very reliable data are at hand for estimating the thickness east and northeast of this point, where it is under cover of later formations. The thickness is not great, however, and is not likely to be in excess of 250 feet.

"The Alum Bluff formation underlies a very large area in Georgia, extending northeastward, from Decatur County to Savannah River in Screven and Effingham counties, the eastern limit of outcrop being 50 or 60 miles from the coast. This formation overlies the Chattahoochee formation conformably. The line of division between the two is, in places, indefinite, as there is no apparent abrupt lithologic or faunal change from one to the other. In the Savannah and Altamaha river exposures small unconformities between the Alum Bluff and the Miocene were observed. This formation presents several different lithologic phases—sand and sandy laminated clay, fuller's earth, phosphatic sand, quartzite, silicified clay, and local limestone or calcareous layers and nodules. Greenish or drab argillaceous sand and fine-grained sandy laminated clay form the greatest portion of the strata. The maximum thickness of the Alum Bluff in southwestern Georgia is estimated at 150 feet. The natural exposures on Savannah River do not exceed 25 or 30 feet. It is not probable that at any place the thickness exceeds 250 or 300 feet, even where it is under cover of the later formations."

Sediments of upper Oligocene age extend westward from western Florida to Mississippi River. The Apalachicola group, or marine upper Oligocene, has been identified by means of fossils in Alabama at Roberts and probably at Wallace. In wells at Mobile fossils characteristic of the Alum Bluff formation were encountered between depths of 1,250 and 1,550 feet; below these is limestone, correlated with the Chattahoochee formation. The marine upper Oligocene is not known west of Mobile, the sediments becoming estuarine in character as the axis of the Mississippi embayment is approached. The unpublished results of the recent field work of Matson and the parallel paleobotanic studies of Berry have shown that the leaf-bearing clays and sandstones near Chicoria, Wayne County, 5 miles south of Florence, Rankin County, and Raglan, near McCallum, Perry County, Miss., are of upper Oligocene age.[a] The exposure at Raglan (the Hattiesburg clays of L. C. Johnson) appears to represent the top of the Alum Bluff of Florida, while the one near Florence is stratigraphically lower and perhaps belongs in the upper part of the Vicksburg group. The exposure of interbedded sandstone, semiquartzitic sandstone, and clay at Grand Gulf, Miss., is, according to the available evidence, to be referred to the upper part of the lower Oligocene and is the Mississippi representative of the Catahoula formation of Louisiana at the type locality. These estuarine or fresh-water deposits of clay and sandstone represent the basal portion of the Grand Gulf group of Hilgard,[438e] which according to his definition included the sandstone and clays lying between the Vicksburg below and the Lafayette above, but which is now known to be a series of geologic formations, including

[a] Paleontologic determinations furnished by E. W. Berry.

those of lower and upper Oligocene, Miocene, and Pliocene age, with perhaps some Pleistocene. The portions of the "group" later than the upper Oligocene will be referred to in Chapter XVII (pp. 806–813). The detailed tracing of the boundaries between the successive formations is now in progress by G. C. Matson.

I 17-18, J 18, K 18-19. NORTH CAROLINA TO MASSACHUSETTS, INCLUSIVE.

The subjoined discussion of the Tertiary deposits of the northern Atlantic Coastal Plain has been prepared by William B. Clark and is based on a briefer statement [144] covering this region.

The Tertiary deposits of the Atlantic Coastal Plain overlie the Cretaceous formations unconformably. They have been as a whole even less changed than the Cretaceous, although they present much the same complexity, owing to the variation in the angle and direction of tilting during the successive movements of the sea floor in Tertiary time. The sediments in general form a succession of thin sheets which are inclined seaward so that successively later formations are found toward the east. At no point do we find a continuous sequence of these formations, a condition which must be regarded as marginal and due to the transgression and retrogression of the sea along the coastal border, as continuous sedimentation must have been going on over a considerable part of the continental shelf.

The Tertiary formations have variously transgressed the underlying deposits and at many points actually reach beyond them and rest directly on the crystalline rocks of the Piedmont Plateau. Similarly later formations of the Tertiary have in many places transgressed the earlier, and the latest formation provisionally referred to the Pliocene has been found over wide areas resting on earlier Tertiary, Cretaceous, and crystalline rocks alike.

The northern Atlantic Coastal Plain contains deposits that are referred to the Eocene, Miocene, and Pliocene epochs. The Eocene formations are best developed in Maryland and Virginia, although Eocene deposits of moderate areal extent are also known in New Jersey and North Carolina. The Miocene formations are most extensively developed in the drainage basin of the Chesapeake Bay in Virginia and Maryland, but strata of that age also cover large areas in North Carolina and New Jersey. The marine Pliocene deposits are limited so far as known to North Carolina, although the Lafayette formation, of somewhat doubtful Pleistocene or Pliocene age, covers extensive areas in North Carolina, Virginia, and Maryland. North of these States only small remnants of the Lafayette have been found.

Long Island and southern New England.—The Tertiary deposits of Long Island and southern New England are confined so far as known at the present time to a few localities on Long Island and the islands off the Massachusetts coast. The scarcity of the exposures and characteristic fossils has led to much doubt as to the age of the beds, although they have been generally regarded as Miocene. The deposits have been studied chiefly by Shaler,[728, 729, 730] Veatch,[837] Fuller, and Crosby.

On Long Island small eroded remnants of supposed Miocene strata have been found overlying the Cretaceous, and certain sandy beds penetrated in deep well borings in the vicinity of the city of Brooklyn have been thought to belong to the same horizon and have been tentatively referred to the Beacon Hill formation of New Jersey.

The residual sandy strata overlying the Cretaceous deposits at Gay Head, Marthas Vineyard, and containing a meager fauna of supposed Miocene age have also been referred to the Miocene and may represent the same horizon. Similar deposits are also reported from Block Island.

New Jersey.—The Tertiary deposits of New Jersey comprise representatives of both the Eocene and the Miocene. Some of the Miocene deposits are evidently unfossiliferous, so that their position in the sequence of Miocene strata can not be clearly determined. Among those who have studied and described these deposits may be mentioned Cook,[169] Whitfield,[926] Clark,[142, 145, 146, 152] and Salisbury.[691]

The following scheme of classification has been proposed for the New Jersey formations:

Miocene	Cohansey sand and Beacon Hill formation. Kirkwood formation.
Eocene	Shark River marl.

The Shark River, which is limited to a small area in eastern New Jersey, consists of greensand marls and apparently overlies the Manasquan formation of the Upper Cretaceous conformably. The deposits are about 12 feet in thickness. The fossils are marine invertebrates of lower Eocene age.

The Kirkwood formation consists of sands and clays which unconformably overlie the older deposits of Eocene and Cretaceous age. It has a thickness of about 100 feet and contains in places a considerable fauna of marine invertebrates similar to the Calvert fauna of Maryland and Virginia.

The Cohansey consists chiefly of buff sands, although sandy clays and coarse white sands are also found. It has a thickness of about 100 feet. No diagnostic fossils have been found.

The Beacon Hill formation consists of gravel and sand and probably represents the shoreward phase of the Cohansey sand in the northern part of the New Jersey Coastal Plain. It has a maximum thickness of about 40 feet. No fossils have been found.

The deep well borings near the coast have penetrated several hundred feet of characteristic Miocene sediments in which fossils that apparently represent the Calvert, Choptank, and St. Marys faunas of Maryland and Virginia are found. It is apparent that the Kirkwood formation represents the Calvert formation, but whether the Cohansey sand and the Beacon Hill formation should be regarded as Choptank, which they resemble lithologically, is impossible of determination in the absence of characteristic fossils. It has been suggested that the Cohansey and Beacon Hill may perhaps overlie all the Miocene formations of the Chesapeake region.

Maryland and Delaware.—An extensive series of Tertiary deposits is found in Maryland and Delaware, including representatives of the Eocene, of the Miocene, and probably of the Pliocene. All the deposits, except the Pliocene, are highly fossiliferous and have been investigated by many students of geology and paleontology. Among those who have studied the region may be mentioned Say,[704] Conrad,[168] Harris,[400] McGee,[565a, 566] Clark,[149, 150] Martin,[149] Shattuck,[733, 734] and Miller.[595, 597]

The following scheme of classification has been adopted for the Maryland and Delaware Tertiary formations:

Pliocene (?)........................Lafayette formation.
Miocene............................Chesapeake group:
- St. Marys formation.
- Choptank formation.
- Calvert formation:
  - Plum Point marl member.
  - Fairhaven diatomaceous earth member.

Eocene.............................Pamunkey group:
- Nanjemoy formation:
  - Woodstock greensand marl member.
  - Potapaco clay member.
- Aquia formation:
  - Paspotansa greensand marl member.
  - Piscataway indurated marl member.

The Aquia formation consists chiefly of greensands and greensand marls, in places highly calcareous and here and there argillaceous. These beds overlie the earlier deposits unconformably. The total thickness of the formation is about 100 feet. The Aquia formation has been divided into the Piscataway and Paspotansa members. The deposits contain a rich fauna of lower Eocene age. The formation is transgressed by the Calvert formation toward the north and disappears near the Maryland-Delaware line.

The Nanjemoy formation consists of greensands, in many places highly argillaceous but less commonly calcareous than the Aquia formation, which it overlies conformably. The maximum thickness of the Nanjemoy formation is 125 feet. It has been divided into the Potapaco and Woodstock members. It contains an extensive fauna of middle Eocene age. It is not known to occur on the eastern shore of Chesapeake Bay.

The Calvert formation, which overlies the Eocene formations unconformably, consists of sands, clays, marls, and diatomaceous earth. These deposits have a thickness of about 200 feet. The formation has been divided into the Fairhaven diatomaceous earth member and the Plum Point marl member. It contains an extensive marine fauna.

The Choptank formation consists of sands, clays, and marls and has a total thickness of 125 feet. An extensive marine fauna characterizes these deposits.

The St. Marys formation consists of clays, sands, and sandy clays, the last typically greenish blue and bearing large quantities of fossils. The formation has a thickness of 150 feet. It carries a distinctive marine fauna.

The Lafayette formation consists of clays, loams, sands, and gravels which are in many places highly ferruginous. The thickness is variable but in few places exceeds 50 feet. No characteristic fossils have been found in these deposits and there is much doubt as to whether they are of late Pliocene or early Pleistocene age. The formation covers a wide area on the southern peninsula of Maryland and is represented to the north, on the western shore of Chesapeake Bay, by many small outliers. It overlies the Miocene and earlier formations unconformably.

Virginia.—The Tertiary deposits of Virginia comprise strata of Eocene, of Miocene, and probably of Pliocene age. The Eocene and Miocene formations are highly fossiliferous. The geology and paleontology of the region have been studied by many investigators, among them Rogers,[676] Conrad,[168] Clark,[149, 150] Miller,[595, 597] Berry,[75] and Gardner.

The following scheme of classification has been adopted for the Tertiary deposits of Virginia:

Pliocene (?)........................Lafayette formation.
Miocene..............................Chesapeake group:
    Yorktown formation.
    St. Marys formation.
    Choptank formation, probably present but does not outcrop.
    Calvert formation.
Eocene...............................Pamunkey group:
    Nanjemoy formation:
        Woodstock greensand marl member.
        Potapaco clay member.
    Aquia formation:
        Paspotansa greensand marl member.
        Piscataway indurated marl member.

The Aquia and Nanjemoy formations of Virginia are similar in their lithologic and faunal characters to the same formations in Maryland, the deposits being less highly calcareous in central and southern Virginia than in the valley of the Potomac.

The Calvert formation in Virginia is similar in character to the same formation in Maryland. It disappears at the outcrop in south-central Virginia, owing to the transgression of the St. Marys formation.

The St. Marys formation overlaps the Choptank formation near the Maryland-Virginia line and in Virginia directly overlies the Calvert formation unconformably.

The Yorktown formation consists of sands, sandy clays, and marls. In many places the marls are highly calcareous and fragmental in character. The deposits have a thickness of 150 feet and contain an extensive fauna of marine animal remains. The formation overlies the St. Marys formation unconformably.

The Lafayette formation in Virginia is similar in character to the same formation in Maryland, the strata being found along the western margin of the Coastal Plain in outliers of various extent.

North Carolina.—The Tertiary deposits of North Carolina comprise representatives of the Eocene, Miocene, and Pliocene. The extent and character of the deposits have not been known until within recent years. Among those who have studied the region may be mentioned Dall,[212a] Clark,[140] Miller,[596] and Gardner. To Miller we are indebted for the detailed stratigraphy and to Gardner for an exact knowledge of the molluscan faunas.

The scheme of classification adopted for the North Carolina Tertiary deposits is as follows:

Pliocene (?)	Lafayette formation.
Pliocene	Waccamaw formation.
Miocene	Chesapeake group:
	Yorktown formation north of Hatteras axis; Duplin formation south of Hatteras axis.
	St. Marys sand (north of Hatteras axis).
Eocene	Castle Hayne limestone, Trent marl — south of Hatteras axis.

The Trent, which overlies the Cretaceous deposits unconformably, consists of calcareous marls and clays, the former locally indurated, forming a compact limestone. The deposits have a thickness of about 50 feet. The fauna consists chiefly of marine invertebrates. The formation covers a small area in the valley of Trent River.

The Castle Hayne consists chiefly of calcareous marls and sandy clays. It has a thickness of about 50 feet and contains a fauna of late Eocene age. It apparently overlies the Trent unconformably.

The St. Marys and Yorktown formations in North Carolina are in general similar in character to the same deposits in Virginia. They are both confined to the area north of the Hatteras axis.

The Duplin formation consists of sands, clays, and marls and represents the Yorktown formation south of the Hatteras axis. It has a thickness of 100 feet and contains an extensive marine fauna similar to the Yorktown but of a warmer-water facies.

The Waccamaw formation consists of sands, clays, and marls. It is confined to a narrow belt along the eastern margin of the State where it rests unconformably on older formations. It has a thickness of about 50 feet. Its fauna is marine in character and consists of characteristic Pliocene forms.

The Lafayette formation consists of sands, loams, and gravels and is confined chiefly to outliers west of the main body of Coastal Plain sediments, where it forms the series of "sand hills."

General remarks.—The Tertiary deposits of this region overlie the Cretaceous strata unconformably, but owing to the differential movements already described the later transgress the earlier formations in certain areas, so that the Cretaceous deposits are in some localities overlain by Eocene and in others by Miocene or later formations. The dip of the Eocene formations rarely exceeds 15 feet in the mile toward the east and is in many places less; the dip of the Miocene formations is 10 to 12 feet in the mile, and that of the Pliocene formations is even less.

The correlation of the Tertiary formations within the region and with other areas is shown in the following tables.

Eocene formations in northern part of Atlantic Coastal Plain.

New Jersey.	Maryland and Virginia.	North Carolina.	Alabama.
		Castle Hayne.	Jackson and Claiborne.
		Trent.	
	Nanjemoy.		Wilcox.
	Aquia.		
Shark River.			Midway.

Miocene and Pliocene formations in northern part of Atlantic Coastal Plain.

	Long Island and southern New England.	New Jersey.	Maryland and Delaware.	Virginia.	North Carolina.
Pliocene (?)			Lafayette.	Lafayette.	Lafayette.
Pliocene.					Waccamaw.
Miocene.				Yorktown.	Yorktown and Duplin.
			St. Marys.	St. Marys.	St. Marys.
	Deposits of Long Island and Marthas Vineyard.	Cohansey and Beacon Hill.	Choptank.	(?)	
		Kirkwood.	Calvert.	Calvert.	

The Eocene deposits are found in three distinct and separate regions, so that the relations of the strata in these areas to one another can not be satisfactorily determined.

The Shark River marl of New Jersey apparently overlies the Manasquan formation of the Upper Cretaceous conformably. The two formations constitute a continuous series of relatively deep water deposits, no evidence of erosional or other unconformity being found. These stratigraphic features, together with a somewhat undiagnostic Eocene fauna, have led to the reference of the beds to an earlier horizon than that of the Aquia formation of Maryland, which overlies the Cretaceous strata with a marked unconformity. The Shark River marl has been referred to the Midway horizon of the Gulf.

The Aquia and Nanjemoy formations contain a distinctively Wilcox fauna, the Aquia being clearly lower Wilcox and the Nanjemoy probably upper Wilcox, although a few Claiborne forms appear in the upper beds of the Nanjemoy and it may in part belong to that horizon.

The Trent and Castle Hayne formations occupy a small area south of the Hatteras axis in North Carolina. The faunas have not yet been fully studied, but the forms found are of late Eocene age, which would suggest their reference to the Jackson, although they may also represent a part of the Claiborne as well. The bryozoans in the Castle Hayne have led Bassler to refer this formation to the Vicksburg.

The Chesapeake group and equivalent Miocene deposits from the New England coast to the Hatteras axis in North Carolina belong to a single geologic province, the strata and the fossils presenting a marked similarity throughout, though showing indications of increasingly colder waters toward the north. The Duplin formation south of the Hatteras axis is a part of the southern province and contains a fauna characteristic of much warmer water than that of the Yorktown, the synchronous formation to the north.

The Waccamaw formation is limited to the belt near the coastal border of North and South Carolina and contains a subtropical fauna.

The Lafayette formation has been traced along the western margin of the Coastal Plain, occurring as outliers on the adjacent Piedmont Plateau, from Pennsylvania, where the last remnants are found, to North Carolina. Berry[80] has shown that the deposits at Lafayette, Miss., the locality from which the name is derived, are of Eocene age, so that the term Lafayette is really a misnomer. Much question still exists as to whether the Lafayette of the Atlantic Coastal Plain is late Pliocene or early Pleistocene.

I-J 11. GREAT BASIN, NEVADA AND CALIFORNIA.

The Esmeralda formation [814] occurs in southwestern Nevada along the base of the Sierra Nevada in the ranges developed by later Tertiary movements. It is tentatively assigned to the Oligocene and described as a lake deposit. Its general character appears to place it among the continental deposits of mixed character. The southern portion of the Great Basin, lying in southeastern California near the Nevada line, comprises Death Valley and the adjoining ranges, which are composed largely of Tertiary strata. Spurr [772a] says:

In the eastern part of the [Grapevine] range, where the road crosses from the Amargosa Valley into Furnace Creek, there is found a great amount of conglomerate, forming high hills. These conglomerates are very coarse and contain rounded pebbles and bowlders of all sizes, made up of reddish and white quartzite and black and gray limestones bearing the badly preserved Paleozoic fossils above mentioned. The conglomerate is as hard and firm as the rocks from which it is derived. It is water-laid and well stratified and evidently a shore formation. The whole thickness exposed is estimated at 4,000 feet. It is sharply folded, together with the limestones from which it is derived, but it abuts abruptly against these limestones on the west.

The irregularity of the contact between conglomerate and limestone denotes a great erosion interval, yet no unconformity of attitude is apparent.

This conglomerate seems to fringe the north edge of the bold Paleozoic scarp of the Grapevine Mountains across the greater portion of the range. It is found at various points. A little west of Pyramid Peak conglomerate occurs, interbedded with and running laterally into a hard limestone, which has all the appearance of being calcareous tufa. A specimen examined microscopically bears out this idea and shows that the rock is probably a chemical precipitate. It is like a rock found in crossing the Panamint Range from Death Valley to Windy Gap, and also like one from the Esmeralda formation, between the Candelaria Mountains and the Pilot Range.

Besides these rocks there occur, as parts of the same series, semiconsolidated gravels, with clays partially hardened to slaty shales, limy clays partially consolidated to argillaceous secondary limestones, and sands partially hardened to cherty and limy sandstones, all interbedded. All these, including the conglomerate and the limestone tufa, have a general light-yellow, often greenish color, characteristic of the series.

This sedimentary series makes up the greater portion of the Funeral Range. Along Furnace Creek valley and on both sides of it the mountains consist chiefly of yellow-green strata capped by basalt. The lava seems to occur interbedded with the sedimentaries, as well as overlying them. The series is here consolidated into a hard clay rock, with occasional thin sandstone, and the general yellow-green color is changed in places to reddish, yellowish, and pinkish. The rocks are often gypsiferous and contain abundant grass remains, which are, however, indeterminable. From the yellow-green Tertiary series in the hills just east of the mouth of Furnace Creek there has been taken much borax, which occurs as borate of lime in beds in the strata. * * *

On the eastern side of Death Valley, southward from Furnace Creek, the upturned yellow-green Tertiaries, with some few intercalated sheets of lava, constitute the mountains. Beneath some of these sheets the clays are baked to a red, natural brick. The lavas seem to occur chiefly at the top of the yellow-green series, or at a still higher horizon, for the great mass of beds exposed in the lower portion of Furnace Creek contains no lava sheets; yet in these beds occur occasionally lava bowlders and pebbles, so that we conclude that the period was one of continual volcanic activity. From fragments of lava picked up at the base of the mountains and from observations at a distance the lower lavas seem to be not so basic as the upper ones, which are chiefly olivine basalt. A single specimen of biotite andesite was all that was collected to represent these more siliceous volcanics.

Near the summit of the pass, just east of Furnace Creek, there come in above the yellow-green Tertiary series softer dark-brown honeycombed conglomerates, recalling the similar rocks of Meadow Valley Canyon. Thin sheets of basalt are interbedded with the conglomerates, but the great sheets lie on top. Patches of this same upper conglomerate series were elsewhere observed, and at one place its contact with the underlying yellow-green series appeared slightly discordant. The conglomerate contains pebbles and bowlders which are chiefly of lava and must have been derived from the sheets of basalt which were periodically poured out during the deposition of the beds.

A rough estimate of the thickness of this whole series of slightly consolidated beds and volcanics puts it at not less than 4,000 feet and the nature of the sediments shows that they must have been deposited in standing water. The presence on some of the beds of gypsum, borax, and calcareous tufa shows that at some periods the waters in which the sediments were deposited were evaporated. They were, therefore, those of an inclosed lake, which was probably of great dimensions. It is likely that a large portion of the beds were deposited in fresh water at a period different from that in which the chemical precipitates were laid down.

The borax in these beds is probably contemporaneous with the borax deposits in similar folded Tertiaries at Daggett and elsewhere in the Mohave Desert. Between these two localities, moreover, the strata, so far as known, appear to be roughly continuous. The strata of Mohave Desert are exposed on a grand scale at Cajon Pass, where they contain beds of black lignite.

Northward from Furnace Creek, at Silver Peak, are found beds of the Esmeralda formation, which are entirely similar in nearly every respect to those at Furnace Creek. Moreover, the fossils found in the Esmeralda beds indicate a nearly similar age to that indicated by fossils found in the Tertiary strata of the Mohave Desert, just west of Cajon Pass.

The upper part of the Furnace Creek beds is identical in appearance with certain semi-indurated and slightly folded conglomerates and sandstones found in Meadow Valley Canyon, which have been referred to the Pliocene.

J 10. SACRAMENTO VALLEY AND COAST RANGES, CALIFORNIA.

The general relations of the Eocene of the Pacific coast to the underlying strata are thus stated by Arnold:[31]

A widespread unconformity exists between the Eocene and the Cretaceous on the Pacific coast of North America. Throughout Washington, Oregon, and certain parts of California this unconformity is angular, while over considerable areas in California and at one locality in Oregon the unconformity may only be recognized by a more or less marked hiatus in the faunas.

It is a noteworthy fact that wherever the line between the marine Eocene formations (Martinez, Arago, Tejon, etc.) and the Cretaceous beds is marked by an angular unconformity, the underlying beds are either of lower Cretaceous (Knoxville) or middle Cretaceous (Horsetown) age, and that wherever the Eocene rests on the Chico, or upper Cretaceous, with the one exception at San Diego, the unconformity is not angular and, as far as the stratigraphic evidence goes, the two formations represent an apparent uninterrupted period of sedimentation.

The apparent conformability of the Eocene on the Cretaceous, together with the superficial similarity of their faunas, led Gabb and Whitney, of the early California Survey, to class the Martinez and Tejon formations with the Cretaceous. White, Stanton, and Merriam have, however, shown the Eocene age of the Martinez and Tejon. Of the relationships existing between these two and the Chico, or upper Cretaceous, Dr. Merriam has the following to say:[a]

"The Martinez group, comprising in the typical locality between 1,000 and 2,000 feet of sandstones, shales, and glauconitic sands, forms the lower part of a presumably conformable series, the upper portion of which is formed by the Tejon. It contains a known fauna of over sixty species, of which the greater portion is peculiar to itself. A number of its species range up into the Tejon and a very few long-lived forms are known to occur also in the Chico. Since the Martinez and Chico are faunally only distantly related it is probable that an unconformity exists between them."

Another fact showing the relations existing between the Eocene and the Cretaceous is the occurrence in the Eocene beds in the Roseburg region, Oregon, of oysters so similar in appearance to the characteristic Cretaceous fossil, Gryphæa, that without their accompanying Eocene fauna these oysters would certainly be mistaken for Cretaceous forms.

* * * * * * * * *

Rocks of marine origin and Eocene age are found at many localities throughout Washington and Oregon west of the Cascade Range and over considerable areas of the Coast Ranges in central and southern California. Although Eocene rocks probably once fringed the greater part of the western base of the Sierra Nevada, they are now all removed by erosion or covered by later formations except at one locality near Merced Falls. For the most part the Eocene rocks of the Pacific coast are either sandstone or shale. Conglomerate is found at the base of the formation throughout southeastern Oregon, north of San Diego, and at a few localities along the northeastern flanks of the Coast Range; and at Port Crescent, Wash., Eocene fossils are associated with tuff, but these occurrences are exceptional. Also, diatomaceous shales occur at the top of the Eocene series in the vicinity of Coalinga, Cal., where they are believed to be the source of important deposits of petroleum. Coal and other indications of shallow and brackish water conditions are found over much of Washington and Oregon and California, usually overlying marine Eocene beds. The maximum thickness of the Eocene sediments varies from 8,500 feet east of the Cascades,[b] 10,000 to 12,000 feet in western Oregon,[c] to 9,000 ± feet in southern California.[d]

The Tejon is the prevailing marine Eocene formation of California. Notes on its general relations and the extent of its occurrence have already been quoted from Arnold. Stanton[777] discussed the stratigraphic and faunal relations with the Chico and concluded that the Tejon and Chico are distinct. Gabb[351] had described the Tejon as Cretaceous, whereas Cooper[170] and White[889] had regarded it as a transition from Cretaceous to Eocene.

Arnold[33] has recently published the following classification and description of the rocks in the Santa Maria district:

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[a] Jour. Geology, vol. 5, 1897, p. 775.
[b] Smith, G. O., Mount Stuart folio.
[c] Diller, J. S., Roseburg, Coos Bay, and Port Orford folios.
[d] Arnold, Ralph, Bull. U. S. Geol. Survey No. 321, p. 21.

Tentative correlation of formations of Santa Maria district with the standard California Coast Range section and with that of the Santa Clara Valley.

Era.	System.	Period.	Standard Coast Range section.	Santa Maria district section.	Santa Clara Valley section.
Cenozoic.	Quaternary.	Recent.	Alluvium.	Alluvium.	Alluvium.
		Pleistocene.	San Pedro.	Terrace deposits and dune sand. ——— Unconformity ———	Sand and gravel. ——— Unconformity ———
	Tertiary.	Pliocene.	——— Unconformity ——— Merced.	Fernando.	Fernando.
			Purisima.		
		Miocene.	San Pablo. ——— Unconformity ——— Monterey.	——— Unconformity ——— Monterey.	——— Unconformity ——— Modelo {Shale. Upper sandstone. Shale. Lower sandstone.
			Vaqueros.	Vaqueros, Sespe, and Tejon, undifferentiated (including some Monterey in Santa Ynez Range).	Vaqueros.
		Oligocene.	San Lorenzo. ———Unconformity?———		Sespe {Upper. Red beds. Lower.
		Eocene.	Tejon.		Topatopa.
			Martinez. ———Unconformity?———	(?)	(?)
Mesozoic.	Cretaceous.		Chico. ——— Unconformity ——— Horsetown. ——— Unconformity ——— Knoxville. ——— Unconformity ———	Knoxville.	
	Jurassic (?).		Franciscan. ——— Unconformity ——— Granite, schist, etc.	Franciscan.	———Unconformity——— Granite, gneiss, etc.

The Santa Ynez Range is mostly composed of a thick terrane of marine sediments equivalent to a part or all of the Tejon formation and the Vaqueros formation. The former is Eocene and the latter lower Miocene in age. This terrane comprises a continuous succession of marine sediments of detrital origin, seeming to present no point at which an angular unconformity exists, although the line at the base of the coarse conglomerate containing the Vaqueros fossils doubtless marks a long time interval.

* * * * * * * * *

The lower portion of the terrane is made up of a thick series of greenish-gray coarse and fine sandstones, many of them concretionary in character, interbedded with dark, fine-grained thin-bedded shales in lesser amount. Toward the middle of the terrane the shale increases in amount, alternating with thin beds of sandstone. Much of the shale has a characteristic olive-gray color. * * * The shales and sandstones give place above the middle of the terrane to deposits of shallow-water character—coarse sandstone and a great quantity of coarse, in many places greenish or reddish gravelly conglomerate. This conglomerate contains abundant Vaqueros [Miocene] fossils and probably represents the base of that formation and a period of shallow-water conditions with which the Vaqueros began. The conglomerate gives place in turn to more shale and sandstone, which continue to the summit of the terrane. At the top there is a conformable gradation into the Monterey (middle Miocene) beds, the summit of the Vaqueros being marked by a calcareous zone in many places—as, for instance, southwest of Lompoc, where the two formations are divided by a very prominent exposure of hard limestone.

In the hills west of Tulare Lake lies the Coalinga oil district, studied by Arnold and Anderson,[34c] who tentatively assigned to the Tejon formation a series of beds described as follows:

The formation mapped as the Tejon in the Coalinga district is made up entirely of sedimentary strata that dip toward the great valley in the monocline along the eastern flank of the mountains and are exposed on the surface in a narrow discontinuous belt between the Cretaceous beds which underlie them and those of the Miocene which overlie them. The beds so mapped have a thickness of 1,600 to 1,850 feet and are divisible into two main members of approximately equal thickness—a lower one consisting of sandstone in the southern part of the district and of dark clay shale and sand in the northern part, which is certainly of Eocene age, with the possible exception of a small thickness at the base, and an upper one of light-colored organic shale which affords few species of fossils and no conclusive evidence as to its age. This upper member may represent either Eocene or Oligocene time, but the facts that there seems to be a gradation from the beds of the lower member into those of the upper and that the two invariably occur together in this region favor its assignment to the Eocene. It is made up of thin beds of whitish and purplish siliceous, argillaceous, and locally calcareous shale, which is easily recognizable and which lends individuality to the formation. The shale is very similar, especially in some places, as north of Coalinga, to the siliceous shale of the formation along Reef Ridge that is described later as the Santa Margarita (?) formation, and the two must not be confused: It is also somewhat similar to the purple shale of the upper Chico. Where the Tejon formation is thick, shale and clay form a greater proportion of the whole than the sandstone, but a great local variation in the thickness of this member is noteworthy because due to the great unconformity between it and the overlying Miocene beds. A large portion of the formation had been worn away before the Vaqueros (lower Miocene) sandstone was deposited on its upturned surface. It is possible that an unconformity occurs within the beds mapped as Tejon at the base of the upper shale, but no discrepancy in dip between the beds of the two divisions has been found, and the succession of beds is seemingly continuous.

As already pointed out, an unconformity exists between the Chico (Upper Cretaceous) and Tejon (Eocene) beds, in spite of the facts that no sharp line of demarcation is to be drawn between the Tejon and the underlying Chico in the northernmost part of the district and that there appears to be a gradation from the beds of the former into those of the latter, as if they had been formed during a continuous period of sedimentation. In the southern portion of the district the Tejon overlies unconformably beds that belong to an earlier portion of the Cretaceous, either lower Chico or Knoxville, thus proving that a period of land conditions and orogenic disturbances preceded the Tejon.

Tejon group was the name applied by J. D. Whitney to the fossiliferous strata in the vicinity of Fort Tejon, Kern County, and Martinez, Contra Costa County, which were included by Gabb under his division B, or Upper Cretaceous.[a] As the result of later studies the fossils of this formation are now considered to be of Eocene age. Strata of the same age occur extensively in the region of Carquinez Straits, east of Mount Diablo, and have been found at a number of different points along the western border of the San Joaquin Valley, notably at New Idria and in the region discussed in the present paper.

For a general correlation table of the Tertiary formations of the California Coast Range see Chapter XVII (p. 818).

[a] Geol. Survey California, Paleontology, vol. 2, 1869, preface, p. xiii.

J 12. PLATEAU PROVINCE OF UTAH.

In southwestern Utah the Cretaceous is overlain by Eocene (Wasatch) strata. Richardson[669a] says:

The Cretaceous rocks are unconformably overlain by Eocene strata, which, as already stated, outcrop in the Pink Cliffs and underlie the Markagunt and Paunsagunt plateaus. The unconformity, marked by a basal conglomerate containing pebbles of the underlying rocks, is emphasized by the absence of the upper members of the Cretaceous system, which are well developed in other parts of the plateau province. The Eocene rocks consist of a variable succession of shale, limestone, sandstone, and conglomerate that are characteristically vari-colored. Shades of red and white predominate and are beautifully developed in the Pink Cliffs. Fossils are extremely rare in these rocks and only a few fragments of Vivipara and Unio have been obtained in this area, but the characteristic peculiarities of stratigraphy and coloring of the rocks leave little room for doubt that, except possibly a few feet of basal beds containing conglomerate of doubtful significance, they belong to the Wasatch formation of the Eocene series, which is so largely developed in the High Plateaus of Utah and from which characteristic fossils have been obtained in a number of places.

J 12–13. SAN JUAN BASIN, COLORADO AND NEW MEXICO.

The Tertiary of the San Juan Basin of New Mexico and Colorado comprises possibly the Animas formation and certainly the Puerco and Torrejon formations (Eocene). The Animas formation is thus described by Cross: [186a]

In the article already cited on the post-Laramie deposits of Colorado, the writer referred to a series of strata occurring on the Animas River below Durango, which had been visited by Mr. T. W. Stanton and found to be very similar to the Denver beds. In the summer of 1894 the writer was able to hurriedly examine this series of beds as exposed on the railroad below Durango and found them to resemble the typical Denver beds in a very high degree. These strata occur above the Laramie and below the Puerco and, as far as the present meager observations show, are conformable with both of them where now preserved. The beds are some 700 feet or more in thickness and are composed of yellowish-brown clays, tuffs, sandstones, and conglomerates, in which andesitic material greatly predominates, and present a variety rivaling that in the Denver beds.

A few fossil plants occur, but those found thus far are poorly preserved, and the only identifiable species collected is *Magnolia tenuinervis* Lx., a common Denver bed species originally described from Table Mountain. No invertebrate fossils have been found as yet, but it seems probable that a number of vertebrate species, described by Cope as from the Laramie of the Animas River section, came out of the strata which so closely resemble the Denver formation.

In an article discussing the relations of the Puerco and Laramie deposits Prof. Cope refers to the succession of beds on the Animas River, saying: "According to the observations of Mr. David Baldwin the Laramie beds succeed [the Puerco] downward, conformably it is thought by Mr. Baldwin; and have a thickness of 2,000 feet at Animas City, N. Mex. [Colorado?]. A few fossils sent from time to time by Mr. Baldwin identify the Laramie. This is especially done by the teeth of the dinosaurian genus Dysganus Cope, which is restricted to the Laramie formation elsewhere, also by the presence of the genera Lælaps and Diclonius, which in like manner do not extend upward into the Puerco beds."

According to the statement of Prof. Cope, made personally to the writer and quoted with his permission, these fossils were collected incidentally to the investigation of the Puerco fauna and for the purpose of identifying the underlying formation. He believes it most probable that they came from what are here called the Animas beds, which extend for several hundred feet below the Puerco. Prof. Cope now regards the Dysganus and Diclonius as closely allied to the horned dinosaurs (Ceratopsidæ Marsh, Agathaumidæ Cope), which, as will be shown, form the most characteristic element of the vertebrate fauna known in the Arapahoe and Denver beds.

The Animas beds, as this post-Laramie formation may be called, are to be regarded as a most direct equivalent of the Denver beds, identical in peculiar lithologic character, lying between typical Laramie and Puerco, and containing fossils which, so far as known, indicate a similar fauna and flora.

The Tertiary of the northwestern part of the San Juan Basin is outlined in a recent map accompanying a report on the coals of the region, in which M. K. Shaler [727] thus states the relations of the Tertiary and Cretaceous:

The Animas beds outcrop only in a narrow belt along the north border of the field, thinning rapidly both east and west from Animas River. If present at all in the central part of the area, they are hidden by the Puerco marl, which north of Pueblo Alto apparently overlaps the Cretaceous rocks. Unconsolidated white sand, unquestionably of Puerco age, here lies in contact with an irregular surface of Laramie coal, immediately overlying the basal sandstone member of that formation. At this place the outcropping Laramie is only about 200 feet thick.

The upper and lower limits of the Puerco marl are difficult to determine in the area of flat-lying beds near Rio Chaco. There is nearly everywhere a marked gradation between these rocks and the Laramie, although the main body of the Puerco is easily distinguished by the presence in it of fossil mammal remains and silicified wood.

The available notes on the stratigraphy of the Puerco and Torrejon have been well summarized by James Hervey Smith: [761]

The Puerco formation is located in northwestern New Mexico at the headwaters of Puerco River, from which the formation takes its name, and where it "reaches a thickness of outcrop of about 850 feet." [a] The rocks of this formation consist of "sandstones and gray and green marls." [a] The formation is thus characterized by Wortman: [b] "The thickness of the beds is roughly estimated at 800 to 1,000 feet, and as far as can be observed they lie conformably upon the Laramie."

The fossils occur at two horizons which are separated by barren strata 700 to 800 feet thick (not 30 feet as erroneously quoted by Dall in the Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 2, p. 347). "The lower fossil-bearing strata occur in two layers, the lowermost of which lies within 10 or 15 feet of the base of the formation. This is succeeded after an interval of about 30 feet by a second stratum in which fossils are found. * * * Both of these strata are red clay, and at no place did we find them more than a few feet in thickness." [c]

This horizon "is especially and sharply distinguished by the occurrence of the remains of Polymastodon, which appear to be entirely absent from the upper horizon." [c] The upper horizon is richer in fossils than the lower. "The genera Chirox and Pantolambda appear to belong exclusively to the upper beds." [c]

Wortman believes that the upper fossiliferous horizon contains several layers, and that their vertical range is somewhat greater than that of the lower horizon. Matthew states that the "Upper and Lower Puerco beds do not contain a single species in common, and only three or four genera pass through. The two faunas are entirely distinct. Dr. Wortman proposes to call the upper beds the Torrejon formation, retaining the name Puerco for the lower beds." [d] Scott correlates the Puerco with the Cernaysien of Europe.[e]

Osborn [623a] briefly describes the Puerco, 500 feet (Polymastodon zone), as basal Eocene, characterized by small archaic mammals; and the Torrejon, 300 feet (Pantolambda zone), as the equivalent of a part of the Fort Union formation of Montana, also still characterized by descendants of Mesozoic types.

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[a] Clark, W. B., Bull. U. S. Geol. Survey No. 83, 1891, p. 138.
[b] Quoted by Osborn, H. F., Bull. Am. Mus. Nat. Hist., vol. 7, 1895, p. 1.
[c] Wortman, quoted by Osborn, op. cit., p. 2.
[d] Science, new ser., vol. 6, 1897, p. 852.
[e] Scott, W. B., Science, new ser., vol. 2, 1895, p. 499.

The coal field between Gallina and Raton Spring, N. Mex., in the San Juan coal region, is described by Gardner [358a] as follows:

In the vicinity of Gallina and to the south beyond Lajara the variegated shales of the Wasatch rest horizontally against the foot of the Sierra Nacimiento, covering the highly inclined strata of the Cretaceous and lower sedimentary rocks. The Wasatch bears many fragments of vertebrates, and collections were sufficient to permit its positive identification.

In the southern portion of the area, along the mountain foot northeast of Cuba and along the headwaters of Rio Puerco, the Wasatch is underlain by a mass of variegated bituminous shale, with two beds of massive sandstone. The sandstones form prominent escarpments, the upper immediately west and the lower about 10 miles southwest of Cuba. The entire thickness of these beds is about 800 feet. They are highly inclined along the mountains, and northeast of Cuba they are overturned and dip toward the mountains at about 70°. The high dips of the massive sandstones are in marked contrast to the unconformable horizontal shale of the overlying Wasatch. The prominent sandstone escarpments swing westward from Cuba, the lower being traced across the area beyond the limits of the present mapping. The upper escarpment could not be traced with certainty. The prominent escarpment of the Wasatch to the north follows in a general way parallel to these escarpments. Near a small pond, about 7 miles N. 76° E. of Ensino Spring, vertebrate fossils were collected from 25 feet of dark and gray argillaceous sand and shale immediately overlying the basal escarpment sandstone. A careful study of these fossils has been made by J. W. Gidley, of the United States National Museum, and the specimens have been compared with original material in the American Museum of Natural History, New York. This comparison definitely places them in the Torrejon formation.[a] The Laramie reappears from beneath the lower escarpment, striking almost at right angles with it, thus bringing out a marked unconformity between the two. It does not follow from the fossils that the lower escarpment is of Torrejon age. It is probable that there is an unconformity between the Puerco and the Torrejon. This accounts for the Torrejon fossils immediately above the basal escarpment sandstone, which is in all probability the lowest member of the Puerco. It is certainly at the base of an 800-foot mass below the Wasatch, exposed along the headwaters of Rio Puerco, as originally described by Cope.[b] Along Rio Puerco the base of the Wasatch is 750 feet above the top of the basal Puerco sandstone. At the point where the Torrejon fossils were collected the base of the Wasatch, as determined by both stratigraphic relationship and fossil evidence, is only 135 feet above the top of the same sandstone. Hence the 800 feet of the original Puerco is represented by only the basal sandstone, from 30 to 50 feet thick, unconformably overlying the Laramie. This sandstone is unconformably overlain by 110 feet of Torrejon, above which, also unconformably, lies the Wasatch.

J 13. GREAT PLAINS OF COLORADO.

In the plains southeast of Denver the Oligocene and possibly part of the Eocene are represented by the Monument Creek formation. Darton [240] describes it as—

an extensive deposit of conglomerates, sand, sandstone, gravel, and clay, known as the Monument Creek formation. It lies on the Laramie formation to the east and the Arapahoe formation to the west, and at Palmer Lake it abuts against the granite at the foot of the mountain. There are two members, a lower one of sands and clays and an upper one of conglomerate and sandstone. The latter caps numerous buttes and plateaus in the high region west and north of Calhan and north of Monument.

Fossil bones of Titanotherium have been discovered by the writer [c] and Mr. C. A. Fisher in the upper member of the region north of Calhan and southwest of Elizabeth, which indicate

[a] Torrejon is a name proposed by J. L. Wortman (Bull. Am. Mus. Nat. Hist., vol. 9, 1897, pp. 260–261) for a fossil zone at the top of the original Puerco of Cope.

[b] Cope, E. D., Rept. Chief Eng., 1875, pt. 2, p. 1008.

[c] Darton, N. H., Age of the Monument Creek formation: Am. Jour. Sci., 4th ser., vol. 20, 1905, pp. 178–180.

that this portion of the formation is of Oligocene age. The lower member may be Oligocene, or perhaps Wasatch or Bridger, in age.

In southern Colorado just east of the mountains is the Huerfano basin, described by Hills [448, 449] and studied by Osborn.[622] The latter summarizes Hills's conclusions and his own:

In this third paper (1891) Prof. Hills positively identified the "upper beds" as equivalent to the Bridger group, and restricted the term Huerfano to these beds, applying the terms Cuchara to the middle division and Poison Canyon to the lower division. These divisions, correlated with the measurements previously assigned them, would then occur as follows:

Huerfano series (Eocene)	Huerfano beds	Bridger group	3,300
	Cuchara beds	Lower Eocene (Green River, Wasatch and Puerco)	300
	Poison Canyon beds		3,500

While these studies were in progress a large collection of fragmentary bones was made by Mr. Milligan, of Gardner, which is now preserved in the museum of the Colorado Scientific Society and which Prof. Hills kindly enabled the writer to carefully examine.

The essential features of Prof. Hills's conclusions may be summarized as follows:

1. The identification of the total Huerfano series of 3,300 feet with the Bridger or middle Eocene, and the provisional identification of the Cuchara and Poison Canyon series with the lower Eocene, in the absence of fossils, upon stratigraphical evidence.

2. The post-Laramie formation of a great anticlinal axis, as the eastern border of the Huerfano Lake to the east and southeast of the Wet Mountain Range and Spanish Peaks, and the subsequent removal of this axis by erosion.

3. The eruption of the laccolithic Silver Mountain and Spanish Peaks subsequent to the deposition of upper lake deposits of Bridger age.

4. The drainage of the Huerfano Lake to the north through the Wet Mountain Valley.

It should be stated here that these opinions were expressed at a time when several geologists had identified Laramie deposits east of the Rockies as Tertiary, owing partly to Prof. Marsh's identification of a Laramie dinosaur with *Bison alticornis*.

For the sake of clearness of contrast it may be well to summarize at this point the geological conclusions formed by the writer and Dr. Wortman during their brief reconnaissance of this region:

1. That west of the Huerfano Canyon the variegated marls, clays, soft shales, and sands aggregate only 800 to 1,000 feet in thickness, and are nearly horizontal in position. They may be positively divided into Upper beds, equivalent to the Bridger, and Lower beds, equivalent to the Wind River, or Upper Wasatch. These constitute the only true Huerfano Lake deposits.

2. That the Cuchara and Poison Canyon beds are unconformable with the Huerfano beds and older than the Eocene, probably marine Cretáceous, as partly determined by the presence of a species of Baculites in the yellow sandstone of the typical Poison Canyon section.

3. That the present canyon of the Huerfano River cuts through the base of the main anticlinal axis of post-Laramie origin, which formed the eastern boundary of the lake. This axis extended to the south so as to include the base of Silver Mountain toward the Cuchara divide; but it lies from 3 to 7 miles west of the anticlinal axis described by Prof. Hills.

4. That the Huerfano Lake deposition did not extend as far to the east or south as the Spanish Peaks, and that the variegated beds observed there are of older origin. This would materially effect the geological age of the prominent neighboring laccoliths.

The geological features of these conclusions can hardly be dignified by the term "a theory of the Huerfano Lake," for thev were formed during a hasty reconnaissance of this basin, while Prof. Hills's theory certainly deserves the deliberate consideration of a prolonged survey. In fact, this basin, with its volcanic disturbances and eruptions, presents in compact form a fascinating problem in the geology of Tertiary times.

Hills[451b] describes the Poison Canyon, Cuchara, and Huerfano formations as they occur in the Spanish Peaks quadrangle. The two older formations (Poison Canyon and Cuchara) are placed doubtfully in the Eocene, the Poison Canyon being regarded as possibly equivalent to the Arapahoe of the Denver basin. Osborn's determination (1897) of the Eocene (Bridger and Wind River) age of the Huerfano formation is sustained by later studies of the fauna by Wortman and Matthew.[623e]

J 13. EAST-CENTRAL COLORADO.

The Florissant lake beds, discovered by Hayden and described by Peale and Scudder,[719] occupy an area too small to be shown on the map, about latitude 39°, longitude 105° 20′, in the pre-Cambrian mass of the Colorado Front Range. The beds consist of volcanic ash, from showers and washed volcanic detritus, more than 50 feet thick. The deposit is noted for the rich harvest of fossil insects it has yielded. For descriptions of these fossils Scudder[720, 721, 722, 723] and Cockerell[161, 162] should be consulted.

J-K 12-13. UINTA VALLEY, ROAN OR BOOK PLATEAU, AND GRAND MESA.

South of the Uinta Range in Utah lies the Uinta Valley, which Emmons[320] examined cursorily in course of his work for the Fortieth Parallel Survey. The strata extend into northwestern Colorado and were there studied by White,[888] who distinguished the Wasatch, Green River, Bridger, and Uinta groups, applying the term Uinta to the rocks described by Powell as the Browns Park group. The Wasatch, Green River, and Bridger are described as conformable, and the Uinta as resting unconformably upon the Bridger and older formations around the east end of the Uinta Range. According to the recent work of Gale[355] in this area, the Browns Park formation is of later age than the true Uinta of King. It underlies the Bishop conglomerate (Bishop Mountain of Powell), which is the same as the Wyoming conglomerate of the Fortieth Parallel Survey. In Gale's preliminary report[354] the Tertiary formations are described as follows:

> [The "Browns Park" formation] consists of loose or slightly consolidated sandy material with local harder sandstone beds and some beds of gravel. Contains much calcareous material in the form of cement or filling between the quartz sand grains. Its color is everywhere chalky or limy white. The thickness is not determined.
>
> [The Green River formation is] composed of shale, sandstone, and beds of oolitic rock. The shaly beds predominate and are very compact and firmly bedded. They are generally exposed in escarpments and high bluffs, in which the weathered beds have a very characteristic chalky-white aspect. The shales are, however, of various shades of gray, drab, and light brown and are in many places hard and thin bedded. In some districts the lower part contains much massive white sandstone. Measured sections exceed 2,400 feet; upper limit not reached.
>
> [The Wasatch formation is] composed chiefly of clay or soft clay shale; commonly variegated, but various shades of red and drab predominate. It also contains beds of pebbles or conglomerate of very perfectly rounded siliceous material, such as jasper, colored vein quartz, chert, or flint. Sandstones in places very massive and hard. From 4,000 feet in thickness on the eastern side of the Uinta Basin to about 2,500 feet near the Utah line.
>
> [The Fort Union or earlier beds are] not readily distinguished from the Wasatch in the Uinta Basin, but are apparently more clearly differentiated in the Yampa field. As developed in the latter region they consist of massive white or light-colored sandstones and shales

containing valuable coal beds sharply defined at the base by a conglomerate or conglomeratic sandstone, without doubt marking an unconformity of considerable magnitude. Thickness estimated as about 800 feet on Lay Creek north of Lay.

Osborn [623g] describes the later Eocene deposits of the Uinta Basin as comprising the Uintatherium zone (800 feet), provisionally equivalent to the upper part of the Bridger; the Eobasileus zone (350 feet), equivalent to the upper zone of the Washakie Basin; and the Diplacodon zone (600 feet), which is the true Uinta of King and properly the Uinta formation. This last he regards as "approaching if not equivalent to the lowermost White River Oligocene—that is, lower Titanotherium zone or Chadron formation."

Eocene strata extend southward from the Uinta Valley and White River in Utah and Colorado and, rising, form the Roan or Book Plateau. Their southern margin has been traced by Taff and Richardson in connection with surveys of the underlying (Cretaceous) coal measures. Lee [530a] states the section as follows:

The Grand Mesa coal field is located on the southern rim of the Uinta coal basin, which lies partly in northwestern Colorado and partly in Utah. It derives its name from Grand Mesa, a high table-land between Grand and Gunnison rivers. The coal beds underlie the mesa and outcrop along the south and west sides. They extend westward into the Book Cliffs field, north of Grand Junction,[a] and eastward into the Anthracite-Crested Butte region,[b] long known for its anthracite coal, and thence northward along the Grand Hogback, recently described by Gale.[c]

Generalized section of rocks in the Grand Mesa coal field, Colorado.

[Only the Tertiary part of the section is here given.]

Formation.	Thickness (feet).	Characteristics.
Green River.	200–1,800	White friable sandstone and clay shale, capped by basalt.
Ruby (probably Wasatch).	500–2,000	Conglomeratic sandstone and shale, varicolored. In the eastern part of the field the rocks are mainly red and conglomeratic beds are numerous. The basal conglomerate consists principally of quartz and chert pebbles and the higher ones of various crystalline, metamorphic, and extrusive rocks. In the western part of the field lighter colors prevail and the rocks are finer in texture.
Unconformity		
Ohio Creek.	100	White friable conglomeratic sandstone, containing pebbles of quartz, jasper, and igneous rock.
Unconformity.		

Detailed sections of certain districts covered by the coal surveys made by the United States Geological Survey, in 1907–8, will be found under L 12 and L 13, pages 774–778.

[a] Richardson, G. B., The Book Cliffs coal field: Bull. U. S. Geol. Survey No. 316, 1907, pp. 302–320.

[b] Eldridge, G. H., Anthracite-Crested Butte folio (No. 9), Geol. Atlas U. S., U. S. Geol. Survey, 1894.

[c] Gale, H. S., Coal fields of the Danforth Hills and Grand Hogback in northwestern Colorado: Bull. U. S. Geol. Survey No. 316, 1907, pp. 264–301.

J-K 13, L 13-14. GREAT PLAINS OF COLORADO, WYOMING, MONTANA, NORTH AND SOUTH DAKOTA.

In the northern and central parts of the Great Plains area there are several nonmarine formations lying near the boundary between the Cretaceous and Tertiary, concerning the exact age and correlation of which there has been much controversy. They are the Denver and Arapahoe formations of the Denver Basin and the Lance and Fort Union formations of the Dakotas, Wyoming, and Montana. The earlier history of the discussion concerning them, in which the more general Laramie question is involved, was summed up by Clark [141] in 1891. The Arapahoe and Denver formations were first recognized as distinct from the Laramie by Cross and Eldridge [322] in the course of their detailed study of the Denver Basin. The following statement concerning their age is quoted from Cross: [322a]

Until the discoveries which are described in preceding chapters were made the strata of the Arapahoe and Denver formations had been uniformly assigned by geologists to the Laramie, under the accepted definition of the latter as the uppermost division of the conformable Cretaceous series; and not only had they been assigned to the Laramie, but no characteristics of any kind had been mentioned, or apparently observed, by which these upper beds might be even locally distinguished from the lower, coal-bearing horizon. This correlation was based on the presence of the true Laramie below the beds in question, on the failure to notice their peculiar and distinguishing characteristics, and on the assumptions regarding the unity of the fossil flora, whose species were, however, collected from widely separated horizons in the Golden section.

In the earliest descriptions of these formations by Mr. Eldridge and the writer they were assigned to the Tertiary. The reason for this assignment was the discovery that between the Laramie and Arapahoe epochs there had occurred an orographic disturbance whose magnitude was measured, for this locality, by the presence in the Arapahoe strata of pebbles of highly indurated clastic rocks, sandstones, conglomerates, etc., clearly belonging to various geological horizons as far down as the Trias, representing erosion of 14,000 feet of strata, according to the section of the formations in question in the Denver region. The lithological character of the Denver beds showed that the interval of unknown duration between the Arapahoe and Denver epochs had witnessed the occurrence of volcanic eruptions on a gigantic scale, and also subsequent local erosion.

Up to the time when these formations were thus identified, great orographic movements in the Rocky Mountains had been commonly supposed to mark the ending of Mesozoic time, and to be in great measure the cause of the wonderful changes that took place at this period, especially in vertebrate life, as shown by the remains in the earliest known Eocene deposits. The beginning of Tertiary time was also known to be widely characterized by great volcanic outbreaks, recorded in the sediments of the Green River, Florissant, and other Eocene basins. Hence it seemed natural to place the Arapahoe and Denver beds in the Tertiary, as, perhaps, the earliest lake deposits of Cenozoic time. Examination of the paleontologic evidence available at the time showed either that it did not controvert the assignment or, as in the case of the fossil plants, was entirely untrustworthy because the floras of the distinct horizons involved could not then be compared.

The recent discoveries of fossil vertebrate remains are said by paleontologists to show that the life of the epochs under discussion was much more nearly allied to Mesozoic than to Cenozoic types, and in deference to this opinion the post-Laramie formations are classed in this report with the Cretaceous. But such a course raises at once the question as to the nature and position of the boundary between Mesozoic and Cenozoic time in the Rocky Mountains and broadens very materially the treatment which must be given to the problem.

Cross [192] recently contributed a paper to the discussion of the age of the Laramie formation in which he proposed to distinguish those strata which unconformably succeed the latest conformable Cretaceous as the Shoshone group. After describing in much detail the various local formations which may be referred to the Shoshone group, he says: [192a]

In the preceding discussion I have avoided the question as to the age of the Shoshone beds, whether Cretaceous or Eocene. I desire now to urge their reference to the Eocene. The Denver beds were originally referred by me to the Eocene, but the great weight attached to the Mesozoic affinities of the vertebrate fauna by paleontologists led to a tentative acquiescence in the assignment of the Arapahoe and Denver formations to the Cretaceous, in the Denver monograph. In that volume I reviewed various aspects of the question and can add but little to what was there said. The main point seems to be that the Laramie and Shoshone beds belong to a transition series between the Cretaceous and Eocene and that whatever break occurs between any two formations is possibly bridged over by deposits of some other locality. The Laramie is related to the Judith River and other brackish-water formations of the Montana Cretaceous, the Shoshone to the great succession of Tertiary local deposits. The retreat of marine waters and the decided uplift of a large continental area marked the appropriate boundary between Cretaceous and Eocene from the stratigraphic side.

The name Lance formation has recently been adopted by the United States Geological Survey for the dinosaur-bearing strata variously known as the "Ceratops beds," "Lance Creek beds," "Hell Creek beds," and "Somber beds," which have by some geologists been assigned to the Cretaceous and referred to or correlated with the Laramie and by others included in the Fort Union and assigned to the Eocene. The typical area is in Converse County, Wyo., where the formation has yielded an abundant and varied vertebrate fauna, including Triceratops and several other genera of dinosaurs and a number of small primitive mammals. Recent areal work in connection with the examination of coal lands by the United States Geological Survey has shown that the Lance formation is widely distributed in Wyoming, Montana, North Dakota, and South Dakota. It is mapped together with the Denver, Arapahoe, etc., as "Earliest Tertiary or latest Cretaceous" (5a).

The Fort Union formation was named by Meek and Hayden,[586a] who stated that it consists of "beds of clay and sand, with round ferruginous concretions, and numerous beds, seams, and local deposits of lignite" and "occupies the whole country around Fort Union [at the mouth of Yellowstone River], extending north into the British possessions to unknown distances; also southward to Fort Clark." The formation as developed in this original area is now generally regarded as Eocene, and it is so mapped with the other formations of the "Continental Eocene" (5b1), but the underlying strata which Knowlton (see pp. 763–764) called the lower member of the Fort Union are excluded from it and assigned to the Lance formation.

The argument for placing the Lance formation in the Cretaceous has been presented by Stanton,[783] who does not share with Cross the view that there is a widespread unconformity of great significance between the Laramie and the Shoshone, although he, like all other geologists, clearly recognizes that there are very pronounced local unconformities. Stanton's argument is based on the actual stratigraphic sequences and upon the relations of the vertebrate and invertebrate faunas. He does not consider that the floras furnish sufficient evidence for correlation with the Tertiary, and he concludes:

In the interior region of North America the formations between the uppermost marine Cretaceous and the Wasatch together constitute a real transition from the Cretaceous to the Tertiary.

Notwithstanding the fact that there are several local unconformities at various horizons and perhaps some of more general distribution, there is no conclusive evidence that any one of these represents a very long period of erosion not represented by sediments elsewhere in the region.

The Fort Union formation, properly restricted, is of early Eocene age, the determination resting chiefly on its stratigraphic position and its primitive mammalian fauna, which is related to the earliest Eocene fauna of Europe. The very modern character of the flora tends to confirm this correlation.

The "Ceratops beds" are of Cretaceous age, as decided by stratigraphic relations, by the pronounced Mesozoic character of the vertebrate fauna with absence of all Tertiary types, and by the close relations of its invertebrate fauna with the Cretaceous. The relation of the flora with Eocene floras is believed to be less important than this faunal and stratigraphic evidence. Taken in their whole areal extent they probably include equivalents of the Laramie, Arapahoe, and Denver formations of the Denver Basin.

Knowlton,[508] presenting the evidence from the point of view of the paleobotanist, also discusses the stratigraphy and regarding his conclusion states:

The present paper deals with the extensive series of fresh-water deposits of the Northwest (that is, broadly, the region east of the Rocky Mountains and between Wyoming and the valley of the Mackenzie River), comprising what is here considered as the Fort Union formation. It is shown that the Fort Union embraces more than has been commonly assigned to it. Conformably below the beds by some geologists considered as the true Fort Union occur dark-colored sandstones, clays, and shales, which have often been incorrectly referred to the Laramie, or its equivalent, but which are stratigraphically and paleontologically distinct from the Laramie, and the contention is here made that these beds, which include the "Hell Creek beds" and so-called "somber beds" of Montana, the "Ceratops beds" or "Lance Creek beds" of Wyoming, and their stratigraphic and paleontologic equivalents elsewhere, are to be regarded as constituting the lower member of the Fort Union formation and are Eocene in age.

Knowlton [508a] sums up his argument as follows:

1. The Fort Union formation is a fresh-water Tertiary formation of wide areal extent, mainly east of the Rocky Mountains, ranging from Wyoming and western South Dakota over western North Dakota, eastern and central Montana, the central Canadian provinces, and reaching the valley of the Mackenzie River.

2. It is shown that the Fort Union formation may be separated into two members on lithologic grounds. The present paper deals only or largely with the stratigraphy and paleontology of the lower member, which includes the "Hell Creek beds" and so-called "somber beds" of Montana and the "Ceratops beds" of Wyoming.

3. The areal distribution of the lower member is traced in Montana, North and South Dakota, and Wyoming, and its probable extension in other areas is indicated. Complete lists of the fossil plants are given by localities for each of the areas.

4. It is shown that the lower member rests, in some cases unconformably, in others in apparent conformity, on the Fox Hills or Pierre, and the conclusion is reached that an erosional interval is indicated during which the Laramie, if ever present, and other Cretaceous and early Tertiary sediments were removed.

5. It is shown that the beds under consideration, being above an unconformity, can no longer be considered as a part of the "conformable Cretaceous series" and hence are not Laramie.

6. It is shown that the two members of the Fort Union, although usually distinct lithologically, can not be separated structurally, sedimentation having been uninterrupted, except locally.

7. The paleontological elements of the lower member are considered at length, beginning with the plants. It is shown that of the 84 species, 61 are common to the upper member and only 11 species to the Laramie of Colorado, while 15 species are common to other American Eocene and nine species to the Miocene. The Eocene age of the Fort Union is fixed by tying its flora to that of various Old World beds of known Eocene position.

8. The invertebrate evidence is shown to be in substantial accord with that of the plants, there being only four of the 49 species common to the Colorado Laramie. All, with a single possible exception, are fresh-water forms.

9. It is shown that the vertebrates afford no positive evidence of Cretaceous age. That the dinosaurs exhibit Cretaceous affinities is not denied, since, being without known descendants, it is possible to compare them only with their progenitors. It has been proved beyond question that they survived the profound orogenic movement and attendant physical break at the top of the Laramie in the Denver Basin of Colorado, and lived on in Arapahoe and Denver time, and it is shown that in the areas considered in this paper they passed over a similar erosional interval and are found in association with the Fort Union flora, which is of Eocene age.

10. The mammals of the lower Fort Union show very little relationship with Jurassic or Cretaceous forms but find their closest affinities with those of the Puerco and Torrejon, which are of acknowledged Eocene age.

11. The chelonians are shown to be of little value in their bearing on the age of the lower Fort Union, especially when compared with the Judith River forms, which are evidently in confusion.

12. It is held that the line between Cretaceous and Tertiary should be drawn at the top of the true Laramie.

13. The final conclusion is reached that the beds here considered ("Hell Creek beds," "somber beds," "Ceratops beds," "Laramie" of many writers) are stratigraphically, structurally, and paleontologically inseparable from the Fort Union, and are Eocene in age.

See also A. C. Veatch [840] and Whitman Cross,[190] and later papers by Stanton,[784] Knowlton,[510] and Leonard.[533]

K 10. ROGUE RIVER VALLEY, OREGON.

Diller [281] says:

Coal occurs at numerous localities in the Rogue River valley of southwestern Oregon, between the Cascade Mountains on the east and the Klamath Mountains, locally called the Siskiyou Mountains, on the west.

* * * * * * * * *

The Cascade Range, east of the coal belt, is made up mainly of Tertiary lavas; the Klamath Mountains, on the west, are composed of granular igneous rocks and a smaller proportion of pre-Cretaceous sediments.

The soft rocks in which the Rogue River valley has been cut are sandstones, shales, and conglomerates. They dip generally eastward, extending beneath the lava fields of the Cascade Range. The older sediments along the western border of the valley, by Bear Creek from the Toll House to Ashland, Phoenix, and Jacksonville, are Cretaceous in age and do not contain coal. The coal-bearing rocks lie east of Bear Creek as far north as Medford, but beyond that point they overlap the Cretaceous rocks and occupy the whole northern portion of the Rogue River valley.

K 12. NORTHEASTERN UTAH AND SOUTHWESTERN WYOMING.

The southwest corner of Wyoming and the immediately adjacent part of Utah were mapped by Veatch,[839a] who subdivided the Tertiary (all Eocene) as follows:

	Feet.
Eocene:	
Bridger formation	1,200–1,800
Green River formation	2,000±
Wasatch group:	
Knight formation	500–1,500±
Unconformity.	
Fowkes formation	0–2,500+
Almy formation	2,100–2,200
Evanston formation ("Upper Laramie")	0–1,600+
Unconformity.	
Cretaceous.	

Veatch's table, from the Jurassic to the Tertiary, inclusive, and his comments regarding the division line between the Cretaceous and the Tertiary are quoted in Chapter XV (pp. 676–677). For detailed descriptions of the formations see the work cited.

The sequence of Wasatch strata thus described by Veatch is correlated by Osborn with the Wasatch near Black Buttes in the Washakie Basin; with the Wasatch of the San Juan Basin, New Mexico (1,500 feet); with the Wasatch of the Bighorn Basin, Wyoming (2,391 feet, Loomis); and with the lower portion of the Huerfano formation of Colorado.

The Bridger and Washakie basins lie in southern Wyoming on either side of the Rock Springs dome. The Eocene on the western margin of the Bridger Basin has been studied stratigraphically by Veatch,[839f] and the lower Eocene on the flanks of the Rock Springs dome by Schultz.[716a] Schultz defines the area and gives the following section of Tertiary rocks:

The field here considered lies along the eastern margin of the great Green River Basin and includes in part, on the east, the Great Divide Basin. It lies on the north flank of the Rock Springs dome, which is completely surrounded by Tertiary beds.

* * * * * * * * *

Section of Tertiary rocks of Sweetwater County, Wyo.

Formation.	Economic designation.	Thickness (feet).	Description.
Green River.		350	Massive irregular-bedded sandstone.
Unconformity			
Green River.		600	Thin-bedded shales, sandstones, and limestones, some of which are oolitic, for the most part light colored, white, gray, yellow, or greenish.
Unconformity			
Wasatch.[a]		400–825	Variegated clays, shales, and sandstones, the sandstones in places being slightly conglomeratic.
	Black Rock coal group.	1,200–2,650±	Alternating layers of white, yellow, and brown sandstones, gray, drab, and carbonaceous shales, with coal beds and conglomerate containing granite and quartzite pebbles. Numerous bands of white concretionary sandstone weathering in irregular shapes. Basal sandstone is conglomeratic.
Unconformity.			

[a] Abundant collections of plants have been obtained from the lower third of this formation and determined by F. H. Knowlton, who studied the collections, as undoubtedly Fort Union.

Osborn [623f] gives a columnar section of the Bridger formation, 1,875 feet, as developed in the Bridger Basin, based on detailed stratigraphic and paleontologic work by Matthews and Granger. Five divisions are distinguished according to faunas. The Bridger is assigned to middle Eocene time and correlated with the upper part of the Huerfano formation, the lower part of the later Eocene (Uintatherium zone) of the Washakie Basin, Wyoming, and the lower part, or Uintatherium zone, of the later Eocene of the Uinta Basin of northern Utah; also with the Clarno formation of the John Day Basin, Oregon.

K 12. WIND RIVER BASIN, WYOMING.

E. G. Woodruff has contributed the following data on the Tertiary of the Wind River Basin:

The highest Tertiary beds recognized in the Wind River Basin are called by Osborn and others the Wind River formation (Eocene). They consist of alternate beds of gray, drab, and pink very sandy shale and a few sandstone members near the base. In several areas about the edge of the basin a conglomerate member is the base of the formation. The Wind River is notably unconformable above the Fort Union formation, and probably was deposited subsequently to the formation of the Wind River Basin. The material composing it is believed to have been derived from the surrounding mountains. The thickness of the formation is undetermined. The Fort Union formation (Eocene) peeps out from beneath the Wind River cover in a few places around the edge of the Wind River Basin. It is believed that all of the Fort Union is not represented in any of these exposures. The formation where seen consists of a series of sandy shales and both shaly and massive sandstones which are generally pale rusty colored but are locally gray. The underlying formation is the Mesaverde (Upper Cretaceous).

Osborn,[623d] who bases a section of the Wind River formation on work done by Hayden and Loomis, assigns 1,200 to 1,400 feet to the formation, with red beds at the base. The strata comprise the Lambdotherium and Bathyopsis zones (lower to middle Eocene) and fall into two divisions which correspond to the upper part of the Wasatch of the Bighorn Basin and the lower part of the Huerfano formation of Colorado. (See J 13, pp. 758–759.)

K 13. WYOMING AND COLORADO.

The eastern border of the Washakie Basin has been mapped by Ball,[53] who determined the following section of the Tertiary on the southern line of Wyoming:

The coal field drained by Little Snake River extends from the Sierra Madre westward to and partly into the Red Desert, and from the summit of the Elkhead Mountains of Colorado northward to the divide between the Pacific and Great Divide Basin drainages, a few miles south of the Union Pacific Railroad.

The area discussed in this paper is located near the middle of the southern boundary of Wyoming.

The stratigraphic relations of the coal-bearing and associated formations, with their general character and approximate thicknesses, are shown in the following table [only the Tertiary part of the table is quoted]:

Generalized section of coal-bearing rocks in western portion of the Little Snake River coal field, Wyoming.

System.	Formation.	Economic designation.	Description.	Thickness (feet). North end of field.	Thickness (feet). South end of field.
Tertiary.	Upper part of Wasatch and later Tertiary.		Variegated clay passing upward into brown and gray shales, sands, and sandstones. Not coal bearing.	Top not seen.	
	Wasatch. ~~~(?)~~~ (?)[a]	Upper coal group.	Shale and soft sandstone, with many beds of impure coal. Conglomerate. Gray and brown sandstones and gray and drab shales, with many coal beds. White to dark clay shale. No coal. Heavy sandstone with interbedded shale and numerous beds of good coal; conglomerate at the base.	8,500	0 to 4,000

[a] The three lower members of the upper coal group have the stratigraphic position of the "Upper Laramie" of A. C. Veatch (Coal fields of east-central Carbon County, Wyo.: Bull. U. S. Geol. Survey No. 316, 1907, pp. 244–260).

Osborn correlates the upper part of the section in the Washakie Basin as later Eocene, Uintatherium and Eobasileus zones. The strata are largely volcanic ash. The lower zone (250 feet) is widely distributed. The upper zone (250 feet or more) is restricted to Haystack Butte and the surrounding badlands.

E. E. Smith [752] gives the following section of the Tertiary in southern Wyoming, on the eastern margin of the large area mapped as Eocene. (See Chapter XV, p. 680, for the Cretaceous section.)

The Great Divide Basin coal field is situated along and north of the Union Pacific Railroad in south-central Wyoming and embraces portions of the northeast end of Sweetwater County, the northwest end of Carbon County, and the southeast corner of Fremont County.

* * * * * * * * *

The coal-bearing rocks of the area here described are of Upper Cretaceous and Tertiary ages. They consist of the Colorado, Montana, Laramie, undifferentiated Tertiary, and Wasatch formations. Of these, only the last four contain workable coal beds. Thin beds of coal occur in the basal portion of the Colorado, but at no place within the area treated do they reach minable thickness. The coal-bearing formations show considerable change in character from the southern to the northern edge of the field. Those of the Cretaceous system thin rapidly toward the north and the outcrops of the beds of the undifferentiated Tertiary become more and more narrow, owing to the overlap of Wasatch conglomerate. The accompanying section shows the thickness and general characteristics of the coal-bearing formations near the Union Pacific Railroad and in the gap between Whisky Peak and the Ferris Mountains.

Section of the Tertiary rocks of the Great Divide Basin coal field, Wyoming.

System.	Group.	Formation.	Thickness (feet). South end of field.	Thickness (feet). North end of field.	General characteristics.
Tertiary.		Wasatch.	900±	1,800±	In the southern part of the area it is composed of massive white and yellowish-brown soft sandstones alternating with layers of drab to black carbonaceous shale. The sandstone members harden locally and weather into forms resembling large concretions. The basal portion is also concretionary and contains small granite pebbles. In the northern part of the field it consists entirely of white conglomerate containing decomposed granite bowlders up to 6 feet in diameter in the upper portion, and of coarse-grained white sandstone containing scattered bowlders of granite and sedimentary rocks in lower portion.
		Unconformity			
	Undifferentiated Tertiary.[a]	(?)	7,980±	2,000	Alternating layers of soft yellowish-brown and white sandstones and drab, brown, and black shales. The middle portion consists of soft shale and sandstone and is not exposed in this area. Massive white sandstone at the base is conglomeratic and contains pebbles of Paleozoic rocks. At the north end of the field only the lower part of the formation is exposed. The proportion of shale is much greater than at the south end. The basal portion contains conglomeratic layers with Cretaceous pebbles up to 8 inches in diameter.
		(?)	800±	1,800	Alternating layers of soft drab, brown, and black shales and thin strata of dark, rusty-brown resistant sandstone. Sandstone is increasingly conglomeratic toward the top. Shales in northern portion erode into bad-land forms.
		Unconformity			
Cretaceous.	(?)	Laramie.[b]	3,900±	1,050	Alternating layers of yellowish-brown and white massive sandstones, thin brown sandstone, and drab, brown, and black shales. Sandstones are very resistant in southern portion. At north end the sandstones in the basal part are more resistant than those in the upper part, and constitute prominent topographic features.

[a] The fossil evidence from this group is conflicting and the age of the group can not be decided until further paleontologic work is done.

[b] Marine Cretaceous (upper Montana) species were obtained about 500 feet above the base of this formation in sec. 1, T. 21 N., R. 89 W., and at the base in sec. 26, T. 26 N., R. 90 W. They may probably be found at various places in the lower portion, and therefore no definite formation line can be drawn on paleontologic evidence. The base of the sandstones has been used in mapping the formation because it is the only line which is marked lithologically.

Between the Washakie Basin on the west and the Laramie Basin on the east lies the Hanna Basin of Carbon County, Wyo., which comprises the "Lower Laramie" and "Upper Laramie" of Veatch.[841a]

Veatch's generalized section of the Cretaceous and Tertiary strata is quoted on page 676. His "Lower Laramie" is now recognized as Laramie and as of Cretaceous age. His "Upper Laramie" is regarded by Knowlton as equivalent to the Lance formation ("Ceratops beds"), which Knowlton believes is of Eocene age and equivalent to the lower part of the Fort Union formation, but which Stanton and others believe is of Cretaceous age and older than the Fort Union, representing in fact the upper part of the Laramie.

Tertiary strata occur in the Laramie Basin and in the valleys of the adjacent slopes on the east and northeast. They have been mapped by Darton,[247] who assigns the deposits on Little Medicine Bow Creek, at the north end of the basin, to the Chadron formation, the lower formation of the White River group (Oligocene). The age of the other occurrences has not been determined.

The elevated basin of Middle Park, Colorado, contains strata which are correlated by Cross with the Denver formation. They were first described by Marvine,[577] who distinguished a "doleritic breccia" and a "lignitic formation," the latter 5,500 feet thick. Cross [185] reviewed Marvine's observations in detail in the field and reported on the stratigraphy and correlation of the formations. The strata are unconformable to the marine Cretaceous, and their correlation with the Denver formation is determined on their stratigraphic condition, lithologic similarity, and closely related floras. Cross [186] says:

The "doleritic breccia" of Marvine is a series of dark tuffs, conglomerates, and breccia beds, made up of a large series of andesitic fragments, of types identical with those in the Denver formation. These beds are coarser in texture and are more variable than the Denver strata but resemble them very much in many details. The sharp line drawn by Marvine between the "breccia" and his "Lignitic" series does not appear justifiable. While Marvine does not refer to volcanic materials in the upper series, there is in fact a gradation between the lower, dark, almost purely andesitic strata and the lighter-colored beds above, in which granitic débris usually predominates, although micaceous and hornblendic andesites are abundant for more than 2,000 feet upward in the series, as far as the writer's observations go.

Plant remains are the only fossils as yet known from the Middle Park strata. These were found by the Hayden Survey party in the "Lignitic" series only, but they occur also in the dark tuff layers of the lower beds. A number of the species described by Lesquereux as from Middle Park are now known to have come from the Eocene lake bed at Florissant, Colo. The entire known fossil flora of the Middle Park series has been studied by Mr. Knowlton. * * * Twenty-five satisfactory species are known from these strata, and by far the strongest alliance is with the flora of the Denver formations.

Along the Grand River near Hot Sulphur Springs the stratigraphic relations of the Middle Park beds are clearly shown. They here rest upon the upturned and eroded section of the Mesozoic series, from the Jura to the Fox Hills, and overlap the former to the granite.

According to Shaw,[735] the following Tertiary formations occur in the Glenrock coal field in east-central Wyoming:

Red and light-gray conglomerate and sandstone.
White clay, more or less calcareous and commonly sandy (White River formation).
Fort Union (?) formation (shales, sandstones, and coal).

K 13-14. GREAT PLAINS OF SOUTH DAKOTA, WYOMING, COLORADO, AND NEBRASKA.

Eocene strata are lacking in part of the northern Great Plains, the lower Oligocene being the lowest Tertiary. In considerable areas it rests on the eroded marine Cretaceous, though there are outlying remnants on later formations, and it constitutes the White River group of Hayden, which includes the Chadron and Brule formations of Darton. Darton [238b] says:

Early in the study of Great Plains geology the Tertiary formations were divided into the White River group below and the Loup Fork above. This distinction is a clearly recognizable one, although, as now well known, there were confused under the name of Loup Fork a number of separate formations ranging in age from Miocene to early Pleistocene.

The White River group has been studied mainly in the Big Badlands, lying southeast of the Black Hills, where three principal subdivisions were defined, the lower one as the Titanotherium beds, the middle as the Oreodon beds, and the upper as a series consisting of the Protoceras sandstone and some overlying clays. This classification is distinctly set forth by Dr. Wortman.[a] In the Oreodon clays there is often a marked sandstone horizon known as the Metamynodon beds.

In mapping the geology of western Nebraska, in 1897, I had need to subdivide the formations in the valley of Platte River and Pine Ridge, where I found that the White River group consisted of the usual basal series, the Titanotherium beds, which I designated the Chadron formation, and the usual overlying series of flesh-colored sandy clays, the Oreodon beds, to which the name Brule clays was applied.

* * * * * * * * *

The Chadron formation [consists mainly of] sandy clays and greenish-gray sandstones, mostly of soft texture, in which characteristic Titanotherium remains are of frequent occurrence. The upper limit to the formation is placed arbitrarily just below some pink clays lying below a thin bed of limestone, which is believed to be at the same horizon as one in the Big Badlands, where it immediately overlies the last of the beds of Chadron character. The thickness of the formation appears to be about 200 feet at most, but, as it lies on a very uneven surface, the amount varies greatly. The sandstones, which occur at various horizons, appear to lie in narrow belts, doubtless indicating channels of deposition. The lineal character of some of these channels is very distinctly exposed in the western portion of Goshen Hole.

The Brule clay consists mainly of a hard sandy clay of pale-pink color and massive structure, having near the base a thin layer of limestone. Locally some portions are sandy and contain beds of sandstone. * * * In the northern face of Scotts Bluff, * * * from the base of the overlying Gering beds to the surface of the river, there is a vertical interval of 500 feet continuous outcrop. The formation also has a small additional thickness below the level of the river. * * * The badlands topography is a characteristic feature of most exposures of the Brule clay. * * * The basal portion of the formation generally includes a thin bed of limestone, and at various horizons there are occasional irregular lens-shaped masses of sandstone. * * * [The limestone] is a very thin bed of compact cream-colored rock lying on a series of pinkish and greenish clays which are regarded as the base of the formation.

Beds of volcanic ash occur in the Brule clay, some of them of wide extent and apparently at constant horizons. One bed conspicuous in many outcrops lies at 60 to 70 feet below the top of the formation in the district south and southeast of Gering. It is about 150 feet below the top at Scotts Bluff, a position which it holds for some distance to the west. Another higher bed often occurs. Fossil bones of various mammals and turtles characteristic of the Oreodon fauna of the Oligocene occur in the Brule clay.

Osborn [623h] assigns the Chadron formation to the lower Oligocene and gives its homotaxis and synonymy. The lower part of the Brule Osborn places in the middle Oligocene and the upper part in the upper Oligocene; the former comprising the Oreodon zone and "Metamynodon sandstones," the latter containing the Leptauchenia zone and "Protoceras sandstones." He also gives the homotaxis and synonymy of the lower and upper parts of the Brule.[623i]

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[a] Wortman, J. L., On the divisions of the White River or lower Miocene of Dakota: Bull. Am. Mus. Nat. Hist. vol. 5, 1893, pp. 95–105.

K-L 10. COAST RANGE OF OREGON.

According to Diller,[273] Eocene rocks form the mass of the Coast Range from a point near the Columbia to Coquille River. Three groups of strata are distinguished—(1) the oldest, composed in general of igneous sediments closely related to lavas of earlier or contemporaneous eruption; (2) shales, containing here and there much material of igneous origin; and (3) sandstones, forming the uppermost group. Diller describes many local occurrences and cites Dall's determinations of fossils from specific places.

These Eocene terranes constitute the Arago group (named from exposures near Cape Arago), which is divided into the "Pulaski" and Coaledo formations.[275]

The "Pulaski" formation comprises all the Eocene strata below the coal-bearing Coaledo formation in the Coos Bay and Port Orford quadrangles. It consists chiefly of soft yellowish sandstone interstratified with thin beds of shale but includes also small bodies of limestone composed largely of remains of algæ and Foraminifera. During the "Pulaski" epoch and particularly toward its close there were volcanic eruptions which resulted in basalt flows and tuff beds.

The Coaledo formation consists of sandstones and shales with coal beds. The strata were deposited chiefly in brackish waters and thus contrast with the marine "Pulaski." Sandstones predominate in the lower part of the Coaledo, whereas in the upper portion light-colored shales are characteristic.

The Arago group, composed of the "Pulaski" and Coaledo formations, comprises about 10,000 feet of strata. The uppermost portion as measured near Cape Arago consists of foraminiferal and other shales (2,200 feet) and sandstones (850 feet). The sandstones are distinguished by Dall [211a] as the Tunnel Point beds.

Regarding the correlation of the Arago group Dall [211b] states:

> These beds are composed of sandstones and shales and extend northward from Cape Arago to Cape Gregory and thence eastward to Miners Flat, on the south shore of the entrance to Coos Bay, Oregon. They have an average dip of 70° NE. and a thickness of over 3,000 feet. They contain *Cardita planicosta*, Ampullina sp., and other middle Eocene forms which suggest their correlation with the Claibornian of the Gulf column. They are apparently newer than the blackish rocks of the region about the junction of Little River and the North Umpqua, which also contain *Cardita planicosta* but which have also a large proportion of distinct species. They appear to be older than the brackish-water deposits which inclose the Coos Bay lignites, though the latter have occasional intercalary marine layers which contain species of fossil shells apparently identical with members of the Arago fauna. The brackish-water species comprise forms belonging to Corbicula, Cyrena, and Melania or Cerithiopsis, forcibly recalling those which occur in the lignite beds of the Puget group, some of which prove to be identical.
>
> The Umpqua beds above alluded to contain a notable number of "*Loxonema*" *turrita* Gabb, which is stated by him to be common in the Tejon, and have been referred by Diller [a] to the Tejon group. While this disposition of them may be confirmed by a study of their fauna and is probable, the Arago beds, which were not at first discriminated from those of the Umpqua, now appear, from the differences in their fauna, to require separation as a distinct series of beds.

[a] Bull. Geol. Soc. America, vol. 4, 1893, p. 219.

See Harris [a] on the correlation of the Tejon. There seems to be a strong probability that part of the beds heretofore referred to the Tejon represent the basal Eocene, but at present we are without sufficient evidence to speak positively.

Diller describes the Arago group in the Coos Bay [275] and Port Orford [277] folios and the Umpqua in the Roseburg folio.[274] The following quotation is from the Coos Bay folio:

The rocks of the Eocene period in this region have been called the Arago formation, but in this quadrangle they are grouped into two formations—the Pulaski and the Coaledo. These formations occupy almost the whole of the Coos Bay region. They are composed generally of sandstones and shales, which are especially well exposed near the mouth of Coos Bay and at Cape Arago, where they contain *Cardita planicosta* and numerous other characteristic Eocene fossils. Heavy-bedded sandstones prevail in the eastern part of the area, toward the Coast Range, where the Eocene rocks have a wide distribution, and shales become abundantly interstratified with the sandstones in the western part, near the coast. In the eastern part of the quadrangle the sandstones are penetrated and separated by dark, heavy intrusions of igneous rock, basalt, and the overlying sandstone near by generally contains much sediment derived from it.

The strata among which the coal beds are found contain at a number of places the fossils which characterize the Arago formation, and it is therefore evident that the coal-bearing strata are of the same age as that formation and form part of it.

L 10. JOHN DAY BASIN, OREGON.

Merriam distinguished as probably Eocene the Clarno formation, a deposit of "tuffs, ashes, and lavas," which overlies the Chico (Upper Cretaceous) and is overlain by the John Day formation (Oligocene) at Clarno Ferry, on John Day River, Oregon. He says: [590a]

At numerous localities along the western side of the John Day Basin there are exposed, either below the lowest John Day beds or above the Chico Cretaceous, several hundred feet of strata which certainly do not belong to either of these horizons. To these beds the name Clarno formation has been applied by the writer.

Typical exposures of the Clarno are to be seen at Clarno's Ferry, on the John Day east of Antelope, near the town of Fossil, on Cherry Creek, and near Burnt Ranch.

The Clarno formation is made up almost entirely of erupted materials. Part of the section consists of rhyolite and andesite flows, but the most characteristic portion comprises sedimentary beds grading from ashy shale to coarse tuff. The ash and tuff beds frequently contain plant remains in abundance and were evidently, at least in part, deposited in water. The strata seem in some places to have accumulated very rapidly. At one locality where large specimens of Equisetum have been found in shaly beds, the stems are standing erect and cutting across the stratification planes. This could occur only where deposition or shifting of the ashy mud was taking place very rapidly. The wide extent of the plant beds, which seem to be present at nearly all of the well-known occurrences of the formation, indicates the existence of lacustrine conditions, intermittently at least, over this region during the Clarno epoch.

The thickness of the Clarno formation is not less than 400 feet. It will probably be found to exceed that limit. The strata are usually gray to buff but sometimes show brilliant coloration in shades of red, green, and blue.

The relations of the Clarno to the Cretaceous may be seen just east of the town of Mitchell, where a considerable thickness of andesite and tuff is resting upon the Chico. Again, on the wagon road between Allen's ranch and Mitchell, the Clarno appears to rest upon the western side of the Knoxville anticline.

[a] Science, vol. 22, Aug. 18, 1893, p. 97.

Where the Clarno has been found in contact with the John Day there is no apparent angular unconformity of the strata. The difference in induration and weathering is, however, very noticeable. The sedimentary parts of the Clarno show a much greater degree of induration than the John Day beds immediately above and tend at all localities to form steep bluffs ornamented frequently with balanced rocks or grotesque figures. The soft beds of the Lower John Day normally weather into rounded, mud-covered domes or more gently sloping banks.

On the river above Clarno's Ferry this formation dips about 15° to 25° to the north and beneath the Lower John Day. Fine exposures continue along Pine Creek east of the ferry. North of the town of Fossil the Clarno is again seen typically developed and dipping under the John Day. Along Currant Creek it is well exposed and is close to or in contact with the Columbia lava.

At most of the localities mentioned the Clarno shows a considerable thickness of lava beds toward the top. These flows are not, however, the uppermost part of the section. The base of the formation is formed by andesite flows in several places, but it was not determined whether the whole section is present at these points.

At most of the Clarno localities where careful collecting has been done, plant remains are found to be fairly abundant. Repeated attempts have been made to obtain vertebrate or invertebrate fossils also, but, so far as the writer is aware, none have ever been discovered. The plants are, perhaps, most common in a bed of tuff and ash, 100 or more feet in thickness, belonging to the middle or the lower part of the formation.

Knowlton [590b] reported on the fossil plants as follows:

In attempting to work out the bearing of the plants above enumerated on the question of the age of the beds, it should not be overlooked that any conclusions drawn might be quite different from what they would be were the whole flora of each of the localities to be considered. For example, Dr. Merriam's collection from Bridge Creek embraces only 14 previously named species, whereas the complete known flora of this locality includes over 40 species. And further, it is impossible at the present time, without having worked out the affinities of the Tertiary floras of California and elsewhere, to give with any degree of completeness the outside relationships of the flora of the John Day region. The following conclusions, however, are not likely to be greatly modified by subsequent work.

The oldest horizon represented by these collections seems to be that near the crossing of Cherry Creek. The species, though few in number, seem to have their greatest affinities with forms from the lower Tertiary, and it is probable that this horizon should be referred to the lower or middle Eocene. There are a few species in common with Bridge Creek, but in general its flora has a slightly older facies.

The Bridge Creek, as already suggested, has an ample flora which is represented by a wealth of individuals. A large proportion of its species are endemic, but on considering the obvious relations of these, as well as the forms known from other localities, an upper Eocene age is indicated.

Several other of the localities seem to be of the same age as the Bridge Creek beds, namely, 1½ miles east of Clarno's Ferry, 3 miles above Clarno's Ferry, and one-half mile northeast of Fossil. Not more than three previously named species are known from either of these localities, and not rarely the identification of some of these is more or less doubtful, but as nearly as can be made out they should be of the same age as Bridge Creek.

It will be noticed that the determination of the plant remains, both as regards the flora as a whole and with respect to its subdivisons, agrees with the statement relating to stratigraphic succession. The Bridge Creek beds, with the few specimens from the shales 1½ miles east of Clarno's Ferry, are considered upper Eocene, while those from Cherry Creek are held to be an earlier facies.

L 10. CASCADE RANGE AND YAKIMA VALLEY, WASHINGTON.

The Eocene of the upper Yakima Valley comprises sediments and igneous rocks which in order from older to younger are the Swauk formation, Naches formation, Kachess rhyolite, Teanaway basalt, gabbro, Roslyn formation, and Manastash formation. The following descriptions are condensed or quoted from those of George Otis Smith:[756, 758a]

The Swauk formation consists of conglomerate, sandstone, and shale, which vary greatly in character from place to place. At the base there is usually a conglomerate or arkose derived directly from the older rocks and composed largely or exclusively of their material. Arkose sandstones and carbonaceous shale make up the greater part of the formation. The thickness is 3,500 to 5,000 feet but varies with inequalities of the underlying surface, which are considerable. The shales contain abundant and well-preserved fossil leaves, which are regarded by Knowlton as of Eocene age.

The Roslyn formation occurs in a small basin in the upper Yakima, where its extent and structure have been well determined in the development of the coal mine opened upon its principal coal bed. The greater part of the formation consists of massive sandstones, with which fine-grained clay shales are interbedded. The thickness is approximately 3,500 feet. The included flora is quite distinct from that of the Swauk formation and has Miocene affinities, but, though evidently younger than the Swauk, it is considered to belong in the Eocene.

The Manastash formation is the latest Eocene sedimentary deposit known in the Yakima Valley. It rests directly upon the pre-Mesozoic schists, with a well-developed basal conglomerate, and consists of about 200 feet of sandstone and shale. But two small areas are known, and they might readily be confused with other similar sandstones, which, however, do not have the flora that the Manastash contains. It has been described by Knowlton, who states that none of the species occur in the Roslyn or Swauk formations. They are correlated with species found in the Florissant beds of Colorado and at Corral Hollow, California.

The Naches formation is composed of interbedded sandstone and basalt, the sedimentary rock predominating in the lower and the volcanic in the upper portion. * * * No occurrences of the Naches formation are known outside of the Snoqualmie quadrangle.

Since the Naches and Swauk formations are not found in juxtaposition, there is lack of direct stratigraphic evidence regarding their relative ages. It is noteworthy, however, that they have similar relations to both the older and later rocks, a fact which suggests that they may be nearly contemporaneous. The evidence afforded by fossil plants confirms this view.

L 12. BIGHORN BASIN, WYOMING.

For the southwest side of the Bighorn Basin Woodruff[947] determined the following section of the Tertiary:

Section of coal-bearing and associated rocks exposed along Shoshone River near Cody, Wyo.

System.	Formation.	Thickness (feet).	Characteristics.
Tertiary.	Wasatch formation.		Various colored shales interbedded with sandstone and conglomerate.
	Unconformity		
	Fort Union formation.	3,100	Gray to drab sandy shale and tan-colored massive sandstone. In the lower part of the formation conglomerates occur at intervals through 1,000 feet of strata.
	Unconformity (?)		
Cretaceous.	Laramie (?) formation.	[See p. 684 for the Cretaceous section.]	

For the east side of the Bighorn Basin Washburne [867] gives the following section:

Stratigraphic column on the east side of the Bighorn Basin, Wyoming.

System.	Formation.	Thickness (feet).	Characteristics.
Tertiary (Eocene).	Wasatch formation.	500	Bright-colored clays, with a few thin lenses of sandstone. Contains workable coal in the central part of the basin.
	——Unconformity——		
	Fort Union formation.	1,000–2,000	Dark-colored shale and massive sandstone. Contains workable coal.
	——Unconformity (?)——		
Cretaceous.		[For the Cretaceous see p. 690.]	

Loomis [546] has discussed the conditions of deposition in the Bighorn Basin and has shown that the strata are mainly fluviatile, using the term to cover all kinds of flood-plain deposits, in contrast to lacustrine. Osborn [623c] says:

Geologically the section is 2,391 feet thick, divided into lower, middle, and upper levels, all showing flood-plain rather than eolian characteristics, but indicating different rates of deposition and consequent longer or shorter exposure of the deposits to the sun and air. Only the middle or red beds are decidedly fossiliferous, and they seem to have been exposed longest to the air, leaving the bones of terrestrial animals on the flats; they contain the typical Wasatch, Coryphodon and Eohippus fauna. Occasionally truly aquatic animals, such as crocodiles, fishes, and turtles, becoming stranded or inclosed in lagoons far from the river, mixed their remains with those of the land animals. Loomis's approximate analysis of the natural habitat of the total vertebrate fauna is: Aerial, 3 per cent; terrestrial and arboreal, 77 per cent; amphibious, 12 per cent; aquatic, 10 per cent.

The section compiled by Osborn [623b] from Loomis gives the Lambdotherium zone as the highest fossiliferous horizon of the Bighorn Basin, with 730 feet of unfossiliferous clays above it. Lambdotherium occurs at the base of the Wind River section and thus serves to correlate the two.

L 12. WESTERN MONTANA.

The areas in southwestern Montana on the headwaters of the Missouri, which are distinguished by the "Later Tertiary" color on the map, include possibly Eocene and certainly Oligocene deposits. Douglass [288] describes the Sage Creek beds (Eocene?), White River (Oligocene), and Fort Logan beds (upper Oligocene, John Day?).

The Eocene (?) "occurs on Sage Creek about 7 miles northeast of Lima, Beaverhead County." The fossils found are considered to represent Heptodon?, *Hyrachynus priscus* Douglass, and Metamynodon?.

The deposits of White River age are shown to be lacustrine, in contrast to those of the Great Plains, and "appear in the main to represent the Titanotherium and Oreodon beds of South Dakota."

The Fort Logan beds of Douglass are the lower Deep River beds of Scott.[717] They occur on Smith River, formerly known as Deep Creek, southwest of the Little

Belt Mountains. Scott quotes from the first description by Grinnell and Dana (1875):

The Tertiary beds found here consist for the most part of homogeneous cream-colored clays, so hard as to be with difficulty cut with a knife. The beds are horizontal. * * * Some bluffs were noticed where the Miocene beds attain a thickness of about 200 feet and these were capped by 50 feet of the Pliocene clays, both beds containing characteristic fossils.

Scott infers an unconformity between the two, there being suggestions of erosion in the surface of the lower and "the fossil contents of the two series of strata" being "very strikingly different."

Calkins, in an unpublished manuscript, states that the age relations of the Tertiary rocks in the Philipsburg quadrangle are very imperfectly known.

If the Eocene is represented at all, it is probably by a very thick accumulation of cemented gravels observed at the east end of the Anaconda Range and by some of the andesitic and rhyolitic tuffs associated with them. These rocks are considerably tilted but show far less deformation and metamorphism than the pre-Tertiary rocks of the region. No fossils have yet been found in them.

See also L 12, Chapter XVII (pp. 831–832).

L 12. BULL MOUNTAIN COAL FIELD, MONTANA.

According to Woolsey,[950] the Fort Union formation in the Bull Mountain coal field (latitude 45° 30′, longitude 108°) is 1,400+ feet thick and consists chiefly of gray to buff sandstone, alternating with gray shale. The sandstone, though extremely variable, is commonly massive and evenly distributed throughout the section. Coal beds occur at intervals of about 100 feet or less and are most numerous in the upper part. The base of the formation is strongly marked by contrast with a band of olive-green clay shale, which belongs to the next lower formation.

Richards[665] and Lupton[553] have reported later on the central and eastern parts of the field respectively.

L 12. RED LODGE COAL FIELD, MONTANA.

Woodruff[946] describes the Fort Union formation in the Red Lodge coal field as 8,500 feet thick and as consisting of sandstone and shale, with carbonaceous shale and coal at several horizons. Workable coal beds are confined to a zone above the middle of the section. The formation is therefore divided into:

	Feet.
Upper barren member	1,975
Middle productive member	825
Lower barren member	5,700
	8,500

The lowest member is composed mostly of yellowish sandstone and shale. Beginning 1,650 feet above the bottom of the formation is a group of beds 1,000 feet thick, composed of varicolored sandy shale with a few beds of soft yellowish sandstone, numerous beds of carbonaceous shale, and in the upper part a few coal beds, one of which contains 18 to 24 inches of coal. Above this group carbonaceous shale and coal beds occur at diminishing intervals as the productive member is approached. * * *

In the middle productive member * * * the sandstone and shale resemble the sandstone and shale of the lower member and do not seem to indicate any essential difference in conditions of deposition, but the carbonaceous shale and workable coal beds intercalated with the other rocks serve to distinguish the member. As indicated above, the coal beds of the middle member do not begin abruptly but are presaged in the lower member by thin beds of coal. At the upper limit of the middle member, however, there is a sharp transition from the productive measures to the barren beds above. * * *

The upper barren member * * * is composed, like the lower member, of sandstone and shale, with a very little carbonaceous material. Shale predominates in the lower portion and sandstone in the upper portion.

L 13. PLAINS EAST OF THE BIGHORN MOUNTAINS, WYOMING.

The Tertiary strata of northern Wyoming were described by Darton[239] under the names De Smet formation and Kingsbury conglomerate and were assigned to the Cretaceous system. Later investigations show that the "De Smet" formation and the Kingsbury conglomerate comprise the Fort Union formation (Eocene). Details of the coal-bearing section of the strata in the Sheridan coal field are given by Taff,[809] and in the Buffalo coal field by Gale and Wegemann.[357] The name "De Smet" has been abandoned by the Survey in favor of Fort Union, and the Kingsbury conglomerate is now treated as a member of the Fort Union, as it also is of Fort Union age.

L 13. MILES CITY COAL FIELD, MONTANA.

The Fort Union formation in the Miles City coal field is described by Collier and Smith [167] as follows:

The rocks consist of comparatively fine material, mainly clay shale and sandstone, including lignite and thin beds of impure limestone. They are all fresh-water deposits and contain an extensive fossil flora of about 400 species of plants which resemble those of modern times, and a fauna including fishes, fresh-water mollusks, and reptiles.

The total thickness of Fort Union rocks exposed in the Miles City field is about 900 feet, which may be increased by data obtained from drill holes at Miles City to a total of 1,400 feet. From a comparison of the section at Miles City with that exposed about 70 miles to the northeast near Glendive, it is inferred that the base of the Fort Union formation is not very deeply buried, and it is probable that some of the drill holes at Miles City have penetrated to underlying Cretaceous rocks.

The Fort Union rocks exposed are rapidly separated into two members by a marked difference in lithologic character. The lower member, about 500 feet thick, consists mainly of alternating beds of clay shale and sandstone, having a general dark-gray or somber hue. In detail the individual layers of this part of the formation, especially the sandstones, show numerous irregularities of deposition. Thin layers of ferruginous limestone occur at short intervals throughout the section, and concretion-like masses of the same material, more or less lenticular in form, are included in the shales and sandstones. The thicker sandstone beds are usually characterized by more or less irregular cross-bedding. Coal is found at numerous horizons, but the beds are extremely variable in thickness and horizontal extent.

L 13. SENTINEL BUTTE COAL FIELD, NORTH DAKOTA AND MONTANA.

The Fort Union formation in the Sentinel Butte field (latitude 47°, longitude 104°) resembles the beds as developed in the Miles City field. It is described by Leonard and Smith[534] as follows:

The Fort Union formation has a thickness * * * as measured on its outcrop of 900 feet. If to this be added 820 feet of lignite-bearing rocks, which are probably to be referred to the Fort Union, penetrated by the Medora well below the lowest lignite outcropping in the field, the total thickness is 1,720 feet.

Overlying the heavy sandstone which forms the summit of Sentinel Butte and constitutes the topmost member of the Fort Union formation, there are about 40 feet of calcareous clay and limestone, as shown in the Sentinel Butte section. These beds are merely the remains of a formation which doubtless at one time covered a large area in this region. Strata which have yielded Oligocene vertebrates and which occupy a similar horizon immediately over the massive sandstones at the top of the Fort Union occur in Chalk Butte, 70 miles farther southeast. Other similar buttes in northwestern South Dakota and southeastern Montana have likewise been referred to the Oligocene.

On the basis of mammalian remains, Osborn[623] correlates a portion of the Fort Union with the Torrejon formation of New Mexico. In the San Juan Basin of northwestern New Mexico the Torrejon is conformably underlain by the Puerco, which carries a basal Eocene fauna.

L-M 10. OLYMPIC PENINSULA AND PUGET SOUND REGION, WASHINGTON.

Arnold[29b] describes Eocene deposits on the north coast of the Olympic Peninsula as follows:

The oldest formation of definitely known age on the Olympic Peninsula is a 1,200-foot series of black basalt and greenish basalt tuffs and tuffaceous sands found in the vicinity of Port Crescent and here designated the Crescent formation. It comprises the region immediately west of Crescent Bay and a prominent ridge extending eastward from the latter to Freshwater Bay. *Venericardia planicosta* Lamarck, *Turritella uvasana* Conrad, and other characteristic fossils found in the tuff indicate the Eocene age of the series and its general contemporaneity with the Tejon of California.

The basalt occurs in two thick sheets, an upper and a lower, each of which may represent several surface flows. Between the two basalt sheets and intimately associated with the top of the lower is a series of roughly bedded fossiliferous tuffs. * * * In the region of Crescent Bay the lower basalt has an exposed thickness of 200 feet, while the tuffs and upper basalt sheet each show approximately the same. The Freshwater Bay section gives basalt and coarse massive basalt tuff 600 feet, thin-bedded green tuff 355 feet, and black vesicular basalt 200 feet. The base of the Crescent formation is not exposed, so that the subjacent rocks are unknown. The overlying sediments consist of coarse conglomerates separated from the basalt by an erosion interval. Faults define the contact between the Crescent formation and the Clallam formation (Oligocene-Miocene) adjacent.

These basalts and tuffs are the only rocks of igneous origin found along the whole length of the northern shore of the peninsula. Taking into consideration the volcanic activity which prevailed during the Eocene in the Cascade Range, only a comparatively short distance away, this single and rather limited occurrence of eruptives seems rather remarkable. The paucity of igneous rocks, however, may possibly be accounted for, at least along the northern coastal border of the Olympics, by the fact that formations younger than the basalt are the only ones exposed, and it is possible that some of these newer rocks are underlain by the Eocene basalt series.

The Puget group comprises many thousand feet of estuarine and marsh deposits, which are extensively coal bearing. Willis[939] says:

The coal-bearing rocks of the Puget Sound basin have been designated the Puget formation. They are prevailingly sandstones of variable composition, texture, and color, thinly interbedded, and frequently cross stratified. Their composition varies from that of a typical arkose, consisting of slightly washed granitic minerals, to siliceous clay. Beds of conglomerates or concentrated quartz sands have not been observed. Carbonaceous materials are generally present as fragments of plants, as vegetal ooze in greater or less proportion to the other constituents, and as distinct coal beds. Carbonate of iron is frequently an integral constituent of the rocks.

In color they are, when fresh, generally bluish gray, shading to brownish black. They weather to buff tints, which are usually dull. The coarser and more massive varieties form beds 20 to 100 feet thick, in which bedding planes are not distinguishable. The finer deposits are thinly laminated and carry abundant leaf impressions, which occasionally interlap with one another so as to form a mass of leaf fragments. * * *

In many of the sandstones silvery-white mica has developed as a secondary mineral, but they exhibit no other indication of metamorphism. The coals, on the contrary, being chemically more sensitive, have undergone metamorphism to a greater or less extent through loss of combined water and concentration of fixed carbon. * * *

The stratigraphic relations of the Puget series are not determinable within the area under discussion, since the strata nowhere come in contact with older sedimentary rocks. Sixty miles northward, on the Skagit River, is a contact between similar coal-bearing strata and older metamorphic schists, described in an earlier report as possibly a surface of deposition or of faulting. Examination of this locality in 1895 led to the discovery of small pebbles of the schist forming a basal conglomerate in the sandstone beds next the contact, which was therefore a surface of deposition during a transgression by the sea. Fossils found in limestone under the schists are stems of crinoids of Carboniferous or Triassic age, whereas the coal-bearing sandstones of this locality are assigned by Knowlton to the Eocene on the evidence of numerous leaf impressions.

The age of the Puget formation has been in doubt because of the obscurity of stratigraphic relations, the general absence of marine fauna, and the indeterminate character of the flora. * * *

A preliminary examination of the fossil plants enabled Knowlton to report that the lower beds of the series are Eocene, whereas the upper beds may be of Miocene age. The floras from horizons several thousand feet apart in stratigraphic range are so distinct as to afford means of correlating separate strata of the Puget formation. * * *

The measured sections of the Puget group exhibit total thicknesses of 5,800 feet on Green River, 5,500 feet on South Prairie Creek, and 5,480 feet in Carbon River Canyon. None of these measures is complete. In each instance the lowest stratum is of the Puget group outcropping on an anticline, and the highest is the limit of exposure where the rocks pass under later formations. These sections overlap, and there are also higher beds exposed on South Prairie Creek above the limit of the measured sections. These considerations justify the inference that the thickness of the Puget group may probably be 9,000 feet or more.

C. A. White,[890] who gave the name Puget to the strata described by Willis, quotes Newberry on the resemblance of the flora to that of the "Laramie" and comments on the molluscan faunas of the two as follows:

The fauna to which one instinctively turns for the purpose of zoological comparison with this Puget estuary fauna is that of the Laramie group. Such a comparison is especially suggested by the known floral relations of the two groups of strata, their presumable contemporaneity of origin, and the nonmarine character of the molluscan faunas of both. Upon making a comparison, however, important zoological differences appear. It is true, there are two species of Corbicula in the Puget fauna that are so closely like Laramie forms as to suggest specific identity upon casual examination, but the differences between the two faunas are strikingly shown by the family and generic characters of the other members of the Puget fauna as compared with the Laramie fauna.

For example, a species of Teredo has been found in the Puget group, but no member of the Teredinidæ has yet been found in the Laramie. Two species of the Puget fauna are referred to the Tellinidæ, but no member of that family has yet been found in the Laramie. But the generic form which gives an especially unique character to the Puget fauna is that of Batissa.

This genus has not hitherto been known to occur in North America in either a fossil or living condition, nor has it been found nearer to this continent than certain of the Pacific islands. Still the hinge characters observable on these Puget estuary specimens leave no room for reasonable doubt that they are strictly congeneric with true Batissa. Indeed, a species of that genus which is now living upon the Fiji Islands is closely related to this fossil form.

Knowlton (in manuscript) has described 365 species of plants from the Puget group. The lower strata are Eocene and the upper are possibly Miocene. The general character and distribution of the flora are stated by Knowlton [507] as follows:

The flora of the Puget formation is an exceedingly rich one. Over 100 species have already been named and described, and from the material in hand it seems safe to assume that the number will reach 250 [365]. Inasmuch as a very large proportion, perhaps more than nine-tenths, of the plants are new to science, it becomes extremely difficult to settle their affinities and determine satisfactorily their bearing on the question of age. It is only by a study of their general facies that results along either line can be obtained.

While the Puget flora as a whole may be considered relatively uniform, there are well-marked differences between the plants found in the lower beds, as represented at Carbonado, Wilkeson, and South Prairie Creek, and those found in the upper beds at the highest point in the Carbon River canyon, the Clay mine on Green River, Snoqualmie Pass, and at Steels Crossing near Black River Junction. Certain few genera are found throughout the series, but thus far no species has been noted as common throughout. On the other hand, both lower and higher beds are characterized by a considerable number of genera. Thus Quercus, Juglans, Rhamus, Populus, and Laurus are found from base to summit. The following genera have thus far been found in the lower beds but not at all in the upper: Cladophlebis, Lastrea, Dryopteris, Anemia, Calamopsis, Sabal, Siphonites, Ficus, Eucalyptus, and Aralia; and the following have been detected in the upper but not in the lower: Rhus, Castanea, Betula, and Platanus.

The lower beds, on account of the abundance of ferns, gigantic palms, figs, and a number of genera now found in the West Indies and tropical South America, may be supposed to have enjoyed a much warmer, possibly a subtropical temperature, while the presence of sumacs, chestnuts, birches, and sycamores in the upper beds would seem to indicate an approach to the conditions prevailing at the present day.

A number of species of plants have been found to be common to the west and east sides of the Cascades. This number is not large, but they are important and easily recognized forms, and there is indication that the number will be increased when the material in hand has been more thoroughly studied. This would indicate that approximately similar conditions of climate and topography prevailed throughout this general area during the Puget epoch. The Cascade Range as it now exists did not then intervene.

The Puget group is well described by George Otis Smith,[754] who brings together the data quoted above, with additional details.

M 10. SOUTHERN BRITISH COLUMBIA.

At the junction of Similkameen and Tulameen rivers, British Columbia, is a basin containing strata assigned by Camsell [129a] to the Oligocene:

These sedimentary rocks alone in the northern part of the district cover an area of nearly 50 square miles, the basin being 14 miles long with a variable width of from 3 to 5½ miles. They consist of thick beds of sandstone, with clay, shales, and several seams of lignite. The base of the series appears to be a very coarse grained sandstone containing many large rounded white feldspars in a matrix of calcareous material. This rests on the eastern side of the basin, on the Copper Mountain series of rocks [monzonite], while on nearly all other boundaries the sediments dip under the more recent volcanic rocks, which lie as sheets on them. In parts also these volcanics have thrust themselves through the sediments and now appear as islands in the older rocks. The strata do not now lie horizontally but have been tilted at low angles, making an irregular series of folds. Some faults also occur.

Many drill holes have been bored in this Tertiary basin in search of lignite seams, and with some good results. Most of them, however, were put down at or near the edge of the river, and only one near the western edge of the basin. * * * These have disclosed the thickest lignite seams to be in the vicinity of the town of Princeton, where a bed over 18 feet in thickness was struck at a depth of 49 feet below the surface. The hole in which this seam was found was sunk near the bridge over the Similkameen River to a depth of 280 feet. In this hole lignite seams aggregating 35 feet 7 inches were crossed in the first 90 feet, while the rest was in shales and sandstones.

Several drill records are given, the strata having been penetrated in one hole to a depth of 1,000 feet. In regard to the character of the lignite, Camsell states:

Though these beds are of the same age as the Coldwater group of the Nicola country, in which coal also occurs, there is a difference in the quality of the fuel contained in each. The Nicola coal is a true bituminous, whereas this is a lignite. The former, also, is considerably higher in fixed carbon and lower in water, while the fuel rate is 1.447, as against 1.108 of the Princeton coal.

Some of the beds of the Princeton coal basin are only in a primary stage of formation, and they still show the brown, woody fiber of the slightly altered vegetable remains. Much retinite also occurs in them. Some also have been completely destroyed by combustion, and it is to the combustion of an underlying bed of lignite that Dr. Dawson attributed the metamorphism and color of the rocks at the Vermilion Bluffs.

M-N 11-12. GREAT PLAINS, ALBERTA.

The Eocene of the Great Plains in Alberta is the Paskapoo series of the Canadian Survey, the so-called "Upper Laramie," which is areally continuous with the Fort Union and is approximately its equivalent. Beneath the Paskapoo lies the Edmonton, which is classed as Cretaceous by Stanton on the evidence of brackish-water faunas and dinosaurian remains, whereas by Knowlton it is placed in the Tertiary on account of the flora which it contains. The Canadian Survey regards the Edmonton as Cretaceous. Both these formations are mapped as earliest Tertiary or latest Cretaceous (5a).

Tyrrell's original descriptions [816a] of the Edmonton and Paskapoo are in part as follows:

The Edmonton series is perhaps, on the whole, the most characteristic series of the entire region, for though its thickness, wherever determinable, was never found to exceed 700 feet, the horizontal position of the strata causes it to underlie a very large extent of country.

It consists generally of whitish or light-gray clay and soft clayey sandstone, weathering very rapidly with more or less rounded outlines. In some places, as on Red Deer River and in the Hand Hills, it is seamed with a great number of beds of ironstone, which, with thin beds of lignite and lignitic shale, give a definite banded character to all the escarpments. It also contains a great number of nodules of compact ironstone, which are often perched on little pinnacles cut out of the soft sandstone. In the northern portion, especially along the North Saskatchewan, the banded appearance is seldom seen, though, with the exception of a smaller quantity of ironstone, the rock has very much the same character as farther south.

This is essentially the coal-bearing horizon within the district, all the coal found east of the foothills, except probably the seams on the upper North Saskatchewan and at Egg Creek, being of this age. The top of the formation is marked by an extensive coal deposit, seen first in the Wintering Hills as a thin bed of carbonaceous shale, but on being traced northward is found to thicken very greatly, till on the North Saskatchewan, near Goose Encampment, it has a thickness of 25 feet. The bottom of the series lies conformably on the Pierre shales, without any sharp line of demarcation between the two. In fact, the shales gradually lose their massive character and change almost insensibly into thin beds, which are of decidedly brackish-water origin. In the Pierre remains of land plants and animals are very rare, while here traces of land plants become fairly plentiful, and on Red Deer River dinosaurian bones are met with in great abundance, showing, with the presence of estuarine shells, the partly land-locked character of the area within which the beds were deposited.

* * * * * * * * *

Under the Paskapoo series we group all the Laramie rocks lying above those of the Edmonton series; thus it will include Dr. Dawson's Porcupine Hills and Willow Creek series and all but the lowest 700 to 900 feet of his St. Mary River series. On the plains no place was seen where its total thickness could be measured, but at the outer edge of the foothills, on Little Red Deer River, a thickness of 5,700 feet at least was determined, the bottom of the formation not being seen, and it is probable that a considerable thickness had been denuded from the top.

The beds consist of more or less hard light-gray or yellowish, brownish-weathering sandstone, usually thick bedded but often showing false bedding; also of light bluish-gray and olive sandy shales, often interstratified with bands of hard lamellar ferruginous sandstone, and sometimes with bands of concretionary blue limestone, which burns into an excellent lime. The sandstones consist of very irregular though slightly rounded grains of quartz, feldspar, and mica, cemented together in a calcareo-argillaceous matrix.

The whole series, as shown by its invertebrate fauna, is of fresh-water origin.

N 4. CHICHAGOF COVE, ALASKA PENINSULA.

Palache[628] distinguished marine sediments containing abundant fossil remains which show them to be of lower Eocene age. He described the terrane as the Stepovak series and divided it into lower and upper beds. The lower beds comprise coarse breccias or agglomerates and fine tuffs composed wholly of igneous material. The coarse agglomerates contain angular fragments, a foot or less in diameter, of white or greenish porphyry, and rarely granite. They are cemented by comminuted material which consists essentially of interwoven hornblende needles. Although macroscopically the rocks are varied in appearance, microscopically they are very similar. They are pyroclastic, but some exhibit a little evidence of water sorting and others may be called flow breccias. They contain pecten-like fossil shells which are too imperfect for determination. The upper beds consist of soft shales, sandstones, and grits, with some thin beds of limestone and here and there a chert band.

After describing local sections and the folded structure of the Stepovak series, Palache continues:

Concerning the fossils collected from this formation Dr. Dall says: "The fossils from the Stepovak beds are Eocene, probably of about Claiborne age (middle Eocene), and are the only typical Eocene yet discovered in Alaska."

(See quotations in regard to the age of the Kenai under O–P 5, Kenai Peninsula, pp. 785–787, and O 4–5, Alaska Peninsula, pp. 783–784.)

N 4, O 4-5. ALASKA PENINSULA.

The general geology of the Alaska Peninsula was thus stated by Stanton and Martin:[786]

The Alaska Peninsula contains a coarse crystalline core of granite or of similar rocks, flanked on the eastern side by Mesozoic sediments and on the western side by late Tertiary or post-Tertiary beds. The Mesozoic beds are overlain in places by early Tertiary formations. Both the Mesozoic and the Tertiary beds are cut by andesite and basalt. The intrusion and volcanic outflow has continued from late Jurassic time until the present, the region containing several active volcanoes.

The structure of the region is varied. The west shore of Cook Inlet has its general position outlined by a number of great overthrusts, by which the Triassic rocks have been brought in contact with the Upper Jurassic. The Alaska Peninsula is a region of open folding, with the folds crosscut by an irregular series of faults.

At Herendeen Bay Atwood,[42a] in 1908, distinguished the following section:

Geologic sequence in western part of Alaska Peninsula.

Age.	Geographic distribution.	Lithologic character.	Thickness (feet).	Remarks.
Recent	Stream valleys	Sands, muds, and gravels		
Pleistocene	Lowlands and along valleys.	Unconsolidated clays, sands, gravels, and glacial drift.		
Post-Miocene	Unga Island, Popof Island, Balboa Bay, Port Moller, and Chignik Bay.	Tuffs, agglomerates, breccias, and flows.		Many volcanic deposits still show cone structure.
Miocene	Unga and Popof islands, Balboa and Herendeen bays, and Port Moller.	Loosely cemented clays, sands, gravels, and conglomerates. Some beds furnish abundant marine fossils.		These deposits usually occur in very small areas.
Eocene	Chignik Bay, Unga Island, center of Alaska Peninsula, and Herendeen Bay region.	Shales, sandstones, grits, and conglomerates. Locally carries lignite.	Up to 5,000	Carries workable lignite bed at Coal Harbor. Occupies a very large part of Alaska Peninsula in Herendeen Bay region.
Upper Cretaceous	Chignik and Herendeen bays.	Conglomerate, sandstone, and shales, with coal seams.	600+	Contains valuable coal beds at Chignik and Herendeen bays.
Lower Cretaceous	Herendeen Bay	Shale, sandstone, and calcareous sandstone.	1,800+	
Upper Jurassic	Chignik and Herendeen bays.	Sandstones, conglomerates, and arkose.	1,000+	

Atwood's comment follows:

Eocene, Miocene, and post-Miocene formations are exposed in this portion of the peninsula. The Eocene strata include at least 5,000 feet of sandstone, shales, conglomerates, and seams of lignite and form the central portion of the Aleutian Range in the Balboa-Herendeen Bay district. They extend westward at least as far as Pavlof Bay and eastward to the Chignik Bay region. Several collections of fossil shells and plants have been procured from these beds. The shells are those of marine invertebrates and have been determined by W. H. Dall to be of upper Eocene age. Mr. Dall reports that some of the material from these strata may be upper Eocene or Oligocene. The plants, as determined by F. H. Knowlton, are all of Kenai age. They were procured from beds that are interstratified with those from which the shells were obtained. Kenai plants from Alaska have been determined by Mr. Knowlton to be of upper Eocene age and the harmony between the age determinations of the plants and animals is exceedingly satisfactory. The nature of the Eocene deposits indicates that the area of sedimentation was several times just below sea level, probably near to shore, and at other times above sea level, receiving wash from higher lands, or overgrown by dense growths of vegetation.

O 5. KODIAK ISLAND AND KATMAI BAY.

Dall[210] refers as follows to Katmai Bay and Kodiak Island:

Katmai Bay, some miles westward from Amalik Harbor, is the site of a village and trading station. The portage across the mountains of the peninsula ends here. On this portage both coal and petroleum have been found, the exact locality not being stated. The latter is a dark lubricating oil, which is said to float on the surface of certain ponds or lakes. No information could be obtained about the coal, but it almost certainly belongs to the age of the Kenai beds.

* * * * * * * * *

Tertiary beds occur in various places on the islands of the Kadiak group, both of Kenai age and of the later Unga beds containing Miocene marine fossils.

On the island of Kadiak marine Miocene strata are found, and among the specimens brought back by Wossnessenski were clay ironstones containing plant remains referable to the Kenai group. These stones were used by the native women for reddening the inner surface of dressed skins, and the only indication of locality for them is that they came from the northern part of the island. About the middle of the island, surrounding Ugak Bay, at the old settlement of Orlovsk and on the northern shore of Miliuda Bay next southward, and on the opposite side of the island, part of the shores of Uganuk Bay and of Uganuk Island in the bay, sandstones with lignite in thin seams, overlain in places by marine sandstones like those of Unga, are reported on the authority of Kharitonoff and other Russians familiar with the island.

O 8. SOUTHEASTERN ALASKA.

During the season of 1907 Atwood visited the two localities in southeastern Alaska where Eocene strata had been reported,[953a] and he has furnished the following information. On the shores of Hamilton Bay, Kupreanof Island, there is a small area of sandstones, shales, conglomerates, and lignite, which lithologically resemble the Kenai formation of other portions of Alaska. The localization of these strata to a somewhat restricted basin is also suggestive of the Kenai. They rest unconformably upon much-deformed beds of Triassic age and older and are overlain unconformably by glacial drift and recent alluvium. The flora obtained from a stratum not more than 15 feet in thickness contains, according to F. H. Knowlton, Upper Cretaceous cycads, possibly redeposited from older strata, and many typical Kenai plants.

At Killisnoo Inlet, an irregular reentrant on the west shore of Admiralty Island, sandstones, shales, conglomerates, and lignites outcrop on the shores. These strata have the same character as those near Hamilton Bay and are of similar small extent. They rest unconformably upon strata that are considered to be of Paleozoic age, and on their truncated edges there is some glacial drift. No record of animal life was found in this locality, but the plant remains contain Upper Cretaceous and Kenai (Eocene) forms.

At these two localities in southeastern Alaska the stratigraphic and floral studies seem to indicate a period of continuous deposition from late Cretaceous time into Eocene time. Such conditions prevailed in other portions of Alaska.

O 10. FINLAY AND OMENICA RIVERS, BRITISH COLUMBIA.

McConnell,[562c] in his report on Finlay and Omenica rivers, British Columbia, says:

Beds consisting of conglomerates, interbedded in places with shales and sandstones, occupy the bottom of the valley of the Finlay from the Ingenica River north to the Tochieca and continue northward along the valley of the latter stream. Similar beds appear again on the Finlay a few miles farther west in a parallel longitudinal valley, which it enters and follows for some distance. They are also found on the Omenica from the Black Canyon up to its junction with the Tchutetzeca.

The pebbles of the conglomerate are usually small but in places are several inches in diameter. They consist mainly of slate, quartz, and limestone. Oxide of iron is occasionally present in the matrix in sufficient quantities to give a reddish coloration to exposures. The shales are dark in color, are evenly bedded, and are interstratified in places with small lignite seams. The sandstones are usually somewhat argillaceous and occasionally consist largely of mica derived from the disintegration of the underlying schists.

The Tertiary conglomerates and associated rocks * * * are distributed in narrow strips along the deep valleys of the district and were nowhere found on the highlands. They were probably deposited in lakes during a Tertiary depression and evidence the pre-Tertiary age of the present main river channels. The conglomerates are occasionally horizontal or nearly so, but in most cases they are tilted at angles ranging from 10° to 40°, showing that they have been affected to some extent by the later mountain-making movements.

Some leaves and other plant remains, obtained from the shales interbedded with the conglomerates, were examined by Sir J. William Dawson, who lists eight species and concludes:

"All the above fossils, so far as determinable, appear to indicate the Upper Laramie period. Of the collections in my possession, the plants seem most nearly to resemble those of the Lignite series on the Mackenzie River, which are referable to the Upper Laramie. There is nothing among the plants to indicate any other horizon."

Knowlton regards these deposits as of Fort Union age.

O-P 5. KENAI PENINSULA.

Kenai Peninsula lies between Cook Inlet and the ocean and is the type locality of the Kenai formation. The strata have been recently studied by Moffit and Stone,[602] who state:

The upper member of the list of bedded sedimentary rocks [of Kenai Peninsula] is a succession of sandstones and shales, with interbedded coal seams, which overlies the lower Jurassic unconformably and forms the whole northern coast line of Kachemak Bay and the eastern coast line of Cook Inlet as far north as Cape Kasilof. Isolated masses of these rocks also occur at various points on the south shore of the bay. These beds, while slightly folded and sometimes faulted, are not always thoroughly consolidated. They were described by Dall and furnish the type exposures of the Kenai beds. * * * This formation, consisting of partly consolidated sandstones and shales, is of economic importance because of the lignitic coal seams interstratified with its various members. As previously pointed out, it rests unconformably on the Seldovia lower Jurassic rocks.

Fossils from the Kenai beds of Port Graham and Ninilchik were described by Heer as early as 1869. The former locality was afterward visited by Dall,[a] who collected fossils there, as well as from other localities on the north side of Kachemak Bay. The Kenai beds probably underlie the whole of the Kenai Plateau, but their northward dip carries them below sea level

[a] Dall, W. H., Report on coal and lignite of Alaska: Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 1, 1896, pp. 787, 842.

a few miles south of Kasilof River, and they do not appear again. These coal measures were thought by Heer to be of Miocene age, but Dr. Dall referred them to the Oligocene and gave a list of plant and animal remains collected at Port Graham, among which are both Coniferæ and broad-leaved trees, the total number of species amounting to 44. He says: "The deposit appears to have formed at the bottom of a lake."

Dr. F. H. Knowlton in the same report [a] gives a list of plant remains from the Kenai formation collected by Dr. Dall in 1895, as well as those previously known from the same region, and states that they are believed to be of Eocene or Oligocene age.

Later, in speaking of the typical Eocene strata of Chichagof Cove, Dr. Dall [b] says:

"The only representative of the Eocene epoch known in Alaska previous to the Harriman Expedition was the Kenai series (formation), which had been referred by Heer to the Miocene and by others to the Eocene but which has of recent years been recognized as Oligocene by the present writer and others."

In the same publication [c] Dr. Knowlton, after describing a collection of fossil plants from Kukak Bay, makes this statement concerning their age:

"It is hardly necessary at this time to go into a history of the plant-bearing horizons of Alaska. * * * It is sufficient to state that the named species above enumerated are typical of the so-called Arctic Miocene, which is now regarded as of the age of the upper Eocene. The species described in this paper as new are in various ways allied to forms characterizing this horizon, and I do not hesitate to refer this collection to the upper Eocene."

The determination of marine Oligocene invertebrates and upper Eocene floras from nearly related strata may seem to suggest that there was a sequence of deposits which included the two terranes, but Atwood's results of 1908 appear to indicate that the Kenai plants are associated with marine Eocene fauna. (See pp. 783–784.) Moffit and Stone continue:

The Kenai formation as exposed in Kachemak Bay is composed of soft light-gray sandstones and clay shales, with numerous interspersed coal seams. Four partial sections of the formation aggregate 1,763 feet of strata. * * * [They contain] seams ranging in thickness from a few inches to 7 feet. * * * The sandstones are medium grained, soft, light gray, sometimes iron stained, and occur in beds from a few inches to 30 feet thick. Cross-bedding was noted at one horizon. Some portions of the heavier beds of sandstone are hard and weather out in nodular blocks. In these blocks the best-preserved fossil plants are sometimes found. In one locality lenses of grit occur in a sandstone mass. The pebbles in the grit are smaller than one-half inch in diameter and are mostly quartz. Dall [d] reports conglomerates in the Kenai series on Kachemak Bay, but the author found none in the portion he visited. Sandstone at places grades into sandy shale.

The shales of the Kenai formation on Kachemak Bay are all light-colored clay or mud rocks, grading on one side into arenaceous shale and on the other into clay. The shales are soft and crumbly on the outcrop and when wet become plastic. Beds of clay that have been baked by the burning of coal seams are red and hard. Small blocks of gray hard limestone were found at one locality and suggest that calcareous sediments in small amount may be contained in the formation. Limestone was not seen in place.

The abundant coal seams in the Kenai rocks of this field are all lignite. They vary in thickness from mere streaks to beds several feet thick. Eldridge [e] counted 36 seams along the

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[a] Dall, W. H., Report on coal and lignite of Alaska: Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 1, 1896, p. 876.

[b] Alaska, geology and paleontology: Harriman Alaska Expedition, vol. 4, 1904, p. 101.

[c] Idem, p. 162.

[d] Dall, W. H., Report on coal and lignite of Alaska: Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 1, 1896, p. 789.

[e] Eldridge, G. H., A reconnaissance in the Susitna basin, Alaska: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, p. 21.

beach at Tyonek, varying in thickness from a foot to 15 feet, and Kirsopp[a] figures 73 seams on the north shore of Kachemak Bay. Much of the Kachemak Bay lignite, especially that in the lower beds, is hard and glossy, clean to handle, and tends to break cubically. The higher beds, however, are dull and lighter and show more woody fiber.

The thickness of the formation exposed in Kachemak Bay has not been determined, and it is almost impossible of determination because there are stretches over which the beds can not be traced. Anchor Point is near the base of the formation, but it is not known how far the coal-bearing rocks extend beyond the head of the bay, except that coal has been found 15 miles up Sheep Creek. Kirsopp[b] published a section from Anchor Point to the head of the bay, including 2,683 feet of coal-bearing measures. This section contains at least 126 feet of lignite in seams over 2 feet thick. Estimated roughly, there probably are about 1,500 feet of strata between Bluff Point and the base of Coal Point. From Coal Point to McNeil Creek the dip is strong and 3,000 feet may be a low estimate. From McNeil Creek to the top of the bluff at Falls Creek at least 1,000 feet are exposed. Hundreds of feet of strata probably overlie the section measured at Falls Creek and outcrop in the bluff north of the head of the bay. The writer is inclined to think that 10,000 feet may not be a high estimate for the thickness of the Kenai formation in the Kachemak Bay field.

P 3. NUNIVAK ISLAND AND YUKON DELTA.

Dall[210a] reported an occurrence of sandstones, probably Kenai, at Etolin Harbor, Nunivak Island, but G. M. Dawson[260] describes the rocks as "cellular olivine diabase" and the island as composed of nearly horizontal basaltic flows.

Cape Vancouver is a prominent point rising from the flats of the Yukon Delta and composed of sandstone and sandy shales, capped by basalt flows in the higher hills. Dawson says:

> The north shore of the cape, which alone was examined, forms scarped bluffs or cliffs, rising from the edge of the sea, and presenting fine exposures of sandstones and sandy shales, well bedded and dipping southward, at low and undulating angles. At the extremity of the cape these beds appeared to be horizontal, and on the south side, though imperfectly seen from a distance, they seem to lie at higher and more irregular inclinations.
>
> The sandstones, where examined, are gray, bluish and brownish in color, rather soft, and sometimes nodular. They contain a few very thin and dirty seams of coal or lignite, of which the thickest seen was only a few inches. There are also in the sandstones numerous carbonaceous fragments and occasional fossil leaves, of which a couple were collected.

Sir William Dawson found these plants to represent *Juglans acuminata* and assigned them to the Miocene. The horizon is now placed in the upper Eocene by Knowlton.

P 5. COOK INLET NEAR TYONEK.

The exposures of the Eocene on the west shore of Cook Inlet, about 3 miles south of the village of Tyonek, and the beltlike continuation of the strata to the northwest at least as far north as Beluga River have been called Kenai and consist of sandstones, shales, conglomerates, and some lignite. None of the material, so far as known, is of marine origin. The deposits are such as to suggest estuarine origin or sediments laid down on the land adjoining bodies of water. In the section exposed along the shore of Cook Inlet, more than 2,000 feet of sediments are shown. The beds are but slightly deformed. The base of the formation is not exposed, the eroded surface of the upturned beds being mantled by glacial drift.

[a] Kirsopp, J., jr., Coal fields of Cook Inlet, Alaska: Trans. Inst. Min. Eng., London, 1901. [b] Idem, p. 3.

Plant remains which have been obtained from this locality have all been determined by Knowlton to belong to the Kenai, or to be of upper Eocene age. The exposures along the beach near Tyonek were described by Spurr [771] in 1900. The Yentna and Hayes River beds of Spurr, which occur north of Tyonek on the lower Susitna and in Skwentna Valley, are now also regarded as of Kenai (Eocene) age.

P 6. MATANUSKA VALLEY.

Matanuska River enters Cook Inlet at its northeastern embayment. It comprises a large area of coal-bearing strata classed as Kenai (Eocene) and described by Paige and Knopf [627] as follows:

The Kenai of the Matanuska basin comprises a series of sandstones, shales, arkoses, numerous coal seams, and a large volume of conglomerate. The rocks are well indurated and, as first noted by Mendenhall, resemble the Paleozoic coal measures of the Appalachian region. The sandstones are gray, hard, and tough and are characterized by the presence of silvery shreds of white mica. At some localities, as in the leaf-bearing strata in the Kings Creek coal measures, the sandstones contain shale fragments. The shales show no unusual features; they are dark bluish, fissile, and interstratified with the sandstones in very regular beds. The arkoses were noted only on the ridge north of Tsadaka Creek, abutting against the quartz diorite mass. They are composed of feldspar, quartz, and chlorite and locally contain granite pebbles. Certain strata are fine examples of regenerated granites.

Conglomerate is found at Castle Mountain, between Kings and Chickaloon creeks, and at Conglomerate Mountain, between Tsadaka and Eska creeks. At both places the deposit is at least 1,000 feet thick. Thin sandstone beds, not exceeding a few feet in thickness, are intercalated with the conglomerate and pinch out along the dip. The pebbles of the conglomerate are well worn and possess a well-defined shingling. Their diameter averages 4 inches and ranges up to 8 inches. Greenstone porphyries form the principal material of the conglomerate, with some quartz prophyry and very rarely some granite and vein quartz. The matrix of the pebbles is a grit.

* * * * * * * * *

Heavy beds of conglomerate dipping to the north can be seen on the east side of Chickaloon Creek. They are part of a great series of sandstones, shales, and conglomerates, probably not less than 3,000 feet thick, which are overlain by basaltic porphyries at an elevation of about 4,700 feet.

The coal of the Kenai of the Matanuska basin is bituminous except where modified by igneous rocks. The seams vary in thickness up to a maximum of 17 feet.

The age of these strata has been determined by Knowlton as Kenai (upper Eocene). Fresh-water gastropods have also been found in them.

P 6–7. CONTROLLER BAY TO CAPE YAKATAGA.

On the southern coast of Alaska, in latitude 60°, Tertiary sediments which resemble the Kenai in character but may be younger have been examined on Controller Bay and are known to extend east to Cape Yakataga. They have been classified in several formations and described in detail by Martin,[573a] who says:

The Tertiary sediments * * * consist of monotonous repetitions of shales and sandstones, with an included mass of coal-bearing arkose and one or more massive conglomerates. The total thickness, as shown in the following table, is many thousand feet. The structure of the region in which these rocks outcrop is complex, exposures at critical points are often wanting, and neither the lithologic character of the beds nor the fossils which they contain are sufficiently distinctive to make it possible to recognize with certainty the complete stratigraphic succession.

The presence of two easily recognized horizons, the arkose and the conglomerate, give distinctive character to two parts of the stratigraphic column. The arkose, with its associated coal, is restricted in areal distribution to the region north of Bering Lake, and the conglomerate to the region south of the lake. Between these regions are areas of no outcrops, and none of the beds of either region can be recognized with certainty in the other.

Section north of Bering Lake.

	Feet.
Tokun formation:	
a. Sandstone	500
b. Shale with thin, flaggy sandstones and with occasional calcareous concretions	2,000+
Kushtaka formation:	
c. Arkose with many coal beds and with some shale and sandstone	2,500±
Stillwater formation:	
d. Shale and sandstone	1,000+

Section south of Bering Lake.

	Feet.
Katalla formation:	
e. Conglomerate and conglomeratic sandstones interbedded with shale and sandstone	2,500
f. Flaggy sandstone	500±
g. Soft shale with calcareous concretions and with bed of glauconitic sand near base	2,000
h. Sandstone	1,000
i. Soft shale	500+

The succession in each of these sections may be assumed as reasonably correct, although there is a possibility that the thicknesses are too great because of there having been repetition of the less characteristic beds by faulting. The correlation of the beds of one section with those of the other rests at present upon evidence which is incomplete and unsatisfactory and must be regarded as suggestive rather than conclusive. It is probable that one of two correlations is true: The shale and sandstone of the Stillwater formation (*d*) may overlie the conglomerates (*e*) of the Katalla formation with a concealed interval of unknown extent between them, or *a* and *b* may be identical with *h* and *i*. In the former case the conglomerates underlie the coal field; in the latter case the coal underlies all, or nearly all, of the entire region under discussion. The stratigraphic and structural field evidence proves nothing either way but suggests, as the most probable relation, that the entire section north of Bering Lake overlies the section south of the lake.

The Tertiary rocks contain fossils at many localities, but they are usually poorly preserved or not characteristic. They consist chiefly of leaves and of marine Mollusca, but include also a few echinoids, Crustacea, fish, and fresh or brackish water Mollusca.

* * * * * * * * *

The paleontologic evidence may be summarized as follows: [a]

1. The marine Mollusca from the sandstone of the Tokun formation are either so poorly preserved as not to admit of specific identification or belong to undescribed species.[b] They are almost certainly Miocene, but can not be definitely correlated with any known Miocene faunas of other regions.

2. The plants from the coal-bearing rocks include poorly preserved individuals which suggest species of the Kenai formation of Cook Inlet, generally considered to belong in the upper Eocene or Oligocene. The best-preserved specimens, however, represent species which are not known in the Kenai and which are suggestive of later Tertiary age. There is no positive evidence that the exact equivalent of the Kenai occurs in this region.

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[a] Data furnished by W. H. Dall and Ralph Arnold on the Mollusca, by F. H. Knowlton on the plants, and by W. B. Clark on the echinoids.

[b] This statement applies to all the faunas of this region.

P 6-7. MOUNT WRANGELL DISTRICT.

Moffit and Knopf [600a] thus refer to the local occurrence in the Mount Wrangell district of deposits which are provisionally assigned to the Tertiary.

A formation consisting of soft, thin-bedded shales and sandstones, associated with large amounts of well-rounded conglomerate composed mainly of diorite cobbles, occurs in the region of Coal Creek, north of White River, near the international boundary. The area in which these rocks are exposed is small, but there is some probability that they underlie the volcanic cappings of the mesas which form prominent features of this part of the White River region.

The strata lie nearly horizontal and rest upon older rocks which stand on edge. In places they are lignitiferous, and petrified wood of exogenous character is common as float in gulches cutting the formation.

The resemblance of these rocks to those of similar patches scattered throughout the Yukon basin [a] leaves little doubt as to their Tertiary and probably Kenai age. Rocks of identical character occur near the head of Chitistone River and, like those of the White River region, are covered by a heavy series of volcanic flows.

P-Q 5-6. FOOTHILLS OF THE ALASKA RANGE.

The Bonnifield and Kantishna placer districts lie on the northern slopes of the Alaska Range. In course of prospecting for gold, lignites have been located and the field is thus described by Prindle: [639]

Deposits containing lignite coal have a wide distribution in the northern foothills of the Alaska Range, but the only section to be considered here is that extending east from Cantwell River to Wood River, a distance of about 50 miles, and northward to the flats. The low spaces within this area between the east-west ridges of old metamorphic rocks are occupied by these deposits. They are for the most part but slightly consolidated and have been so deeply incised by the drainage systems that in places nearly complete sections are exposed. That the present areas are only a part of masses formerly much larger in extent is shown by small isolated patches of these deposits that lie slantingly on the upper slopes of ridges and by well-worn pebbles derived from them that lie scattered on the tops of the highest ridges, 1,500 to 2,000 feet above the occurrences of the valleys. These deposits have been folded, the flexures being for the most part broadly open, with dips of 30° to 35°, but locally closer, with resultant vertical dips attended in places by consolidation of the gravel beds to conglomerate; in addition, here and there parts of the deposits have been faulted.

The material comprises alternating beds of sands, clays, coal, and gravels that are divisible into three parts—an underlying white deposit composed of angular and some well-worn, subangular, fine quartz gravels, with a large admixture of kaolinic material where the bedrock is feldspathic; an intermediate member of yellowish cross-bedded sands and fine well-worn gravels, dark plastic clays, and coal beds; and an upper member composed almost entirely of gravels. The feldspathic schists produce by weathering a large amount of white clay, and the quartz veins which in places in these rocks are very numerous furnish abundant quartz material, and these characteristics of the old bedrock have gone over into the basal members of the sediments. The transition from the decomposed products of the schists that still retain their structural position to the same materials in the overlying deposits is in some places strikingly exhibited. The thickness of these underlying deposits was not determined, but one section was observed in which 100 feet of them was exposed. The sands and clays of the intermediate member are naturally less conspicuous than the underlying beds but have in many places become indurated by the burning of the coal beds and baked to a conspicuous red color. The

[a] Collier, A. J., Coal resources of the Yukon, Alaska: Bull. U. S. Geol. Survey No. 218, 1903, p. 19.

overlying gravels at the localities where their relations to the underlying deposits were observed, whether in horizontal or tilted strata, were found to be structurally conformable. They are characterized by a yellow color. They include both fine and coarse material, are well worn and well rounded, and the predominant constituents are white quartz and chert of various colors, principally black. There is a considerable proportion of metamorphic rocks and many pebbles of compact chert conglomerate. In the upper part of the gravels, in strong contrast with their medium to fine grained material, are locally many bowlders of granitic rocks and diabase and a few well-rounded bowlders of dense chert and quartzite conglomerates. The greatest observed thickness of these deposits was approximately 3,500 feet. The upper gravels constitute about half of the entire deposit.

Fossil leaves are observable nearly everywhere in the beds associated with the coal, but except where these beds have been baked by the burning of the coal the fossils are poorly preserved. The age of the coal-bearing member has been determined as Kenai. The age of the gravels has not been determined, nor is it definitely known that they are chronologically conformable with the underlying deposits, but they have been folded at every point where folding was observed, along with the underlying deposits. Where valleys have been extensively developed in these deposits bench gravels have in many places been laid down on the truncated edges of the older deposits, and where these older beds are horizontal the bench gravels are in apparent conformity with them, obscuring the relationship. It is probable that deposits of various ages since the Kenai, formed under varied conditions of sedimentation, occur in this area and that the coarse material in the uppermost part of the gravels owes its origin to glaciation.

Parts of the gravel members of these deposits are auriferous and have supplied the gold for the Bonnifield region. There is a marked resemblance between these coal-bearing deposits, with their thick beds of overlying gravels, and the Kenai beds of the Seventymile Creek area near Eagle, with their coal-bearing deposits and thick beds of conglomerate formed largely of the same kinds of material.

Q 3. SEWARD PENINSULA.

Moffit,[598] in his report on the Fairhaven gold placers, states that "In the northeastern part of Seward Peninsula lignitic coal has been mined in a small basin on Kugruk River. The associated strata are sandy and shaly and include thin limestones. Though folded and jointed, they are less metamorphosed than the neighboring schists. No fossils have been found and the age is indeterminate," but the rocks are presumably late Cretaceous or early Tertiary. The area is too small to be shown on the map of North America.

Q 3-4. NORTON SOUND.

Mendenhall [587] mentions the occurrence of coal-bearing strata supposed to be of Tertiary age outcropping on Tubutulik and Koyuk rivers.

Q 4-5. KOBUK RIVER.

Strata belonging to the early Tertiary were found by Mendenhall [588] on Kobuk (Kowak) River and also farther east on Dall River, in separate local basins. They comprise conglomerates, of quartz pebbles with some pebbles of the neighboring crystalline rocks, soft sandstones, shales, and lignite beds. On the basis of four recognized species of plants Knowlton referred the strata to the "Arctic Miocene" (upper Eocene).

Q 5-6. YUKON VALLEY.

Spurr[770] distinguished an occurrence of Tertiary strata which he described as the Twelvemile beds and provisionally referred to the Miocene or Pliocene. These are now regarded as of Kenai (Eocene) age, according to Brooks (personal communication). Spurr says:

Twelvemile Creek is one of the branches of Mission Creek. Near the point of junction of these two streams are exposed in numerous outcrops slightly consolidated and coarse-bedded gravels and sands which carry seams of light-brown sandy lignite. Fragments of wood, considerably altered, having a diameter of as much as 2½ inches, are found, but no fossil leaves or shells. Occasional pieces of black, shiny lignite, such as is found in the Kenai series and less abundantly in the Mission Creek series, occur, but in such a manner as to lead to the suspicion that they are fragments derived from these older rocks. The beds are slightly folded, having a dip of about 20°. Near the mouth of Twelvemile Creek the dip is southward, though about a mile above Twelvemile Creek, on Mission Creek, the dip is to the north, though the strike remains nearly the same; thus a shallow syncline is indicated.

The rocks of the Mission Creek series, which underlie these beds, are sharply folded, and although no actual contact was seen, it is probable that an unconformity exists. Below Mission Creek the rocks of the Kenai series are well indurated, forming compact conglomerates and sandstones, and they are apparently conformable with the rocks of the underlying Mission Creek series, with which they are infolded. It appears, therefore, that the Twelvemile beds can not be correlated with the Kenai series, and yet they are older than the horizontal Pleistocene silts and gravels which are exposed all along the course of the Yukon. They may be provisionally referred to the Miocene or Pliocene. From their nature they seem to be fresh-water lake deposits.

Q 7. UPPER YUKON.

A belt of coal-bearing, probably fluviatile deposits crosses the international boundary in the Yukon Valley. The occurrences on the Alaskan side of the line are described by Brooks and Kindle:[103a]

The Kenai formation has usually been described as occurring in local basins, either of lacustrine or fluviatile origin. That described here appears, in part at least, to be of fluviatile origin. The distribution * * * indicates that a belt of the Kenai rocks runs parallel to the Yukon from Eagle to Birch Creek. While this zone has not been traced continuously, it is sufficiently well known to justify the opinion that it was originally deposited as one continuous belt. * * * The conglomerate of the Kenai on Woodchopper Creek and Seventymile has been found to be auriferous, which lends weight to the assumption that the deposits are of fluviatile origin.

R 5-6. ARCTIC COASTAL PLAIN.

In traversing the Colville region Schrader[708a] distinguished the Eocene and Pliocene strata as the Colville series, which he describes as follows:

The Colville series is named from the large river along which it occurs and is excellently exposed. It is a series of Tertiary terranes which underlies the flat tundra country, or Arctic Coastal Plain, that succeeds the more southerly rolling plain formed by the Upper Cretaceous or Nanushuk series, which it apparently unconformably overlies, being itself in turn unconformably overlain by the Gubik sands. * * *

The series consists principally of heavy-bedded silts, soft sandstone, limestone, shale, and lignite. It is best exposed along the Colville in the region of the mouth of the Anaktuvuk, where it forms steep-faced bluffs about 200 feet in height, extending for a number of miles both up and down the river.

The Colville series has been but little disturbed. The beds lie nearly horizontal. * * * Observations made along Colville River indicate that the series has a thickness of 500 or 600 feet.

On account of difference in degree of consolidation of the beds, together with their fossil and lignite contents, the series has been separated by the writer into two parts, upper Colville and lower Colville. It is possible that an unconformity may exist between the lower and upper parts of the series, but if present it must be very slight.

The lower Colville (Oligocene) constitutes the main portion or lower three-fourths of the section exposed at the mouth of the Anaktuvuk. It is about 150 feet thick, while the upper Colville at this same locality is about 40 to 50 feet thick. The lower Colville contains the more indurated class of rocks and consists mainly of partially consolidated silts in beds 6 to 8 feet in thickness. They are usually light slate-colored or ash-colored, constitute about one-half of the lower Colville section, and are generally much less consolidated toward the top than near the base. The harder rocks, which increase in volume toward the base of the section, include impure dull-gray medium to fine grained sandstone with detrital lignitic plant remains; slate-colored and brownish calcareous shale, with disseminated undeterminable vegetable detritus; lignitic coal in layers 1 to 5 feet in thickness; dark slate-colored or brownish chert, containing cavities incrusted with chalcedonic silica; rusty brown, very ferruginous sandstone or impure ironstone, and some iron-stained siliceous conglomerate, which also contains lignitic vegetable remains. There are also a few layers of hardened silts, forming a rock of very fine texture, resembling soft, smooth hone stone.

The lower Colville is tentatively classed as Oligocene, on account of the presence in it of lignite beds and vegetable remains, and from its resemblance to the Kenai beds occurring elsewhere in Alaska, and also on the ground of its relation to the supposed Pliocene silts which it immediately underlies.

The Kenai is now generally referred to the Eocene. For Schrader's description of the upper Colville (Pliocene) see Chapter XVII (p. 838).

R 26-27. NORTHEAST COAST OF GREENLAND.

Nathorst,[609] in a report on the geology of northeastern Greenland states:

The Tertiary is found in two different facies. On Hochstetters Vorland they occupy a large territory and are composed of fine-grained yellowish sandstone with impressions of marine shells. These are found, according to Copeland, in great quantities, but the collections that were here brought together had to be left behind to a great extent on Kuhn Island. The specimens that were brought home were some unidentifiable casts of Cytherea, Venus, and Lucina, to which Th. Fuchs later added Astarte and Pecten, after he had again been over the collections. This locality deserves to be explored again, but unfortunately the ice rarely breaks up and, remaining solid for years, makes the shore seldom accessible from a vessel.

The rest of the Tertiary is found in connection with the basalts and is covered by them. Whether it is also underlain by them is not made clear from the text, but judging from the map it would seem to be the case. They sometimes contain layers of coal, and on Sabine Island are found fossil plants, namely *Taxodium distichum miocenum* Hr., *Populus arctica* Hr., *Diospyros brachysepala* Al. Br., and Celastrus sp., described by Heer. These specimens indicate the flora to be contemporaneous with the common Arctic Tertiary flora that Heer considers to be of Miocene age [upper Eocene (?), Knowlton].

CHAPTER XVII.

LATER TERTIARY (MIOCENE AND PLIOCENE).

Colors, yellow, light yellow, lemon-yellow
Symbols, 4, 3, 2.
Distribution: Later Tertiary, where the Miocene and Pliocene are recognized but can not be separated or individually identified in the present state of knowledge. The Miocene is separately indicated on the Pacific coast and on the Atlantic and Gulf coasts, so far as surveys permit. Elsewhere on the map it is comprised with Pliocene under the term, "Later Tertiary" (4). The Pliocene is distinguished on the Atlantic and Gulf coasts, so far as surveys permit, in California, and in northern Nevada. Elsewhere on the map it is classed with the Quaternary (1), as in the valley deposits of the Great Basin; or with the Miocene under the heading "Later Tertiary" (4). The Lafayette formation of the Atlantic and Gulf slopes, including the Altamaha of Georgia, is shown only where it completely conceals the underlying formations.
Content: Pacific coast marine deposits; Alaskan Arctic Coastal Plain deposits; fluviatile and lacustrine beds of the Interior; western Gulf coast marine formations; and late marine Tertiary of Mexico, Central America, and South America. Monterey shale and equivalents of the Pacific coast; beds of Carrizo Creek, California; and marine Miocene of the Atlantic and Gulf slopes. Does not include so-called "Arctic Miocene" nor "Old Miocene," both of which are included in "Marine Eocene." Marine Pliocene of the Coast Ranges of California; Humboldt formation (nonmarine) of Nevada; and marine Pliocene and Lafayette of the Atlantic and Gulf slopes east of the Mississippi, including the Altamaha of Georgia; also Yucatan.

Later Tertiary areas.

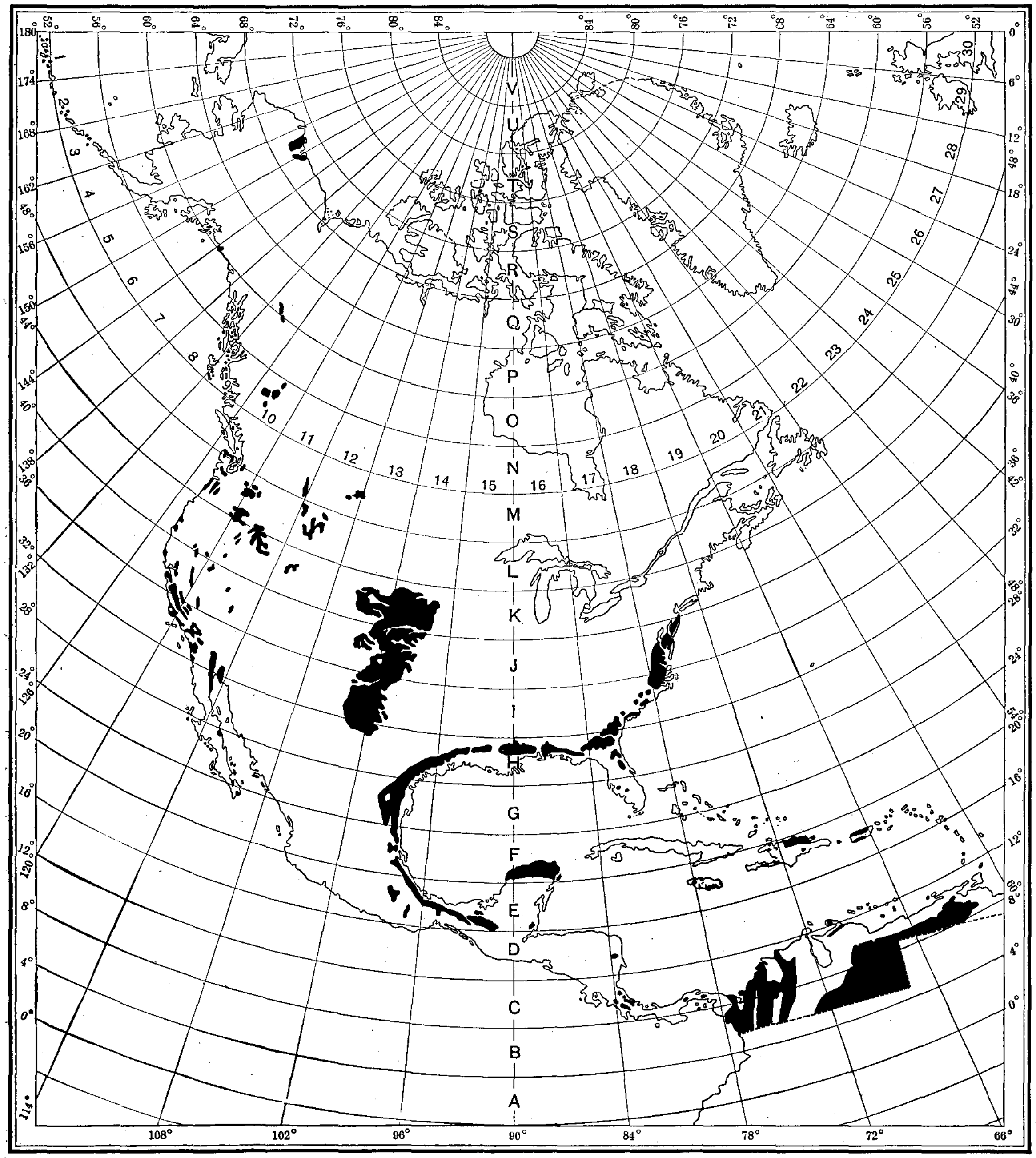

Figure 19.—Sketch map showing the distribution of later Tertiary rocks represented on the geologic map of North America and the key to references in the text. Miocene and Pliocene mapped separately where their extent is known.

B–C 18. COLOMBIA.

Karsten [473] describes certain strata of Cretaceous age as occurring in the Cordillera of Colombia (see Chapter XIV, pp. 581–582) and states that they are covered unconformably by a micaceous white or yellow sandstone, of more or less coarse grain, succeeded by quartzose (?) and variegated marls and by clay shales, which include beds of lignite that alternate with the shales in thin layers and in beds up to 3 meters in thickness. The latter group, which is distinguished by paucity of fossils, is not very thick in the higher regions, but it becomes thicker and more important in the lower regions and in the valleys of Magdalena, Cauca, and Patia it constitutes the surface to the exclusion of almost everything else.

According to the region it is sometimes represented chiefly by conglomerates, or again by sands and clays; the latter, which are for the most part variegated in color and micaceous, often contain pebbles and pass into puddingstones. The conglomerates are formed of pebbles, of the size of a fist or smaller, of a siliceous schist or of a quartzite which belongs to the rocks which contain Foraminifera and which are united by siliceous cement. In some districts of Magdalena this complex overlies the reddish-brown sandy marls which have been described above and which contain flakes of mica; the latter should be studied in order to ascertain whether it belongs to the Cretaceous or itself constitutes the lowest member of the Tertiary series. The latter hypothesis appears to me most probable because the Tertiary conglomerates rest directly upon this dense marl; the Cretaceous marls do not contain any mica. They are firmer and more distinctly stratified and in their upper portion inclose thin layers of limestone.

Karsten mentions the occurrence of petroleum in these strata, and continues:

Limestones are rare in this Tertiary series. On the Upper Magdalena I have never observed any fossils. At Popayan I found a thin bed of argillaceous shale and limestone resting upon porphyry and containing shells of Tertiary mollusks (gastropods, Cardium, and *Rostellaria guadichaudi* D'Orb.) very like those of the present. * * *

With regard to the gigantic bones of extinct mammals, I may say that I saw them in Colombia, constantly in a red sandy marl which lies upon the Tertiary. In Ecuador one finds them not only in the lower places but also upon the plateau and on the slopes of trachytic volcanic cones, where they lie in part in a volcanic tuff that is to the general view very like this marl. These remains are very widely distributed in the country.

Karsten gives numerous localities at which he observed the remains of fossil bones.

E 14–15, F 14 AND 16, G 12 AND 14, AND H–I 11. MEXICO.

Several localities at which the Miocene or Pliocene have been identified in Mexico are mentioned by Aguilera,[9e] and are here referred to under the index headings enumerated above. A general account of the Tertiary of Mexico is given by Felix and Lenk.[327] The local occurrences are the same as those given by Aguilera, but it is profitable to refer to their lucid and connected description.

E 14. OAXACA.

The Pliocene of Paso Real, at Tuxtepec, in Oaxaca,[9f] includes conglomerates of old crystalline rocks which overlie sands and white sandstones and contain *Pecten* (*Euvola*) *bowdmensis* Dall, *Lævicardium sublineatum* Conrad, *Calliostoma* cf. *linuum* Dall, *Anguinella virginica* Conrad, *Xenophora* cf. *conchyliophora* Born, *Natica canrena* L., *Natica* (*Polynices*) *perspectiva* Rogers, *Strombus pugilis* L., *Sconsia sublævigata* Guppy, *Pyrula papyratia* Say, *Melongena* (*Solenistra*) *mengeana* Dall, *Marginella wilcoxiana* Dall, *Marginella cinerarea* Dall, *Oliva* cf. *litterata* Lamarck, *Pleuritoma* (*Drillia*) *alesidota* Dall, *Conus* cf. *verrucosus* Bruguière.

E 15. CHIAPAS.

In Chiapas,[9e] in the vicinity of Simojovel, the Miocene is composed of dark argillaceous shales, blue clays, brown sandstones, and interbedded limestone of a white color, which assumes a reddish tint and which extends to the north in the plateau of central Chiapas. The following fossils have been found: Pecten, Ostrea, Turritella, *Conus planiceps* Heilprin, *Clypeaster* cf. *meridamensis* Michelin, etc.

In the vicinity of Coatzacoalcos, upon the river of the same name, there are white and brown sandstones which contain *Amusium papyraceum* Gabb, *Anomia simplex* D'Orbigny, and *Lævicardium sublineatum* Conrad, of the Pliocene.

In the vicinity of Tenejapa, Chiapas, occur marine Pliocene rocks consisting of micaceous sandstones and argillaceous shales, together with andesitic tuffs, conglomerates, and marls which contain Ostrea. This terrane occurs also in the valley of the Rio Chiapas beyond the boundaries of the State of Chiapas. It is found in the hills of Tabasco, near Macuspana, with *Natica canrena;* on the frontier between Tabasco and Vera Cruz, near Tenosique; and in the peninsula of Yucatan with *Ostrea virginica, Pecten gibbus, Pyrula papyracea,* etc.

F 14. VERA CRUZ AND HIDALGO.

In the States of Vera Cruz and Hidalgo[9e] lacustrine deposits of Miocene age occur in the vicinity of Zacualtipan and at Tehuichila. They consist of argillaceous shales with beds of lignite and contain Hippotherium (*Hipparion peninsulatum* Cope), *H. rectidens* Cope, and *Protohippus castilloi* Cope.

The marine Pliocene is recognized by its fossils at Santa Maria Tatetla, at Papantla, and at Tuxpan, in Vera Cruz.

F 16. PENINSULA OF YUCATAN.

The northern portion of Yucatan is occupied by Pliocene and possibly in places by post-Pliocene limestone, which forms a broad plain that rises gradually southward to the hills of the Sierra de Yucatan. Heilprin [433] describes the plain and says:

The rock formation over the greater part of the plains is that of a gray or white shell limestone, highly indurated or subcrystalline in local areas, but rarely to the extent of obliterating its fossiliferous character. Secondary depositions of calcite, in the form of veins, crystals, and nodular masses, are abundant. Where less compact the rock may be said to be a mass of loosely united shells, a condition that is best shown in the superficial layers. Good sections of the rock are seen only in the walls of the aguadas and cenotes and in a number of railway cuts which traverse it both in a north-south and east-west line; the rock surface is, however, visible over a very large part of its extent, being but scantily covered with soil and supporting only an indifferent vegetation. Its decomposition has liberated large quantities of red earth, similar to that which is found in our own northern region (*terra rossa*) and on coral islands (for example, the Bermudas, Bahamas), and which is seemingly a residual product representing impurities of one form or another which were introduced into the limestone at the time of its formation. * * *

The paleontological evidence of the fossils contained in the limestone is to the effect that the latter belongs to two periods of geological time, the Pliocene and the post-Pliocene, but stratigraphically it is not easy to draw a line of demarcation between the two formations. It, indeed, appears as though the post-Pliocene, except in the coastal area, were present only in patches, having been removed through atmospheric decay and denudation. It is in most places easily distinguished by the large numbers of *Venus cancellata* which fill the rock, making a true *Venus cancellata* bed, such as I observed capping the Pliocene beds on the Caloosahatchie, Florida, just below Fort Thompson. The beds occupy similar positions and hold equivalent relations to the construction of the land and may, therefore, be considered as counterparts of an identical formation.

For lists of living and extinct species, see the work cited. Heilprin continues:

The exact position in the Pliocene series which these Yucatan rocks hold can not, perhaps, be stated, but they with little doubt correspond at least in part with the series occurring in Florida which I have designated the "Floridian." It is true that the number of extinct species of the mollusks is seemingly less in the Yucatan rock than in that of Florida, but it should be said that in addition to the forms above enumerated, there are a considerable number, occurring mainly in the condition of unrecognizable casts, which may largely represent extinct species.

Dall and Vaughan agree with Heilprin on the Pliocene age of the fossils cited by him. Sapper [694b] says:

The Tertiary beds are in general but slightly inclined. In the vicinity of Istapa, of San Antonio, Tenejapa, and Tumbala there are horizontal beds. They are more modern than the andesitic eruptions, for they include the andesites in the conglomerates and the horizontal strata even rest directly upon the andesite.

In the peninsula of Yucatan the Tertiary terranes predominate and it would seem that from south to north there is a sequence of more recent beds until one reaches the post-Pliocene (Quaternary) deposits of the northern coast.

The southern region of Yucatan is composed of calcareous formations which in many places abound in cherts. Between the beds of limestone there are also some beds of marl and others of alabaster, and in the marls there may be found in the Cerro de Ixconconcal, near Icaiche, certain fossils which may serve to determine the relative age of the deposits.

These fossils are apparently not cited, but the beds are supposed to be those which are mapped by Sapper as limestones with marl and alabaster and are regarded by Dall as Oligocene. All the other formations distinguished by Sapper, comprising the white and red limestones, as well as his Pliocene, are here placed in the Pliocene.

F–G 12. LOWER CALIFORNIA.

At Santa Rosalia and Boleo, Lower California,[9d] there are deposits of upper Miocene age which probably correspond to the beds of Carrizo Creek, California, and which are characterized by *Pecten* (*Plagioctenium*) *cedroscensis* Gabb, *Pecten* (*Pecten*) *carrizoensis* Arnold, *P.* (*P.*) *keepi* Arnold, *Semele* aff. *pulchra* Sowerby, and *Malea* aff. *ringens* Swainson.

For a general statement of the geology of Lower California and sources of information, see Chapter XV (pp. 644–647).

G 14. TAMAULIPAS.

In the valley of the Rio Bravo, near Matamoros, Tamaulipas, the marine terrane of the late Tertiary is well represented, and according to Aguilera [9d] it is possible to recognize several of Dumble's subdivisions of the later Tertiary of Texas, namely, Oakville, Lapara, and Lagarto.

H–I 11. TIA JUANA, LOWER CALIFORNIA.

At Tia Juana, Lower California,[9d] there occurs a formation equivalent to the Purisima formation of California, which belongs at the base of the Pliocene. In the island of Cedros this formation is present but not mapped and is characterized by *Pecten* (*Nodipecten*) *veatchi* Gabb, *Pecten lecontei* Arnold, and *Pecten* (*Plagioctenium*) *cedroscensis* Gabb.

E 18. JAMAICA.

The classification of the geologic formations of Jamaica is given in Chapter XV (p. 640), and the older formations are discussed in Chapters XV and XVI (pp. 639–642, 717–721).

According to Hill [443] the later Tertiary is separated from the early by a hiatus corresponding to the middle Oligocene. The formations representing the late Oligocene or Miocene and the Pliocene are classified as the Bowden, May Pen, Kingston, and Manchioneal formations, in ascending order.

Under the heading "Bowden and allied formations" (the Yellow limestone of some previous authors), Hill [443g] says:

> This series includes a class of formations which represent the products of events more recent in the history of the Jamaican sequence than those hitherto enumerated. Its members occur around the coastal perimeter of the island, principally along the margins of the sea at altitudes nowhere exceeding 250 feet, and deposited unconformably against the sides of an older mainland. Here and there on the south coast they fill previously formed erosion plains. They were all made during epochs subsequent to an epoch of elevation whereby the white limestones of the Oceanic series and all preceding formations had been elevated into land, had undergone tremendous denudation, and had again suffered partial marginal subsidence.
>
> They are of four types of formations, to wit, beds of impure marine limestone, gravel, and marl; alluvium of the Kingston type; elevated coral reefs as illustrated in the Barbican and Hopewell formations; and littoral deposits of calcareous mud, with embedded fossils of contemporaneous origin with the elevated reef formation. The four types in their general lithologic characters are analogous to the marine, littoral, alluvial, and coral-reef formations now being made around the margins of Jamaica.
>
> The Bowden and allied formations of later Tertiary age constitute the older beds of the Coastal series and are all marginal to the main upland mass of the island. They apparently

represent a series of fringing formations extending around the older plateau region. These in turn are bordered by still later and lower-lying formations.

Along the south coast of the east end of the island, between Morant Bay and Port Morant, there is an extensive occurrence of gravel beds less than 50 feet in thickness, containing rolled specimens of nearly every species of volcanic rock found in the island, which grades upward into an impure stratified brown and buff colored marl, the latter having a thickness of 200 feet as measured in the bluff upon which Capt. Baker's house at Port Morant stands. The loose gravels at the base of this section have a very recent appearance, a deception which is further aided by the fact that they occur at beach level and contain perfectly preserved fossils resembling modern shells. The fossils heretofore reported from Bowden are found in the gravel bed and, less abundantly, in a few feet of the lower part of the overlying marls, at the foot of the hill, at the beginning of the road leading up the hill to Capt. Baker's, and in such abundance that as many as 400 species of mollusks have been determined by Dr. Dall from two barrels of material collected by Messrs. J. B. Henderson, jr., and C. T. Simpson, and the writer. A few specimens occur higher up the hill, while near the summit there is a body of firm crystalline secondary limestone containing molds of the characteristic fauna. The physical characters of this formation can be traced from Bowden to Morant Bay and beyond nearly to Yallahs Island, but there it loses its identity. On the road from Bath to Bowden its position above the Cambridge beds is fairly well revealed.

The stratigraphy of the formation has not hitherto been presented correctly, although in the Jamaican reports under the name of the "Yellow limestone" it was partially confused with the entirely different beds herein described as the Cambridge formation, and the gravel beds were mapped with the Pleistocene and Recent formations. Hence its identity as a formation did not appear in these reports.

It is only on the south coast of the east end of the island that the Bowden beds have the characters mentioned. It is evident that the formation with modified lithologic features occurs elsewhere on the island, for the Bowden fossils have been found on the opposite side by us and reported from round the district of Vere, near the coast of Clarendon, by other writers, in formations of quite a modified lithologic nature. Probably the Buff Bay, May Pen, and Porus formations, next to be described, are allied and synchronous deposits.

For details of the several related formations named, see the report cited.

The Manchioneal formation is of marine origin and is composed of alternating layers of loose yellow marl and lumpy white limestone with well-defined bedding planes, and locally of alternating evenly bedded marl and impure limestones. Hill describes exposures that exhibit from 100 to 200 feet of deposits of this character. Fossils are not numerous and the occurrences appear to be of small area. Hill [443h] says:

From the low position of the Manchioneal formation adjacent to the coast and unconformably against the older and more disturbed white limestones, it is evident that it was a marginal fringing deposit. Its stratigraphic position above the Bowden formation and below the undoubted elevated reef rock, as well as the paleontologic evidence of its pteropods and Brachiopoda, indicates the Pliocene age of this formation. The contained corals, here poorly developed but occurring in increased proportions in the succeeding beds, mark the first definite appearance of the marine reef-building species in the Jamaican sequence.

The Kingston formation is described as consisting mainly if not entirely of material derived from adjacent uplands of the mountains and plateau. It varies in composition, being mostly detritus of the Blue Mountain series to the east of the Rio Cobre and largely white limestone débris to the west of that stream. It has been successively accumulated through several geologic epochs and may ultimately be classified into several distinct terranes. Hill[4431] says:

For the present, however, we shall recognize but two principal stages—an older one, to which the name of Kingston will be applied, and a newer one, which will be called the Montego.

The Kingston formation is the oldest of the formations of old gravel and other alluvium occurring upon the plains of the Liguanea type. This is the formation upon which the city of Kingston and suburbs are built, including the strip of land known as the Palisades, and the plain extending back of Kingston to the foot of the mountains. * * * The material consists of bowlders, gravel, and pebble of varying sizes, usually very angular, and representing every known material of the Blue Mountain series. These are embedded in a matrix of dull red arenaceous clay, producing a chocolate soil and derived from the Minho beds so conspicuously exposed in situ in the mountains north of Kingston.

The thickness of this formation is unknown, but over 200 feet are exposed in the thalweg of Hope River, and probably fully this thickness is concealed. It is even likely that it may be nearly a thousand feet in places. * * *

As a whole, it represents excessive deposition, first as estuarine or littoral material during an epoch when the coasts were submerged, and later talus deposits of subsequent epochs, when the land was rapidly rising and stream erosion was very active, as discussed more fully in another part of this paper. The alluvial deposits in the bottom of the larger interior basins are also closely synchronous with the Kingston formation, and it is probable that these basins are products of the same great erosion epoch which preceded the Kingston deposition.

Fossils are generally missing from the Kingston formation; speculation concerning its age must be founded entirely upon stratigraphical relations. In our opinion it is clearly older than the elevated reefs of the Barbican and Hopewell formations, of presumable Pleistocene age, and younger than the Bowden formation, being nearly allied by position to the age of the Manchioneal, which we consider Pliocene.

The present beds of both the Hope and the Cobre rivers deeply indent the Kingston formation, cutting far below the surface of the plain. The alluvium of these stream valleys and their general level constitute distinct deposits which are later described under the head of the Montego formation.

In his further description Hill gives many details regarding the elevated reefs and miscellaneous coastal formations contemporaneous with them.

E 19. SANTO DOMINGO AND PORTO RICO.

Gabb[252b] placed the Tertiary of northern Santo Domingo in the Miocene and probably that of Porto Rico as of the same age. Regarding Santo Domingo Gabb says:

All of that part of the island which lies north of the Cibao Mountains, except a part of the peninsula of Samana, is made up of Tertiary rocks, usually bordered by a narrow strip of more modern age. They also form one or two insignificant deposits on the south side about San Cristobal and the Nizao, and are said further to cover a part or all of the valley of the lakes running to Port au Prince in Haiti. The work of the geological survey not having extended to the latter region I shall confine my observations to the others.

The district covered by this formation in the north, including its extension into Haiti, toward Cape Haitien on the west, and into Samana and south of the bay east, is little less than 150 miles long, although, cutting off these prolongations, it forms a compact area of about 100 miles long by 30 miles wide, or say, in round numbers, about 3,000 square miles. It abuts against and even overlaps the lower foothills of the central chain, underlies the whole valley of the Yaqui and Yuna, makes up the entire northern or Monte Cristi Range, and sends others along both sides of Samana Bay. In the south it forms a little group of hills extending from near the Jaina River across the Nigua and thins out in a few isolated patches toward the Nizao. Its total thickness in the vicinity of the Nigua River is about 400 feet, and it is made up of a succession of brown earthy and sandy beds, occasionally calcareous, superposed on a thin stratum of conglomerate. The top of the series is a rather compact calcareous deposit containing corals. The fossils, except the corals, are usually badly preserved and very meager in species; a small oyster, two species of Pecten, and some echinoderms being the only recognizable forms. Besides these, a few internal casts of gastropod shells have been discovered. The corals are so embedded in their matrix that they can only be collected satisfactorily when they are weathered out, and this same process of weathering is only too apt to destroy the delicate structure of their surfaces. They are, however, nearly all of the massive forms and are so thoroughly fossilized as to be well adapted for polishing.

But while the formation is so small in area and so unsatisfactory in general characters on the Santo Domingo side, it becomes, in the Cibao, the most interesting on the island. Cut through by all the tributaries of the Yaqui the sections are numerous and excellent for study. Its local modifications are well illustrated by sections innumerable, into and across the Monte Cristi Range on one side and into the southern hills on the other. In short, it would be difficult to find a region where the facilities furnished to the geologist are greater, or where the results could be more certainly arrived at. Add to this that a larger part of the formation is highly fossiliferous, and that the fossils, whether shells or corals, are almost always preserved entire and hard; as beautiful as the famous fossils of the Paris basin, or as the less known though equally beautiful specimens from Jackson, Miss.

The entire thickness of the formation in the Cibao is probably over 1,500 and under 2,000 feet. It is made up of coarse sandstones at the base, sometimes bearing beds of conglomerate, which are, however, rather local in extent. These beds are best developed between the Bao and the Yaqui, where, being uptilted, their thickness is best seen, and are about 600 feet thick. They gradually merge into gray shales, which form a transition to the heavy blue-shale beds underlying the town of Santiago and called by the English paleontologists the Nivaje shale. The upper part of this member is always of a light yellowish brown or buff color and sometimes, especially at its upper part, contains beds of sandstone. The whole of this shale member may be safely estimated at about 800 feet of average thickness. The remainder of the formation, say 400 feet more in all, varies locally. It caps the greater part of the Monte Cristi Range, and while north of Moca it forms high bluffs of a nearly white earthy rock, in which it is doubtful whether the argillaceous or the calcareous ingredients preponderate, it forms north of Esperanza sheets of a compact limestone, which, less pure, forms the cap on the isolated table mountain of Monte Cristi. Near Cevico it appears as an impure lime rock containing corals and Foraminifera, and similar beds occur also on Samana and south of Savana la Mar; while the caves of San Lorenzo, in the same beds, are in a hard, coarse-grained calcareous sandstone. Nor do the variations cease here. Near the mouths of the ancient Miocene rivers running from the then much smaller islands now constituting the Cibao Mountains, and among which the Mao was probably the largest, the gravel débris of these streams was deposited, occasionally alternating with a bed of coarse sandstone, synchronously with the formation of the coral reefs and beds of fine white mud which now glistens in the sun on the top of the Monte Cristi Range. We have thus an ideal section as follows:

	Feet.
White calcareous marl, north of Moca; white or light-brown limestone ("Tufaceous limestone" of Heneken); light-brown calc sandstone, San Lorenzo Bay; gravels of Mao and Savaneta; limestones of Samana, San le Mar, Cevico, and the north face of the Samba Hills; oyster beds of Samba Hills, south of Guayubin	400
Brownish or yellowish shale of Guayubin; conglomerate of Angostura of the Yaqui; sandstone strata near Santiago: dark-blue shale of Santiago; gray shale with beds of sandstone of Rio Verde and in the hills north of Moca	800
Coarse gray sandstone with some conglomerate; seen best in the hills south and southeast of Santiago, also in a few places in the north range	600

These three members are so intimately united that their separation is purely arbitrary. Beds of sandstone are found in the shale, and beds of shale extend far down into the lower member. Very few if any fossils have been found in the sandstone, though the gravels of Angostura yield shells abundantly, in connection with fragments of fossilized wood. The same species of fossils occur in all parts of the series, and I have collected from a bed of sandstone at the very summit of the Mao gravel a series of shells identical with those embedded in the rocks of the "nonfossiliferous sandstone" plain east of Guayubin, and which are found abundantly in the blue shale of the Gurabo, Amina, or Verde.

Fossils are not regularly distributed either vertically or laterally, but seem to occur in colonies. The blue-shale bluff under the city of Santiago, 60 feet high from the level of the river, does not show a single streak where they are ever abundant enough to repay the trouble of hunting, although isolated shells occur throughout. At Puñal, but a few miles off, near the Rio Verde, shells and corals abound. The same irregularity exists throughout, and although there is but little change in the species of the Mollusca in their vertical range, there is a marked difference between the eastern and western ends of the basin. Shells that are absent or scarce on the Verde are common on the Gurato and westward, and vice versa. The corals found in the shale are almost always of the cup forms, while the massive corals are almost exclusively confined to the upper beds and are particularly abundant on the north flanks of the Samba Hills. In all the shale beds and to the extreme top of the series Foraminifera occur and in some places are found in great numbers. They are not very numerous in species, probably not exceeding half a dozen. The Orbitoides ranges throughout all the strata and is not only found wherever any other fossil occurs but is often, especially in the higher beds, the only recognizable organic remains. It has more than once proved of great value to me in distinguishing these limestones from the overlying post-Pliocene calcareous beds.

With one or two small exceptions all these rocks are entirely unaltered. On the southern limit, in contact or nearly so with the underlying Cretaceous in the vicinity of the Bao River and on the Yaqui, the coarse sandstones are slightly modified, though still retaining their stratification and mechanical structure unchanged. On the Yaqui at Tabera this rock is highly uptilted and slightly contorted, as will be seen by reference to the description of the locality. Also in the northern range a similar slight metamorphism occurs southeast of Puerto Plata.

Gabb then discusses the geologic age of the West Indian Tertiary rocks and gives the age of many fossils, including 217 supposed extinct species and 97 known to be living. He concludes, "We are therefore at or near the top of the Miocene."

F 17–18. CUBA.

T. W. Vaughan has contributed to this work the following notes on the later Tertiary of Cuba:

An extremely interesting fact in the Cuban stratigraphy is that, so far as we at present know, there is absolutely no true Miocene on the island. The Miocene as described by De Castro, Salterain, and others is now referred to the upper Oligocene. From the evidence now before us, it seems most probable that during Miocene time none of the now existing portions of the Island of Cuba were submerged beneath the ocean.

The data regarding the presence of Pliocene strata are unsatisfactory. The only data on which we could base a conclusion are derived from the notes and collections of William Palmer. In the western part of Havana, on the Calle Infanta, opposite Castillo de la Punta, Palmer collected fossils from a quarry in soft white limestone. The bottom of the quarry is about at sea level. According to Palmer the same formation extends to approximately 60 feet above sea level. The fossils obtained from this locality may be Pliocene, though it is probable that they are Pleistocene. The limestone which is being quarried between Almandares River and Camp Columbia, on the north side of the road, may be of Pliocene age.

Surrounding the greater portion of Cuba, but especially along the northern coast and bordering the southern coast of Oriente from Cape Maisi to Cape Cruz, is a low coastal shelf nowhere exceeding a maximum elevation of 30 or 40 feet. There is beneath this shelf in places a lower terrace some 5 or 6 feet above the water's edge. Both of these terraces are composed of elevated coral-reef rock. The material is a limestone presenting an extremely rough upper surface and replete with the remains of numerous species of corals which are all, so far as examined, at present living in the surrounding Antillean seas. These reefs have been formed and elevated within very late geologic time.

A coating of surface gravel exists over the plain in the Province of Pinar del Rio on the south side of the Sierra de los Organos. The material has been derived from the rocks constituting the mountains and has been distributed through the agencies of streams and floods. It is probably of Pleistocene age.

G-H 14, H-I 15. TEXAS, LOUISIANA, AND ARKANSAS.

The following discussion has been compiled by T. W. Vaughan from the literature and from manuscripts of A. F. Crider and Alexander Deussen. Most of the literature is cited in Chapter XVI (p. 723); other references are given in the discussion.

MIOCENE.

No surface outcrops of marine Miocene deposits between Mississippi River and the Rio Grande have yet been described. Buried marine Miocene beds occur in southern Louisiana and in the coastal region of Texas. The two most thoroughly studied occurrences are those of the Jennings oil well, Louisiana, and the deep well at Galveston, Tex.

In the Jennings area the equivalent of the Pascagoula formation of Mississippi was penetrated at depths ranging from 1,040 to 2,183 feet, the variation being due to folding.[407a] In the Crowley field the "*Rangia johnsoni*" zone is from 1,960 to 2,600 feet below the surface.[407b]

Harris [402] has described a large Miocene fauna encountered in the Galveston deep well between 2,158 and 2,920 feet below the surface.

Deussen has discovered in De Witt County, Tex., littoral or fresh-water beds in which the remains of Miocene vertebrates were found. The material consists of cross-bedded coarse gray semi-indurated sands, gray sandstones, and local lenses of clay. The beds grade seaward into a marine phase and are overlain by Pleistocene deposits. Deussen thinks that these beds may be a littoral phase of the marine Miocene encountered in the Galveston well.

Dumble [297c] has proposed the name Oakville for "grits and coarse sands, cross-bedded, with some beds of clay, but oftener with balls, nodules, or lenses of clay embedded in the grit. Some of the sands form a sandrock which is apparently firm and hard, but much of it is so feebly coherent as to fall apart on a slight blow of the hammer. Local beds of conglomerate occur." A few fossil vertebrates were obtained, but they were considered sufficient to determine the age of the formation as "Loup Fork." The formation in which Deussen found Miocene vertebrates in De Witt County may belong to Dumble's Oakville.

Above Dumble's Oakville are formations named by him Lapara and Lagarto,[297d] but they have not been correlated with the geologic time scale.

PLIOCENE.

No marine Pliocene deposits are known to outcrop between Mississippi River and the Rio Grande, but a recent discovery of G. C. Matson in Louisiana, 8 miles west of south of Alexandria, indicates that such deposits may have a considerable development in south-central Louisiana and may even extend into Texas.

The problematic Lafayette formation covers extensive areas in northeastern Arkansas, southern Arkansas, northern and central Louisiana (especially over the Catahoula and Fleming formations), and eastern Texas.

The following description for northeastern Arkansas is taken from a manuscript by Crider:

"Overlying the Tertiary in Crowleys Ridge and also on the western border, and extending for a short distance over the Paleozoic rocks, there is a thin blanket of sand and gravel of the Lafayette with a maximum thickness of about 30 feet. The Lafayette has been removed from the lowland regions east and west of Crowleys Ridge, along with the Tertiary.

"Where the loess is absent, as in many places on Crowleys Ridge north of Jonesboro, the Lafayette is present on the highest divide. South of Jonesboro it appears beneath the loess in the railway cuts and deep ravines which have been cut to the middle portion of the ridge. Nearly all the principal streams of Crowleys Ridge have cut through the loess and Lafayette, and their materials have been carried down and spread out on the slopes and the adjacent bottoms. It is probable that most of the Lafayette which was originally deposited on the eastern foothills of the Paleozoic rocks from Missouri to Pulaski County, Ark., has been reworked by the streams and carried farther down the slopes.

"Where undisturbed the Lafayette is made up of chert, quartzite, and white and black quartz pebbles indiscriminately mixed with a coarse, well-rounded reddish sand. The whole is roughly stratified, showing the effects of ever varying currents. At the base of the formation the pebbles are, in places, interbedded with materials reworked from the underlying formation. The cherts constitute a large proportion of the pebbles in the formation. They are much larger and more angular than the quartz pebbles, and many of them contain fossil crinoid stems. They are, therefore, evidently derived from the cherty limestones of the adjacent Paleozoic hills. The quartz pebbles are much smaller than the cherts, and are well rounded and polished.

"Sand everywhere accompanies the gravels and in places forms the bulk of the formation. The grains are well rounded and, like the pebbles, are almost universally stained with oxide of iron. It is probable that some of the sand has been derived from the underlying formations, but a current that would be strong enough to bring in a large amount of foreign gravel would also carry a still larger amount of sand. Much of the sand, therefore, doubtless has the same origin as the pebbles.

"The Lafayette contains a large amount of ferruginous matter. Under favorable circumstances the iron oxide has cemented the sand into a rough, hard brick-red sandstone and the gravels into an ironstone conglomerate which is in few places more than 5 feet thick. These hard ferruginous masses are prone to form where the percolating waters, carrying the iron oxide in solution, come into contact with a compact clay or any other impervious layer. Subsequent erosion exposes these cemented masses, which in places protect the hills from further erosion, while large blocks break loose from the main ledge and cover the slopes."

This description applies well enough to the other areas in Arkansas and Louisiana.

According to Deussen (unpublished manuscript), "A wide area of the Coastal Plain in Texas east of Brazos River is occupied by a series of clays, sands, and gravels, which overlap the Miocene beds and in many places overlie and obscure the Fleming clay and are seen to rest directly on the Catahoula formation. Originally these beds mantled the older rocks over this entire area and the adjacent Black Prairie and extended in broad tongues up the valleys in the region to the west. These exposed portions have been subjected to erosion for so long a time that the interior margin, once very far to the west, has been gradually transferred seaward. In the area of the former extent many outliers persist on the higher divides and plateaus where their isolated position has protected these materials against erosion. These high-level gravels are so common within this area that they generally obscure the older underlying formations. The latter are exposed only in the channels and valleys cut by the streams since the deposition of the Lafayette.

"Toward the coast these sands, clays, and gravels dip beneath the overlying Pleistocene gravels and are recognized in many of the wells put down in this portion of the Coastal Plain.

"These sands and clays and gravels wherever exposed unconformably overlie the lower beds, indicating an erosion epoch between their deposition and that of the underlying beds.

"As a rule the materials carry no fossils indigenous to the strata. Waterworn fragments of fossils from older rocks are sometimes found embedded in the gravels, but these give no important clues to the age of the formation. At Sour Lake, Texas, they lie beneath beds of known Pleistocene age and above beds of known Miocene age, a position which would fix their age as Pliocene. This is also in accord with evidence from other sources."

In the region of Austin and San Antonio three distinct terraces flanking the rivers are recognizable. The highest and oldest of these occupy the divides, and the material consists almost entirely of flint embedded in a calcareous matrix. This is the Uvalde formation of Hill [446a] and corresponds to the Lafayette of more easterly areas. It consists of the products of destruction of the Edwards limestone. This material is now found only in the divides of the Coastal Plain, but it constitutes the uppermost terrace in the canyons of the Edwards Plateau.

The terraces of the second series occupy a lower level and are therefore younger than the Uvalde terraces. The materials composing these in the vicinity of Austin consist of granitic débris derived from the granites of the Llano region, which was exposed only after the Cretaceous cover was removed. In a terrace along Onion Creek, just west of Pilot Knob, Travis County, occur vertebrate remains of early Pleistocene age.[446b] This would make the upper terraces pre-Pleistocene.

The Uvalde formation is present from Austin to Rio Grande along the interior margin of the Rio Grande plain and extends many miles seaward. For further description see Hill and Vaughan.[446]

PLEISTOCENE.

For the areas bordering Mississippi River the brief description given on page 813 will apply. In southern Louisiana the Port Hudson attains a great thickness—usually over 1,000 feet and in places over 2,000 feet. This is also true of the Pleistocene of the coastal region of Texas. Landward from the border of the coastal prairies of Texas there are two systems of terraces between the level of the present flood plains and that of the Uvalde formation.

G 17, H 16-17, I 15-17 (EAST OF MISSISSIPPI RIVER), AND J 16. SOUTH ATLANTIC AND EASTERN GULF COASTAL PLAIN AND NORTH END OF MISSISSIPPI EMBAYMENT.

The following discussion (pp. 806-813) has been compiled by T. W. Vaughan from the literature and from unpublished results of G. C. Matson and E. W. Berry in southern Alabama and Mississippi and of his own researches. The principal references to the literature have been listed in Chapter XVI (p. 731). To the list there given may be added Nos. 566, 653, and 693 of the bibliography on pages 840-865.

MIOCENE.

Vaughan [834] describes the subdivisions of the Miocene along the Georgia-South Carolina line, their correlation with formations farther north, and their relation to the upper Oligocene:

"The following section of the exposure at Porters Landing is adapted from the description of it given by Mr. Earle Sloan in his 'Catalogue of the mineral localities of South Carolina,' page 273:

	Feet.
6. Pleistocene—white, red, and yellow sands, with phosphatic pebbles and vertebrate fragments at the base	64
5. Miocene—compact yellow fossiliferous marl (Duplin horizon)	6
4. Miocene—grayish fossiliferous marl (Marks Head marl)	29
3. Fine-grained laminated shale with sandy partings; a line of rounded pebbles at the base	14
2. Oligocene—fossiliferous marl (Alum Bluff formation)	½
1. Laminated drab shale with arenaceous partings	8
	111½

"Recent collections made at Porters Landing have rendered possible definite correlation of the two Miocene horizons with those of the area farther north. From bed No. 5 of the section 34 identified species were obtained, 30 of which also occur in the Duplin marl of North

Carolina. The four species which have not as yet been reported from there occur in other localities in horizons the stratigraphic equivalent of the Duplin, or in deposits of later age. Bed No. 5, therefore, can be definitely correlated with the Duplin marl of North Carolina and the fossiliferous Miocene marls of Darlington and Mayesville, S. C.

"The Marks Head marl, which was first named by Sloan and is represented by bed No. 4 of the section, contains specimens of the genus Carolia, which suggests an Oligocene age, but every other identifiable species may be Miocene, and only three of them range downward into the Oligocene. Nine of the species are not known below the Miocene, and of these nine, six are confined to the Miocene. The horizon is, therefore, Miocene, while the presence of *Turritella æquistriata* Conrad, *Calliostoma aphelium* Dall, *Ostrea mauricensis* Gabb, and *Pecten marylandicus* Wagner definitely points to a horizon low in the series, approximately equivalent to the Calvert formation of Maryland.

"The recognition of the stratigraphic position of this horizon is of importance, as it is the only low Miocene horizon known south of Virginia. Farther south in Florida, along the western extension, on the Ocklockonee and Apalachicola rivers, the Miocene rests upon the eroded surface of the upper Oligocene. The Miocene deposits of these localities represent a horizon high in the series. Therefore, the Marks Head Miocene is the equivalent in part to the erosion interval between the upper Oligocene and the Miocene of western Florida.

"Bed No. 2 of the section at Porters Landing contains fossils indicative of an upper Oligocene age. Bed No. 3 is very likely of Miocene age, and the line of rounded pebbles at the base suggests that the Miocene may rest upon the eroded surface of the upper Oligocene. It seems probable that along the Savannah River an erosion interval occurred between Oligocene and Miocene depositions, but the interval was of shorter duration than in western Florida."

The Marks Head marl is the oldest Miocene known south of the Hatteras axis. Sloan has applied the name Edisto marl to the indurated phosphatized marl in the vicinity of Charleston, the source of the rich phosphate deposits of that area. This material overlies the Cooper marl (Eocene) and underlies the Pleistocene and is only 2 or 3 feet thick. Although the identifiable fossils from it are few, stratigraphic equivalence with the St. Marys formation of Maryland and Virginia is definitely suggested. The Edisto marl is overlain by a softer, yellow sandy marl near the old Cohen plantation, three-fifths of a mile west of Goodrich station. To this marl Sloan has applied the name Goose Creek marl. According to Sloan it is overlain by the Duplin marl. The following section at Davis Landing, on Peedee River 16½ miles N. 75° E. of Lake City, shows the relations of the beds:

	Feet.
5. Pleistocene sands and loam	8
4. Indurated ledge of dirty yellow marl containing *Pecten eboreus*, especially at the base	16¾
3. Compact yellow marl with large numbers of *Chama striata* and *Arca incile*	8
2. Friable yellow marl, containing *Amusium mortoni* and *Pecten eboreus* (Goose Creek marl of Sloan)	4¾
1. Dark blue-green marl, with Cretaceous fossils	23
	60½

Beds Nos. 3 and 4 represent the Duplin marl. The faunal affinities of the "Goose Creek" marl have not yet been positively determined. The Duplin marl is an extension of the marl of the same name in North Carolina southward into South Carolina, where it is well developed along Peedee River and in the vicinity of Darlington, Mayesville, and Porters Landing, the last-mentioned locality being on the Georgia side of Savannah River.

Otto Veatch, in the manuscript of a report that has been published since this discussion was compiled, gives the following account of the Miocene in Georgia:

"Miocene strata have been discovered in the bluffs of Savannah River in Screven and Effingham counties; on Altamaha River near Doctortown, Wayne County; at Brunswick; and at Owens Ferry, on Satilla River in Camden County.

"The Marks Head marl is typically exposed near Porters Landing, on Savannah River, Screven County. It has not been differentiated at other localities than the bluffs of this river.

This formation rests unconformably upon the Alum Bluff formation and is also separated from the overlying Duplin marl by a small unconformity represented by an uneven line of quartz pebbles. The strata consist of gray or brownish compact argillaceous sand containing large calcareous nodules and, in places, of friable phosphatic sand containing shells. The formation does not reach a thickness of more than 30 or 35 feet in natural exposures.

"The Duplin marl as exposed along Savannah River overlies the Marks Head marl and is separated from it by a small unconformity indicated by quartz pebbles. It is overlain by Pliocene (Lafayette?) and Pleistocene deposits of sand and clay. It is a shell marl consisting of shells in a matrix of coarse phosphatic sand; in places it consists of a fine gray or brown quartz sand. It probably does not reach a thickness of more than 10 or 12 feet.

"The Duplin on Altamaha River consists of friable sandy and pebbly shell marl and bluish fine-grained argillaceous sand, which is also fossiliferous. The formation unconformably overlies strata of probable Alum Bluff age, and is in turn overlain by varicolored sand and clay which is probably Lafayette (Altamaha). The Duplin reaches a thickness of not over 12 or 15 feet.

"The Miocene at Brunswick is not exposed naturally and was discovered in dredging operations on Brunswick River. The material thrown off the dredge consists of fragments of bones, teeth, sand, quartz pebbles, and compact sandy marl, or shells embedded in a phosphatic sand matrix, together with some argillaceous limestone and hard clay. A study of the fossils has been made by Vaughan and they were found to range from Miocene to Recent.

"Miocene rock is exposed in the bed and banks of Satilla River at low tide, at Owens Ferry, 8 miles west of Woodbine. The rock is a brown or grayish compact sand and calcareous sandstone, containing poorly preserved fossils."

The Miocene in Florida rests upon the eroded surface of the upper Oligocene Alum Bluff formation, as is shown in the exposures at Jackson Bluff, on Ocklockonee River, and at Alum Bluff, on Apalachicola River. The series in this State is divided into two formations that occupy different areas but are probably in large part contemporaneous. The formation in the eastern area is the Jacksonville, that in the western area the Choctawhatchee. Matson and Clapp[580d] describe the Jacksonville as follows:

"From well records and samples obtained along the east coast of Florida, the Jacksonville formation appears to rest unconformably upon the eroded surface of the limestones of the Vicksburg group at Jacksonville, St. Augustine, and other localities. Farther westward it probably rests on the beds belonging to the Apalachicola group, but no contacts were observed.

"When fresh, the limestone of the Jacksonville formation varies in color from light gray to nearly white, but upon weathering it changes to pale yellow or yellowish gray. It usually has a porous texture but occasionally becomes hard and dense. The presence of a large percentage of clear quartz sand may be easily distinguished by the use of an ordinary hand lens, and microscopic examination shows that there is also a large amount of clayey material which varies in color from light gray to pale yellow. In certain horizons fossils are very abundant, the shells having usually been dissolved, leaving nothing but casts or molds; and this fact, together with the friable character of the rock, makes it very difficult to obtain satisfactory collections. However, enough material has been obtained to indicate the Miocene age of the rock. Unlike the Choctawhatchee marl, the Jacksonville formation appears to contain practically no mica. It also differs from the marl in its relatively higher percentage of lime and a correspondingly lower percentage of sand.

"Although the Jacksonville formation is fossiliferous, the organic remains are less numerous and in a much poorer state of preservation than in the Choctawhatchee marl. An examination of well samples shows that limestone forms only a minor part of the formation, a fact which is well illustrated by the log of the well at Jacksonville, where the formation attains a thickness of about 500 feet and is composed largely of arenaceous and siliceous beds. From samples obtained in drilling a well at Jacksonville the clays are known to be siliceous and the hard materials described as gravel found to be chert nodules. Some of the beds consist of a hard gray siliceous rock which appears to have been formed by the replacement of the calcareous portion of a sandy limestone by silica which was probably derived from organic remains such as sponge spicules and diatoms.

"The exposures of the limestone of the Jacksonville formation seldom exceed 5 or 6 feet in thickness, but there is a maximum exposure of about 15 feet at a locality 2 miles above Middleburg, on Black Creek."

The maximum thickness of the formation is indicated by well borings to be about 500 feet, according to Matson and Clapp. Miocene strata have been identified in well borings as far south as Key Vaca, at depths between 375 and 400 feet.[835a]

The Choctawhatchee marl is described by Matson and Clapp[580e] as follows:

"The Choctawhatchee marl includes the 'Ecphora bed' and 'aluminous clay' of Dall. It comprises a grayish sandy shell marl and gray plastic sandy clay of Miocene age. It lies stratigraphically between the Oligocene and Pliocene beds and contains characteristic species of Miocene fossils.

"The Choctawhatchee marl rests unconformably upon the Alum Bluff formation at Alum Bluff, where the contact shows a wavy surface marked by shallow channels due to erosion. At this locality there is also a sharp change from the coarse light-gray sands of the Alum Bluff formation, which contain few fossils, to the bluish-gray shell marl of the Choctawhatchee, with its abundant fauna. Several years ago Dr. Vaughan noted similar evidence of an unconformity between the Oligocene and Miocene at Jackson's Bluff, on the Ocklockonee River. This fact is well shown by his section at that locality. * * *

"The paleontologic evidence indicates a stratigraphic break between the Oligocene and Miocene as is shown by the following quotation:[a]

"'As I have on various occasions insisted, the faunal gap between the uppermost Oligocene (Oak Grove) and the Chesapeake (Choctawhatchee) or Miocene is the most sudden, emphatic, and distinct in the whole post-Cretaceous history of our southeastern Tertiary and indicates physical changes in the surrounding region, if not in Florida itself, sufficient to alter the course of ocean currents and wholly change the temperature of the waters on our southern coast.'

"Lithologically the two members of the Miocene in Florida are very unlike, both in character of the material and state of aggregation. The Choctawhatchee marl varies from greenish gray to light gray in color and consists of quartz sand containing very large admixtures of shells and shell fragments and a smaller percentage of calcareous sand. In some parts of the formation the shells comprise a large percentage of the whole, and they are often in an excellent state of preservation. Elsewhere the organic remains form a very subordinate part of the whole or they may be entirely wanting. One phase of this formation is distinctly plastic and was called 'aluminous clay' by Dall and Stanley-Brown.

"When examined with a microscope the marl is found to consist of clear quartz sand, of medium fineness, coated and partially cemented with calcium carbonate mixed with more or less dark clay. The presence of calcium carbonate may be detected by the effervescence when treated with dilute hydrochloric acid. There is also a certain amount of dark-colored clayey material which appears in the form of a flocculent sediment in water. This material varies from light gray to nearly black and is, without doubt, organic matter. In addition, hydrous iron oxide may be detected, usually in the form of a coating about the sand grains or as a stain along the cracks and on the exposed surfaces of the beds. It is this iron compound which sometimes gives the exposed surfaces a rusty color.

"The Choctawhatchee marl attains a thickness of over 50 feet in the vicinity of Redbay, Walton County, where it is exposed in some small ravines and on the banks of Mill Creek; near Holland post office, Leon County, its thickness exceeds 30 feet. However, from observations elsewhere it appears probable that the average thickness is not more than 25 to 30 feet."

West of Florida Miocene beds have been recognized in the well of the Mobile Oil Co., at Mobile, at a depth of 700 feet, and probably continued to a depth of about 1,100 feet, where upper Oligocene fossils representing the Alum Bluff formation were encountered. Beds of

[a] Dall, W. H., Trans. Wagner Free Inst., vol. 3, p. 1594.

pebbles and conglomerate lying above the Apalachicola group (Oligocene) in this well probably indicate an erosion unconformity between the Apalachicola and the Miocene.

Miocene rocks are exposed at Shell Bluff, on Chickasawhay River, near Merrill, Miss., the type locality of L. C. Johnson's Pascagoula formation. G. C. Matson has discovered that the Miocene along the Alabama-Mississippi line is separated by an erosion unconformity from the underlying upper Oligocene. Across southern Mississippi the Miocene is represented by estuarine deposits that have not yet been definitely discriminated from the underlying upper Oligocene deposits, which are also estuarine and of similar lithology.

PLIOCENE.

The marine Pliocene of South Carolina is a southward extension of the Pliocene of North Carolina. The principal area lies along Waccamaw River, near Conway, in Horry County. The material is yellow, brown, and gray shell marl. Sloan gives the thickness at the mouth of Tilly's Lake as 10½ feet.

The Charlton formation of Georgia and Florida, which outcrops along St. Marys River from Stokes Ferry, 11 miles south of St. George, Charlton County, Ga., to Orange Bluff, 2 miles above Kings Ferry, Nassau County, Fla., is probably of Pliocene age. The formation is composed of calcareous shell marl, sand, and clay, having a maximum exposed thickness above low-water level of about 15 feet.

The most extensive development of the marine Pliocene in the Coastal Plain area is in Florida, where it is divided, largely because of its areal distribution, into two formations—the Nashua marl, which occurs along St. Johns River below the town of Nashua, and the Caloosahatchee marl, which takes its name from Caloosahatchee River. Matson and Clapp [580g] give the following description of these formations:

"The Nashua marl bears a strong lithologic resemblance to the Caloosahatchee marl. There is the same alternation of sand beds with shell marl. The matrix of the Nashua marl, while usually calcareous, is always more or less sandy and sometimes consists of nearly pure sand. The shells are commonly well preserved, though locally a marl consisting of broken and eroded fragments of shells is not uncommon. However, the organic remains are so well preserved that it is easy to obtain good collections of fossils from this formation.

"The Nashua marl is much thinner than the Miocene strata. This fact, together with its distribution beneath the lowlands near the coast, indicates that the Pliocene submergence was less extensive than the Miocene; and the presence of shallow-water fossils shows that the Pliocene sea did not attain any great depth over that part of the State where the marine beds are now exposed. The Nashua marl is seldom more than 6 or 8 feet thick, but locally it attains a greater thickness. A series of samples of sand and marl from a well at DeLand indicates that at that locality this marl has a thickness of about 32 feet.

"The Nashua marl occupies the St. Johns Valley, where it underlies a broad terrace bordering the stream. It probably occurs beneath the plain east of St. Johns River, but the overlying Pleistocene forms such a thick mantle that the Nashua marl has no influence on the topography. On the whole, this formation has little or no influence on the topography of the State.

* * * * * * * * *

"The Caloosahatchee marl consists of a light-gray shell marl which is often interbedded with nearly pure sand. The matrix is usually very calcareous, but locally it consists of sand and even in the most calcareous portion sand is abundant. The shells are remarkable for their excellent state of preservation and their abundance in certain layers makes it possible to secure excellent collections.

"It is difficult to form a correct estimate of the thickness of the Caloosahatchee marl, but its maximum is probably about 25 feet. Single exposures seldom exceed 5 to 10 feet, and the average thickness is probably less than 8 feet. On the whole the Caloosahatchee marl is probably to be regarded as thin, though it may thicken considerably toward the central portion of the peninsula and toward the southern end of the State.

"The Caloosahatchee marl occupies a region of such low altitude that it has only been slightly dissected. In fact, with the exception of the valleys of the streams entering Charlotte Harbor the surface of the region underlain by this formation is an almost unbroken plain. While this is doubtless in part due to the later deposit of Pleistocene sand, it is doubtful if the surface of the Caloosahatchee marl has ever been greatly eroded."

The nonmarine Pliocene of Florida includes the Alachua clay and the Bone Valley gravel. The Alachua is thus described by Matson and Clapp: [580h]

"The Alachua clay is known to occupy depressions such as sinks and gullies in the Oligocene and probably also in the Miocene beds. Observations made by Dall along the banks of Peace River have established the fact that a bone bed ('Peace Creek bone bed'), which he correlates with the Alachua clay, rests upon older Pliocene beds. The relation between the Alachua clay and this bed on Peace Creek has not been observed, but they are believed to be lacustrine or fluviatile deposits which may have been formed at about the same time. The Alachua clay is also thought to be contemporaneous with a part of the Caloosahatchee and Nashua marls. It consists of blue to gray sandy clay which weathers to light yellow or red from the presence of iron oxide. There is usually sufficient clay to give the material a distinct plasticity, and sand is commonly present in considerable quantities. The weathered material is frequently more or less concretionary as a result of the aggregation of the iron oxide. The formation is nearly destitute of fossils except in a few localities where it is filled with vertebrate remains."

As the accumulations took place in depressions of the surface of the Oligocene beds, the thickness is variable. In places it is 15 feet or more, and the average thickness is probably not less than 10 feet.

The Bone Valley gravel, which comprises nearly all the pebble phosphates now being mined in Florida, derives its name from a locality west of Bartow, where the beds are exploited on a large scale. Eldridge designated this deposit land pebble phosphate, while Dall called it simply pebble phosphate, both writers distinguishing between the Tertiary deposits of Pliocene age and the younger pebble phosphates, which vary in age from Pleistocene to Recent. The deposits, according to Matson and Clapp,[580i] "are situated in the valleys of streams and vary in altitude from less than 25 feet to nearly 100 feet above tide. Lithologically the formation is composed of very poorly assorted materials, such as clay and phosphate pebbles, which usually show some evidence of stratification. * * * The poor assortment of the materials and the absence, locally, of distinct stratification point rather to fluviatile than marginal origin. It is, however, probable that some of the deposits were made in the margin of estuaries. The presence of such organic remains as bone fragments and shark's teeth is readily explained by the fact that the phosphatic gravels were derived from older formations in which such materials occurred.

"The Bone Valley gravel rests upon beds of Pliocene or older rocks, and the relation is probably unconformable, but the poor exposures make it impossible to observe contacts except in a few localities. For this reason it may not be safe to postulate an unconformity between the Bone Valley gravel and the underlying Pliocene marls, though the contact with the post-Pliocene beds is certainly unconformable. * * *

"While the exact correlation of this formation is somewhat uncertain, it is believed to be younger than the 'Arcadia marl' and older than the upper beds of the Caloosahatchee marl. It is probably in part contemporaneous with the Alachua clay. * * *

"The exposures frequently reach a depth of more than 30 feet, without encountering the underlying beds, and hence the maximum thickness may be safely fixed at more than 30 feet. The average thickness, however, is probably lower and it may not exceed 15 to 20 feet."

West of Florida the presence of Pliocene rocks has not been definitely determined. It is probable that a portion of the 700 feet of strata above the *Rangia johnsoni* bed in the Mobile well is Pliocene. Berry examined outcrops and collected fossil plants in Alabama at a point

1 mile south of Lambert, Mobile County (elevation about 325 feet), and at Red Bluff, Perdido Bay (just above tide). He bases the following opinions [a] upon studies of the fossil flora:

"Red Bluff is obviously of the same age as the outcrop near Lambert and the same age as the bluffs on Mobile and Pensacola bays. The flora, considered with that of the locality near Lambert, is decidedly modern in its facies as compared with the other so-called 'Grand Gulf' outcrops which contain fossil plants, the difficult question being to differentiate between Pliocene and early Pleistocene. The flora is a mixture of swamp types and those of live-oak barrens and indicates climatic conditions such as occur along the Gulf coast to-day, as, for example, on the Santa Rosa Peninsula.

"In the absence of any American floras for comparison I am disposed to regard the age of the deposits as Pliocene, as the species are nearly all extinct and embrace positively identified genera (for example, Trapa) which no longer occur in North America."

The Lafayette formation was first discriminated by E. W. Hilgard in 1855 and 1856, and named by him in manuscript from Lafayette County, Miss., but the name was not published until 1891. This formation was included in the Orange sand of Safford in Tennessee and the Orange sand of Hilgard in Mississippi. In 1888 McGee [565a] applied the name Appomattox to the formation from "the river of typical development in the middle Atlantic slope." McGee's name Appomattox antedates the publication of Hilgard's Lafayette by about three years, but a fact that is perhaps more to the point is that the recent studies of Berry, Lowe, and others around Oxford, Miss., have shown that exposures in Lafayette County, formerly regarded as typical Lafayette formation, are of Wilcox (Eocene) age, rendering very doubtful the propriety of applying the name to deposits of probably late Pliocene age. The nomenclature has, therefore, been unsettled by the attempt to supplant McGee's Appomattox and must temporarily be regarded as only tentative. From the evidence now in hand it seems probable that the term Lafayette for the deposits presently to be described will have to be abandoned, and McGee's Appomattox be revived. However, McGee's usage in his paper "The Lafayette formation" will be followed here.

According to McGee,[566a] "In composition the Lafayette formation is a bed of loam, sand, and gravel, with several minor elements, notably kaolin or kaolinic clay, comminuted silica or siliceous clay, etc. The clay element of the loam and much of the sand are evidently residua derived from decomposition of a variety of older rocks, the local characters generally reflecting the characters of local terranes; the gravel and a part of the sand represent the terranes traversed by the upper reaches of the rivers along which they are found; and the gravel varies in abundance and size with the volume, declivity, etc., of these rivers.

"In geographic distribution the Lafayette formation coincides approximately with the Coastal Plain of the southeastern United States. In hypsographic distribution the formation ranges from altitudes of 700 or 800 feet to probably some distance below tide level.

"In thickness the Lafayette deposits range from a mere veneer over many interstream tracts to 200 feet or more about the mouth of the Mississippi; and in general the thickness varies directly with the volume of neighboring rivers and inversely with the inland extension. The formation has, however, been degraded from considerable areas, particularly along the larger waterways.

"In structural relation it is separated from the newer Columbia formation by the strongest unconformity of the Coastal Plain, an unconformity representing degradation of probably half the volume of the Lafayette formation and profound trenching of subjacent formations along the larger waterways; and it is separated from all of the underlying formations by a noteworthy unconformity of such character as to indicate that during pre-Lafayette time the Coastal Plain was a land surface and was wrought into a configuration much like that existing to-day.

[a] Unpublished manuscript.

"In structural composition the formation is a unit, varying from place to place in local characters yet indivisible throughout its area of 250,000 square miles, save on arbitrary grounds."

The formation is important especially in the interstream areas across South Carolina, northern Florida, and each State from Georgia to southern Illinois.

PLEISTOCENE.

Marine Pleistocene deposits cover considerable areas along the coasts of South Carolina and Georgia and are greatly developed in Florida, where Pleistocene marls, coquina beds, and limestones underlie over half the present land surface of the State.[a]

Below the Lafayette level in the south Atlantic and Gulf Coastal Plain States are several persistent terraces above the present flood plain, representing McGee's Columbia group. From Georgia to Tennessee there are at least two—(*a*) one major terrace between the Lafayette and the "second bottoms" and (*b*) the "second bottoms." The loess of the Mississippi seems correlative with the major terrace below the Lafayette level. The terraces slope coastward and merge with shallow-water and estuarine deposits, to which in Louisiana Hilgard has applied the name Port Hudson group.

H-J 13-14. GREAT PLAINS, COLORADO, KANSAS, OKLAHOMA, NEW MEXICO, AND TEXAS.

Darton[238e] maps the Miocene (Ogalalla and Arikaree formations) southward from Nebraska (see p. 822) through Colorado and Kansas into Oklahoma, Texas, and New Mexico. The following notes are taken from a paper by Gould:[373c]

Lying unconformably upon the surface of the red beds and Cretaceous over a large part of western Oklahoma is an extensive deposit of Tertiary rocks, the exact age of which has never been determined with accuracy. Paleontological evidence is rare, but, following the usual classification of beds of apparently the same age in western Kansas and Nebraska, there seems no valid reason for not considering them Miocene or Pliocene. * * *

With the exceptions of the alluvium and sand hills the Tertiary is the uppermost formation in Oklahoma. The red beds underlie it, except that between the red beds and the Tertiary occur sometimes Comanche Cretaceous members. * * *

In general the later Tertiary occupies the uplands of the western half of Oklahoma, almost always occurring on the high divides between the streams. * * *

The Tertiary consists for the most part of clay, sand, and gravel. These materials are in no regular stratigraphic succession. * * * In places the entire thickness of the formation is clay; again sand and gravel predominate, and often deposits of different character will be interbedded. * * *

The clay is usually white or pinkish and sometimes forms steep banks or cliffs along the bluffs or around the heads of canyons. To the harder ledges the name "mortar beds" has been applied. * * *

The sand is of various degrees of fineness and is composed for the most part of quartz, although other minerals are present. The grains, when examined under the microscope, are usually rounded. * * *

"Tertiary pebbles" is the term usually applied by geologists to the smooth, rounded, waterworn pebbles scattered abundantly over the slopes and points throughout western Oklahoma and Kansas. These pebbles have been washed out of the Tertiary deposits, of which they often constitute a moderately large proportion. They are frequently cemented together and form a hard conglomerate rock known as Tertiary grit, which on exposure forms conspicuous ledges. * * *

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[a] For detailed information see papers on Florida by Sanford[693] and Vaughan.[835]

The pebbles are of all sizes, from coarse sand to stones several inches in diameter. Quartz is the principal mineral, granite, feldspar, and other minerals also being present. * * *

It is probable that the Tertiary deposits at one time covered the entire western part of Oklahoma. The valleys of the present streams have been carved in these deposits, and in many parts of the Territory all traces of the Tertiary are gone, except scattered quartz pebbles.

The thickness of the formation varies with the locality, being greatest on the high divides. Throughout a large part of western Oklahoma its thickness averages 100 feet or more, while in a few localities distant from the streams it may reach as much as 300 feet. On the other hand, in a great many places there is but a thin blanket of the deposit over the red beds.

I 10-11. SANTA BARBARA COUNTY AND SOUTHERN CALIFORNIA.

Arnold and Anderson [32] thus describe the Monterey shale (Miocene) in the Santa Maria oil district, California:

A great series of fine shales, largely of organic origin, overlies conformably the coarse and fine sedimentary deposits of the Vaqueros. These shales make up the Monterey formation and are representative of the whole of middle Miocene time. The formation is of great thickness and is doubly important as the probable source and the present reservoir of the oil. The areal extent of the Monterey is not adequately represented on the map. It doubtless covers as one continuous sheet the whole basin between the Santa Ynez and San Rafael mountains, as well as a large part of these ranges, but it is covered over considerable areas by later deposits, which are in many places very thin. The character, structure, and relations of the Monterey have been the chief subject of the present study.

The name "Monterey" was given by William P. Blake[a] in the early fifties to an organic shale formation typically developed in the vicinity of Monterey, in Central California. It is very extensive in the California Coast Ranges, being the "bituminous shale" series described by Whitney in the reports of the Geological Survey of California as occurring at widely separated points north and south of the Golden Gate. Its age is generally considered to be middle Miocene. It is the source of much of the petroleum found in California. The shale that characterizes this unique formation is not similar to ordinary clay shale but is composed largely of the remains of minute marine organisms. In its unmetamorphosed condition it resembles chalk but is of siliceous instead of calcareous composition.

The Monterey in the part of California treated here may be divided on lithologic grounds into two parts, although there seems to be perfect conformity throughout the formation. There is no definite dividing line to be drawn, but taken as a whole the lower half, composed chiefly of hard, metamorphosed, in places flinty shales, is distinct from the upper half, in which soft shale, giving evidence to the naked eye of its organic origin, is predominant.

The following summary description of the stratigraphy of the Summerland district, Santa Barbara County, is quoted from Arnold: [30]

The formations involved in the geology of the Summerland district are 9,000 ± feet of conglomerate, sandstone, and shale of the Topatopa (Eocene); 4,300 ± feet of conglomerate, sandstone, and shale of the Sespe (Eocene or Oligocene); 2,400 ± feet of sandstone and shale of the Vaqueros (lower Miocene); 1,900 + feet of shale and volcanic ash of the Monterey (middle Miocene); 1,000 + feet of conglomerate, sandstone, and clay shale of the Fernando (upper Miocene-Pliocene); and 50 + feet of gravel, sand, and clay of the Pleistocene—in all, 18,650 ± feet of sediments, practically all of Tertiary age. Unconformities occur between the Monterey and Fernando formations and between the latter and the Pleistocene.

[a] Proc. Acad. Nat. Sci. Philadelphia, vol. 7, 1855, pp. 328-331.

Tentative correlation of formations of Summerland district with the standard California Coast Range and Santa Clara Valley sections.

Era.	System.	Series.	Standard Coast Range section.	Summerland district section.	Santa Clara Valley section.
	Quaternary.	Recent.	Alluvium.	Alluvium.	Alluvium.
		Pleistocene.	San Pedro. —Unconformity—	Marine and stream deposits. —Unconformity—	Sand and gravel. —Unconformity—
	Tertiary.	Pliocene.	Merced.		
			Purisima.	Fernando.	Fernando.
		Miocene.	San Pablo. —Unconformity—	—Unconformity—	—Unconformity—
Cenozoic.			Monterey.	Monterey.	Modelo {Shale. Upper sandstone. Shale. Lower sandstone.
			Vaqueros.	Vaqueros.	Vaqueros.
		Oligocene.	San Lorenzo. —Unconformity?—	Sespe {Red beds. Lower sandstone.	Sespe {Upper. Red beds. Lower.
		Eocene.	Tejon.	Topatopa.	Topatopa.
			Martinez. —Unconformity?—		
Mesozoic.	Cretaceous.		Chico. —Unconformity— Horsetown. —Unconformity— Knoxville. —Unconformity—	(?)	(?)
	Jurassic (?).		Franciscan. —Unconformity— Granite, schist, etc.	Franciscan? (fide Whitney).	—Unconformity— Granite, gneiss, etc.

I-J 10-11. COAST RANGE, CALIFORNIA.

Lawson [525] states, in a paper on the geological section of the middle Coast Ranges:

The paper is an attempt to summarize recently acquired information as to the sequence of formations and their respective volumes of sediments in the middle Coast Ranges of California. The results given for the thickness are approximations sufficiently close to afford a general idea of the section. Other features of the paper are the subdivision of the Franciscan into seven stratigraphic subdivisions by the recognition of a persistent horizon of foraminiferal limestone and two important horizons of radiolarian chert; a similar subdivision of the Monterey into seven stages and a summary announcement of the character and history of the post-Monterey Tertiary. The essential features of the paper are given in the following tabulation:

Geological section of the Coast Ranges of California in the vicinity of the Bay of San Francisco.

	Feet.
Merced:	
Upper marine sandstones, sandy shales, and clay shales	5,830
Lower marine clays, sandy shales, sandstones, fine pebbly conglomerates	
Unconformity.	
Campan:	
Volcanics, andesites, basalts, rhyolite agglomerates	500
Fresh-water conglomerates, sandstones, clays, limestones	
Unconformity.	
Upper Berkeleyan:	
Volcanics, basalts, and tuffs	200
Siestan, fresh-water clays, limestones, sandstones, shales, lignite, tuffs, conglomerates	
Volcanics, andesites, basalts, rhyolite tuffs	
Unconformity.	
Lower Berkeleyan:	
Volcanics, andesites, basalts, rhyolite tuffs	2,000
Trampan, marine shales, sandstones, pebbly conglomerates	
Orindan, fresh-water conglomerates, sandstones, clays, limestones, tuffs	2,400
Pinole: Tuffs (pumiceous) fossiliferous	1,000
San Pablo: Blue tuffaceous sandstone, marine	1,500
Unconformity.	
Monterey:	
Upper: Stage 7—Sandstone	1,800
Middle:	
Stage 6—Bituminous shale	670
Stage 5—Sandstone	1,200
Stage 4—Bituminous shale	460
Stage 3—Sandstone	600
Stage 2—Bituminous shale and chert	250
Lower: Stage 1—Sandstone	400
Unconformity.	
Karquinez:	
Tejon: Massive sandstones	2,100
Martinez: Massive sandstones	2,200
Rhyolite flows (age not certainly determined).	
Unconformity.	
Shasta-Chico:	
Chico: Sandstones and shales	3,000+
Oakland: Conglomerate	500
Peridotite irruptions.	
Knoxville: Shales with subordinate limestone and conglomerate	1,000
Unconformity. Volcanics.	
Franciscan:	
Bonita sandstone	1,400
San Miguel cherts, radiolarian	530
Marine sandstone	1,000
Sausalito cherts, radiolarian	900
Bolinas sandstone (volcanics)	2,000
Volcanics.	
Calera limestone, foraminiferal	60
Volcanics.	
Pilarcitos sandstone	790
Unconformity.	
Montara granite (correlated tentatively with late Jurassic granite of Sierra Nevada).	
	34,290

In the hills west of Tulare Lake, southern California, lies the Coalinga oil district studied by Arnold and Anderson,[34d] who thus describe the post-Eocene formations:

The periods following the Eocene are here represented by a great series of sandstone, shale and conglomerate beds, all tilted at about the same angle, having usually similar characteristics, and presenting an appearance of conformity and intergradation. By means, however, of discontinuous fossil faunas, distinguishable lithologic groups, the absence in some places of formations or zones known elsewhere, as a result of erosion and the overlapping of later beds, and the appearance of fragments of older formations within younger ones, several important breaks may be definitely made out, which prove the intervention of periods of time during which land conditions existed over wide areas or locally. The important post-Eocene formations that represent the epochs of submergence of the land in the area now occupied by the Coalinga district are the Vaqueros (lower Miocene), the Santa Margarita (?) (upper middle Miocene), the Jacalitos (early upper Miocene), the Etchegoin (late upper Miocene), and the Tulare (Pliocene and lower Pleistocene) formations. The Tulare formation is probably in large part of different origin from the others but is similar to them in the general features of its appearance. These formations are all united into one series in the monocline dipping down the east flank of Joaquin Ridge in the northern part of the district and again in the monocline dipping away from Reef Ridge in the southern portion, but the character of the series is not entirely the same in the two regions.

In the northern part of the district the base of the Miocene-Pliocene is formed of coarse and fine oil-impregnated sands unconformably overlying the whitish and purplish petroliferous Eocene (Tejon) shales, these sands being overlain by prominent sandstone beds (the "reef beds"), a prominent zone of white siliceous shale (the "indicator"), and soft sand up to the base of a zone of bluish-gray and variegated clay, sand, gravel, and serpentine detritus locally known as the Big Blue. Up to this point the beds are fossiliferous, have a thickness of about 550 feet, and are mapped as Vaqueros (lower Miocene). The Big Blue has a thickness of about 300 feet and is nonfossiliferous. It corresponds in stratigraphic position to the Monterey shale (middle Miocene) of regions nearer the coast, but nothing has been discovered to indicate that it may belong to that formation. It is overlain by a thickness of about 175 feet of sand, sandstone, and conglomerate beds full of immense oysters, barnacles (Tamiosoma), scallop shells (Pecten), and other fossils. These fossiliferous beds will be referred to as the Tamiosoma zone. They are overlain by 400 to 500 feet of sand and gravel beds up to the base of a very prominent gravel zone full of petrified wood. The beds from the base of the Big Blue up to this point are mapped as the Santa Margarita (?) formation (upper middle Miocene). The gravel zone with fossil wood forms the base of a succession of sand, sandstone, gravel, and clay beds extending up to the base of a prominent zone of bluish-gray sand beds having near their base a rich fossil bed, the Glycymeris zone. The succession of beds up from the base of the fossil-wood gravel zone to this point has a thickness of about 1,600 feet and is mapped as the Jacalitos formation (early upper Miocene). The fossil bed (Glycymeris zone) and bluish sands immediately overlying grade upward into sand and clay beds, the whole forming a thickness of about 1,700 feet, which is mapped as the Etchegoin formation (uppermost Miocene), and this finally is overlain by poorly exposed coarse gravel deposits, which are mapped as the Tulare formation (Pliocene-lower Pleistocene). The total thickness of the succession in the Coalinga field thus outlined is about 4,600 feet, exclusive of the Tulare formation, which can not be measured in this portion of the district.

In the southern part of the district the basal portion of the Miocene-Pliocene series consists of about 700 to 900 feet of steeply dipping hard sandstone and conglomerate beds forming the face of Reef Ridge. These overlie, with an important though usually not apparent unconformity, the shale of the Tejon (Eocene) and are locally petroliferous. At the summit they grade into softer beds which are overlain by hard siliceous shale. Up to this shale the beds are fossiliferous and are mapped as the Vaqueros formation. The overlying shales are hard and whitish, form a prominent zone varying up to 1,200 feet in thickness, and are mapped as Santa Margarita (?), although only tentatively referred to that formation. These shales are overlain by a great succession of beds of sandstone, shale, sand, clay, gravel, and conglomerate of many varieties, having a thickness as measured in a section south of Big Tar Canyon of about 9,500 feet. This succession is divided on the map, on the basis of criteria to be discussed later, into three approximately equal divisions corresponding to the formations in the north, namely, the Jacalitos (early upper Miocene), Etchegoin (uppermost Miocene), and the Tulare (Pliocene-lower Pleistocene). The total thickness of the Miocene, Pliocene, and lower Pleistocene series measurable in the above-mentioned single section is over 11,000 feet.

The following table, from Arnold and Anderson's report,[34] gives a correlation of the Mesozoic and Cenozoic formations of the California Coast Range:

Tentative correlation of formations of Coalinga district with the standard California Coast Range section and those of other localities in California.

Era.	System.	Series.	Standard Coast Range section.	Coalinga district section.	Santa Maria district section.	Santa Clara Valley (Ventura County) section.	Los Angeles and Puente Hills section.	Santa Cruz Mountains section.
Cenozoic.	Quaternary.	Recent.	Alluvium.	Stream conglomerate and alluvium.	Alluvium.	Alluvium.	Alluvium.	Alluvium.
		Pleistocene.	San Pedro. —Unc.— —Unc.—	Stream deposits, valley fillings, and raised beach. —Unconformity—	Terrace deposits and dune sand. —Unconformity—	Terrace deposits, sand, and gravel. —Unconformity—	Terrace deposits, sand, and gravel. —Unconformity—	Terrace deposits, sand, and gravel. —Unconformity—
	Tertiary.	Pliocene.	Merced. San Diego.	Tulare. —Unconformity—				Merced. Santa Clara.
		Miocene.	San Pablo. —Unconformity (?)— Santa Margarita. —Unconformity— Monterey. —Unconformity— Vaqueros. —Unconformity—	Etchegoin. —Unconformity— Jacalitos. —Unconformity— Santa Margarita(?). —Unconformity— Lacking (with possible exception of a small part). Vaqueros. —Unconformity—	Fernando. —Unconformity— Monterey. Vaqueros.	Fernando. —Unconformity— Modelo. Shale. Upper sandstone. Shale. Lower sandstone. Vaqueros.	Fernando. —Unconformity— Puente. Upper shale. Sandstone. Lower shale.	Purisima. Santa Margarita. —Unconformity— Monterey. —Unconformity— Vaqueros.
		Oligocene.	San Lorenzo. —Unconformity (?)—	Wanting (?)	Sespe and Tejon undifferentiated.	Sespe. Upper beds. Red beds. Lower beds. Topatopa.		San Lorenzo. —Unconformity(?)— Undifferentiated Eocene, probably Martinez.
		Eocene.	Tejon. Martinez. —Unconformity—	Tejon. —Unconformity—				—Unconformity (?)—
Mesozoic.	Cretaceous.		Chico. —Unconformity— Horsetown. —Unconformity— Knoxville. —Unconformity—	Chico. Knoxville. —Unconformity—	(?) Knoxville. —Unconformity—			Chico. Knoxville. —Unconformity—
	Jurassic (?).		Franciscan. —Unconformity— Granitic rocks, schist, etc. —Unconformity—	Franciscan.	Franciscan.	—Unconformity— Granitic rocks, gneiss, etc.	—Unconformity— Granitic rocks, gneiss, etc. —Unconformity—	Franciscan. —Unconformity— Granitic rocks. —Unconformity—
	(?)		Schist; limestone.				Black schist.	Schist; limestone.

J–K 11. NEVADA, OREGON, AND IDAHO.

The Miocene and Pliocene sediments of Nevada and adjacent parts of Oregon and Idaho have been described by King under the names Truckee and Humboldt, respectively, and Cope has applied the name Idaho formation to certain Pliocene deposits. King [505g] postulates an extensive lake (Pah-Ute Lake) and says:

The beds of this lake, to which, in the Fortieth Parallel area, I have given the name of Truckee Miocene, are made up of, first, detrital rocks and gritty sandstones, with more or less conglomerate, never over 150 feet. Over this lie about 250 feet of palagonite tuff, which, for reasons already described, is referred to the age of the augite andesites; over this, 250 to 300 feet in Nevada, with a greater thickness in Oregon, of infusorial silica, followed by 120 feet of sandy, gritty rocks, purely detrital, but containing always a considerable amount of infusorial silica, succeeded by a fresh-water limestone of about 60 feet, in its turn succeeded upward by 250 feet more of detrital grits, which give way to an enormous formation of volcanic tuffs of the trachytic period. The thickness of these trachyte muds in Nevada can not be less than 2,000 or 3,000 feet; in Oregon, according to the observation of Prof. Marsh, they are even more fully developed. It is in these volcanic muds that the enormously abundant Miocene fauna of this lake is mostly entombed. Out of the grits overlying the limestone in Nevada have been obtained teeth of a rhinoceros, probably *R. pacificus*.

At the close of the Miocene, according to King, the Truckee strata "were thrown into bold folds, their dips reaching angles of 30°." Louderback [547a] recognizes "a certain amount of deformation in later Tertiary."

Ball [54a] gives an account of the relations of igneous rocks and lake beds in southwestern Nevada and eastern California, from which the following partial columnar section and extracts are taken:

Columnar section [in part] of rocks of southwestern Nevada and eastern California.

Quaternary.	Pleistocene and Recent.	Older alluvium, with Pliocene lake beds at base.
Tertiary.	Pliocene.	Rhyolite. ——Unconformity—— Siebert lake beds, with rhyolite and basalt flows.
	Pliocene. Miocene.	Rhyolite. ——Unconformity—— Basic andesite.
	Miocene.	Second rhyolite, with minor basalt flows.
	Eocene.	Monzonite porphyry and acid andesite. ——Unconformity—— First rhyolite. ——Unconformity——
Carboniferous.	Pennsylvanian.	

The Tertiary rocks include a number of igneous rocks, lava flows, and fewer intrusive masses, and sediments laid down in lakes. * * *

The oldest of the Tertiary rocks is a rhyolite which occurs in Stonewall Mountain. This occupies a similar stratigraphic position with rhyolites in the Panamint Range, in the Randsburg district, and near Daggett in the Mohave Desert, which, according to Spurr, lie beneath "lake beds which are probably, in part at least, Upper Eocene." This rhyolite in Stonewall Mountain is cut by dikes of quartz monzonite porphyry and quartz syenite, which are probably contemporaneous with monzonite porphyry, quartz monzonite porphyry, hornblende-biotite latite, and biotite andesite of other ranges. These rocks are in part intrusive masses and in part flows. Prior to the succeeding extrusion of rhyolite these rocks * * * were eroded, unconformities being observed in the Kawich, Amargosa, and Cactus ranges, in the Bullfrog Hills, and in Shoshone and Skull mountains. Then followed an extrusion of rhyolite, with minor siliceous latites and dacites, which was attended by insignificant basalt flows. This period of extrusion of rhyolitic lavas, the most important in this portion of the Great Basin, was not, however, strictly contemporaneous over the whole area. * * * This rhyolite is everywhere separated from the Siebert lake beds by a marked erosional unconformity, and in the Kawich and possibly in the Cactus Range it is separated by an erosional unconformity from the succeeding andesites. The next younger igneous rocks * * * are basic andesites. These two rocks were found in contact only in the area covered by the Goldfield special map, and here Mr. F. L. Ransome found dacites intrusive into the andesites. The succeeding igneous rocks are rhyolites and siliceous latites and dacites which occur only in the Goldfield and Southern Klondike hills and the Silver Peak Range. In the latter two localities at least these rocks are interbedded with the Siebert lake beds without erosional unconformity.

Thick masses of sediment occur in the majority of the ranges of the area and on lithologic and stratigraphic grounds are correlated with the Siebert lake beds of Miocene age at Tonopah described by Spurr. These tuffaceous sandstones and conglomerates, largely composed of rhyolitic material, reach an observed maximum thickness (in the Amargosa Range) of 1,150 feet. * * *

The succession of the lavas of the Great Basin has recently been treated at length by Spurr.[a] His succession for the petrographic province of the Great Basin and that of the writer for the portion of that province here treated are practically identical. Both assign the first rhyolite to the end of Cretaceous and to Eocene time. It is believed, however, from the length of time indicated by the complex history of extrusion and erosion intervening between this rhyolite and the deposition of the Siebert lake beds, that the monzonites and acidic andesites may well also be in part Eocene, while the second rhyolite is believed to be largely of early Miocene age. The andesite and dacite are also of comparatively early Miocene age, while the third rhyolite covers the middle and late Miocene and early Pliocene. The basalts range in age from late Miocene to Pleistocene, the major extrusions occurring in late Pliocene and Pleistocene time. As to the genetic relations of the magmas, the writer is wholly in accord with the views of Spurr in the article already cited. He believes that the Tertiary lavas of the Great Basin are the representatives of two complete cycles of the differentiation of a magma of medium composition into acidic and basic lavas and that probably the end of a still earlier cycle is also represented.

K 10. NORTHERN CALIFORNIA.

Miocene and Pliocene deposits occur in the old valleys of upper Sacramento and Trinity rivers, on the southeastern slope of the Klamath Mountains and west of Lassen Peak. They comprise auriferous gravels, fresh-water sediments with some coal, allied to the Ione formation, and tuffs. These deposits have been described by Diller,[272, 276a] Anderson,[28] and Hershey.[436]

K 11-12. NEVADA, UTAH, AND IDAHO.

Only the later Tertiary (Pliocene) is represented in the northern and eastern parts of the Great Basin. King [505f] states:

Along the western base of the Wasatch a portion of the terrace country, rising to 700 or 800 feet above the level of the lake, is composed of loose, friable Tertiaries, carrying very

[a] Spurr, J. E., Jour. Geology, vol. 8, 1900, pp. 621-646.

recent fresh-water mollusks, the genera at least being chiefly the equivalents of existing types. These beds along the western base of the Wasatch are approximately horizontal. Three considerable depressions east of the main ridge of the Wasatch—Morgan, Cache, and Ogden valleys—which unquestionably represent bays formerly connected with the main Pliocene lake west of the Wasatch, have been receptacles of Pliocene sediments very similar to the fragments of horizontal Pliocene terraces on the west base of the Wasatch. They are all characterized by recent genera of fresh-water mollusks. The height of the Tertiary in all these valleys reaches a full thousand feet above the level of Salt Lake.

With the exception of terrace masses along the western base of the Wasatch, which for the most part are deeply covered by Quaternary deposits, the valley of Salt Lake carries a sheet of Quaternary, through which rise masses of Paleozoic and volcanic rocks. The northern boundary of this great basin is beyond the limits of our map but has been crossed by us in several places, and the members of the exploration have been unanimous in referring to the Pliocene period a considerable series of horizontal rocks which occupy a divide between the waters of the Utah Basin and those of Snake Valley. These rocks are composed chiefly of friable gray, white, and drab sandstones and marly limestones, for the most part horizontal but in places uplifted at low angles. At the northwest boundary of the Salt Lake Basin, near the one hundred and fourteenth meridian, at latitude 40°, are further exposures of horizontal Pliocene rocks, which rise to altitudes of 1,000 to 1,800 feet above the level of the basin.

K 13-14. NORTHERN GREAT PLAINS, WYOMING, NEBRASKA, AND SOUTH DAKOTA.

The lower Miocene of the northern Great Plains in the United States is the Arikaree formation, including locally the sediments to which the names Gering, Monroe Creek, and Harrison have been applied.[623k] The Arikaree rests on the Brule clay (Oligocene), in some places unconformably, and is unconformably overlain by the later Miocene Ogalalla formation.

Darton[234, 235] originally described the Gering as a distinct formation, rather than as part of the Arikaree. The deposit is locally developed and consists of coarse sands and soft sandstones which contrast with the finer sediments of the Arikaree. It is now[238c] interpreted as a river deposit laid down in the channels of early and possibly somewhat later Miocene streams. Osborn[623l] says:

The typical Gering formation of Darton, 1899, is at Scotts Bluff, western Nebraska; the broad extension by Darton of this formation to other localities is somewhat doubtful. The name Gering formation as used by Darton, Hatcher, and Peterson probably applies to noncontinuous river sandstones and conglomerates (maximum 200 feet), which are in a manner analogous to the "Titanotherium," "Metamynodon," and "Protoceras sandstones" that traverse the lower Arikaree clays or finer beds and partly erode irregular channels in the upper Brule clay (Leptauchenia zone). This formation is thus probably of the same age as the lower parts of the Arikaree, Monroe Creek, and Rosebud. Its known fauna is very limited. The so-called Gering of Hatcher and Peterson is in southeastern Wyoming and northwestern Nebraska; in their section it is said to be lithologically similar to the overlying Monroe Creek.

The typical Arikaree formation of Darton, 1899, is at Pine Ridge Bluffs, in South Dakota; whether or not this extends to southeastern Wyoming rests on future paleontological correlation. The Arikaree as described and mapped by Darton would broadly include the whole of the Rosebud formation of Matthew, as well as the Monroe Creek and Harrison, and broadly cover the whole of the Miocene. The entire Arikaree formation of Darton consists of finer materials, whitish or light-buff sandstones, more continuous and widespread, lying either on the Gering formation or on the Brule clay.

Approximate correlations of the Arikaree formation.

	Westerly section, southeastern Wyoming and northwestern Nebraska. Hatcher, 1902; Peterson, 1906.	Feet.	Easterly section, South Dakota, Porcupine Creek. Matthew, Gidley, 1904; Matthew, Thomson, 1906.	Feet.
Upper division	Upper part of Harrison	200	Upper part of Rosebud	[a] 250
Lower division	Lower part of Harrison	200	Lower part of Rosebud	[a] 250
	Upper part of Monroe Creek	300		
	Lower part of Monroe Creek (Gering of Hatcher and Peterson)	200		
	Upper part of Brule clay, or Leptauchenia zone	150	Upper part of Brule clay, or Leptauchenia zone.	

[a] Estimated.

Darton[238d] described the Arikaree and Ogalalla as follows:

A large portion of the higher lands of western Nebraska and southeast Wyoming extending south from Pine Ridge is capped by sands and soft sandstones which have been designated the "Arikaree formation." It is the principal component of the series formerly termed "Loup Fork." Generally it lies unconformably on the Brule clay but overlaps the margins of that formation in some portions of the area. It attains a thickness of over 800 feet in southeast Wyoming and, judging from the occurrence of outliers, formerly extended far up the slopes of the mountains to the north and west.

The predominant material is sand loosely cemented into a soft sandstone. The colors vary from white to light gray. Characteristic, partly calcareous concretions occur throughout the formation and greatly predominate in its lower members. They are mostly of elongate cylindrical form, usually occurring in layers connected to a greater or less extent into irregular sheets. * * * From observations by Profs. Barbour and Fisher it has been found that these concretions are due to the growth of calcite crystals in certain portions and layers of the sandstone.

* * * * * * * * *

In studying the geology of North Platte Valley in west Nebraska it was discovered that the Arikaree deposits were overlain unconformably by deposits of sand, gravel, and calcareous grits, which, on being traced south, were found to be the north extension of the Tertiary grit and mortar beds of the Kansas and east Colorado region. They were given the local designation Ogalalla formation.

* * * * * * * * *

The materials of the Ogalalla formation are mainly sands, merging into gravels, and gravelly sands more or less cemented by carbonate of lime into a grit rock which often has the appearance of rough mortar, from which the name "mortar beds" is derived. Sometimes the lime rock contains but little sand, and usually it varies from grit to conglomerate or conglomeratic grit.

The original descriptions of the Monroe Creek and Harrison are by Hatcher,[413] as follows:

Returning to the Arikaree formation, I have already remarked that in Sioux County, Nebr., and Converse County, Wyo., it is lithologically and faunally divisible into two easily distinguishable horizons. Commencing below, these may be named and characterized as follows:

1. *The Monroe Creek beds.*—These are well shown in the northern face of Pine Ridge, at the mouth of the Monroe Creek canyon, 5 miles north of Harrison, Nebr., where they overlie the Gering sandstones and are composed of some 300 feet of very light-colored, fine-grained, not very hard, but firm and massive sandstones. On account of their usually barren nature they have been neglected by collectors, and very little is known concerning their fauna beyond the fact that toward the top they contain Promerycochœrus. They decrease in thickness very rapidly to the eastward and increase to the westward.

2. *The Harrison beds.*—These are well shown in the bluffs of all the small streams that head near the summit of Pine Ridge, in the vicinity of Harrison, Nebr. They are also known to cover a considerable area to the east, west, and south of that village, extending well into the State of Wyoming. They are composed of about 200 feet of fine-grained, rather incoherent sandstones, permeated by great numbers of siliceous tubes arranged vertically rather than horizontally. They are further characterized by the presence, often in the greatest abundance, of those peculiar and interesting but as yet not well understood fossils known as Dæmonelix, and by a considerable variety of fossil mammals belonging to characteristic Miocene genera. They immediately and conformably overlie the Monroe Creek beds and pass insensibly into them.

Osborn [623m] distinguished the upper Miocene, comprising the Procamelus zone, and the "latest Miocene or first phase of the Pliocene," the Peraceras zone. He gave an extended homotaxis and synonymy.

K 18. LONG ISLAND.

Veatch [837b] mentions a possible occurrence of Miocene strata on Long Island as follows:

In the Long Island region and in the New Jersey region the Miocene sediments were deposited under similar conditions, and as these two areas have been subjected to the same forces, except glacial action, their distribution in both should be similar. The only bed thus far seen on Long Island which is regarded as possibly Miocene is a thin bed of "fluffy sand" which Mr. G. N. Knapp recognized in the upper part of the Melville section, and which is the counterpart of certain sands occurring in the Miocene of New Jersey. A comparison of the sections indicates that if this structure is normal, and there is every reason to believe it is, a Miocene outlier should be expected at this point. The same evidence shows the absence of the Miocene above sea level on southern Long Island, except possibly along a portion of the South Fluke. This line of argument is important, for it shows that the Tertiary deposits can not be expected on the north shore any more than in the Hightstown Vale in New Jersey, and that the occurrences on Long Island are probably limited to erosion outliers, with the embed beneath the Atlantic.

K 19. MARTHAS VINEYARD AND NANTUCKET.

Dall [209a] carefully examined the meager occurrences (too small to appear on the map) of Miocene strata on the islands of Marthas Vineyard and Nantucket and the collections which had been made from them and reported lists of species upon which he comments as follows:

It will be observed that this is a distinctly northern assemblage; any of the species might be at home in the waters about Gay Head to-day, as far as we can judge by analogy in the case of extinct species.

As regards correlation with the divisions of the southern Miocene it may be said (1) that the Gay Head Miocene is Chesapeake and not older; and (2) that it belongs in all probability to the upper part of the Chesapeake, certainly not lower than the St. Marys fauna, and probably between that and the Yorktown beds.

For a description of the strata see Chapter XV (pp. 682–683).

In regard to the Pliocene, Dall says that a small collection of shells (for list see the work cited) taken from a "layer of sand unconformably overlying the Miocene" appears to belong to a "more recent fauna than the Miocene and may perhaps be regarded as Pliocene."

K-L 11. SNAKE RIVER BASIN, OREGON AND IDAHO.

The Payette formation of the Snake River valley is described by Lindgren[537] as follows:

During the earlier part of the Neocene (Miocene) a large fresh-water lake occupied at least the lower part of the Snake River valley, and its sediments are now prominent features of the region. For these lake beds the name Payette formation is proposed, and their age is determined as upper Miocene.

* * * * * * * * *

It extends over large areas to the north of the Payette, along the flood plains of the Snake River, and is seen to occupy vast areas in Oregon between the mouth of the Owyhee River and Weiser, where the Snake River canyon begins. On both sides of the lower Snake River the bluffs of the Payette formation attain a height of over 800 feet. In the Payette Valley south of Emmett the sharply defined bluff of Payette beds rises 600 feet above the alluvium. Smaller masses, detached by erosion or uplifts, lie in the intermontane valleys, as far east as the Idaho Basin.

Along the Boise Mountains the Payette beds rest against the irregularly eroded and sharply sloping surface of the granite, and the top stratum attains a height of 4,100 feet. A total thickness of 1,000 feet is exposed near Boise, and wells bored show several hundred feet of similar strata below the surface. Over the larger part of its extent the formation lies nearly horizontal or dips only a few degrees. Near the mountains dips of 8° to 10°, generally westward, are noted, and the smaller detached masses in the intermontane valleys are still more disturbed, generally dipping westward at angles up to 50°.

* * * * * * * * *

As might be expected from the character of the land mass from which the sediments were obtained, the latter consist chiefly of granitic, light-colored sands, locally cemented by hot-spring deposits to hard sandstones or clayey semiconsolidated sandstones. Heavy masses of conglomerates and gravels begin to appear at Table Mountain and reach their greatest development opposite the mouth of Boise River, in the high ridge extending in a westerly direction. Purely clayey deposits are rarer, occurring only in convenient sheltered locations near the shore line or in places where volcanic eruptions took place. The basal part of the formation contains, at Horseshoe Bend, Jerusalem, and other localities along the Payette, small coal seams. In the clay accompanying these coal seams vegetable remains are of frequent occurrence. The following forms were identified by Prof. Knowlton:

Sequoia angustifolia? Lx.
Quercus consimilis Newb.
Quercus simplex Newb.
Acer trilobatum productum? Heer.
Salix angusta Al. Br.
Platanus aspira? Newb.
Ficus ungeri Lx.
Ulmus speciosa Newb.
Betula angustifolia Newb.

* * * * * * * * *

From these data Prof. Knowlton draws the conclusion that the age is Upper Miocene, contemporaneous with the flora of the auriferous gravels and the Ione formation of California, the Lamar flora of the Yellowstone National Park, and the John Day formation of Oregon. The paleobotanical evidence confirms the conclusion, confidently drawn from the field work, that all these smaller detached masses of lake beds are of practically the same age.

During the time of the maximum extension of the Payette Lake its surface stood at the present elevation of 4,200 feet. Its deposits, over 1,000 feet thick near the shore, rested against the abrupt slope of the Boise Mountains and filled the old canyon of the Boise to the same depth. The canyon must have formed a fiord, the branches of which reached as far back as the Idaho Basin, and in which vast quantities of gravel and sand accumulated. Isolated occurrences of well-washed gravel on the summit of high ridges in the lower Moore Creek drainage, at elevations of 4,500 feet, confirm the above conclusions. The data are not at present sufficient to determine the extent of the Payette Lake, though it is probable that it was confined to the Snake River valley, inclosed on the west by the Blue Mountains and on the east by the divide toward the Salmon River.

In a subsequent study Lindgren extended the observations on the Payette (Eocene?) and overlying Idaho (Pliocene) formation in the Snake Canyon region. Details of occurrence and notes on the fauna by Dall and flora by Knowlton are given in his report.[539]

Russell [686] gives the following sketch of the Payette formation in Oregon:

The Payette formation, which consists principally of unconsolidated sands, clays, gravel, etc., together with important beds of light-colored and frequently white volcanic dust, and which is widely exposed in southwest Idaho, extends westward into Malheur County, Oreg., where it forms a large portion of the surface. This formation was crossed during my reconnaissance in 1902 and again in 1903, but its entire extent in Malheur County can not as yet be stated. It occupies the Snake River valley, from near Owyhee northward beyond Ontario, and extends westward to a locality about 30 miles southwest of Vale. Similar beds occur also along the courses of Jordan and Succor creeks and in several other valleys. As exploration progresses it will probably be found that many of the valleys of Malheur County are floored to a depth of several hundred feet with soft unconsolidated deposits like those of the Payette formation and probably of the same or of approximately the same age. Whether all of these deposits are portions of one continuous formation, or were laid down in separate and contiguous basins, is not as yet determined. It is probable, however, that they were accumulated in much the same manner that beds of like character are now being spread out on the surface of the valleys of the same region by existing streams. In most of the sediments referred to as being analogous to the Payette formation, however, volcanic dust added materially to the depth of the deposits.

L 10. COAST RANGE OF OREGON.

Diller [273a] says:

The Miocene is widely distributed in western Oregon on both sides of the Coast Range. It occurs over a large part of the Willamette Valley * * * and on the coast more or less continuously from Astoria to Coos Bay, and most likely beyond, with interruptions, to California.

Descriptions of local observations and identifications of fossils by Dall follow this general statement. A type section of the Miocene is exposed near Empire City, Oreg., from which the Empire formation takes its name. Diller [275] states that the Empire formation consists chiefly of sandstones and dark shales below with white shales above, in all not more than 500 feet thick at the type locality.

Dall [211] classifies the Empire formation in relation to the Astoria group as follows:

Empire beds.—From typical exposures near Empire City, Coos Bay, Oregon. * * * These beds are well exposed between Pigeon Point and Fossil Point, 3 miles southwest of Empire City, and abut unconformably upon the Oligocene beds at Coos Head and the Eocene at Marshfield, in the same region. At Fossil Point they are overlain by the richly fossiliferous Pleistocene beds of the Coos conglomerate. So far as can be judged from the fauna collected, the Empire beds are the exact equivalent of the upper part of the Miocene beds at Astoria, called by Dall, in 1892, the Astoria sandstones, to distinguish them from the (Oligocene?) Astoria shales (formerly called Miocene), which conformably underlie them. The exact place of the Astoria shales in the column must await a better knowledge of the fauna. If the double use of the name

Astoria in this manner is regarded as objectionable, the name Empire beds might be taken for the sandstones.

Dall[213] has made an elaborate report on the fauna, with a discussion of the stratigraphy and the history of investigation of the Empire formation, particularly at Astoria.

L 10. CASCADE RANGE AND YAKIMA VALLEY, WASHINGTON.

The Miocene of the Cascade Range and Yakima Valley includes both sedimentary and igneous rocks, but the sediments consist largely of volcanic material. In order of age from older to younger the formations are the Taneum andesite, Yakima basalt, Guye formation (probably contemporaneous with the basalts), Keechelus andesitic series and Ellensburg formation. The following notes are condensed from the accounts by George Otis Smith:[755, 758]

The Guye formation consists of dark shale and gray sandstone, with some chert and limestone. It is interbedded with basalts and rhyolites. The formation is represented in a very small area near Snoqualmie Pass, in the Cascade Range, where it is sharply folded and has been intruded by granodiorite. The black shale contains *Platanus dissecta* Lesq., *Acer æquidentatum* Lesq., Ficus n. sp. cf. *F. artocarpoides* Lesq., and Cinnamomum n. sp., which are assigned by Knowlton to the Miocene.

The Ellensburg formation occurs extensively in the Yakima Valley. It is composed largely of volcanic sediments, occasionally but rarely containing pebbles of the underlying basalt. The greater part of the conglomerate bed is composed of pebbles of light-gray and purple hornblende andesite and of white pumice of the same composition, while the sandstones and shales consist of finely comminuted andesitic material. The composition of the conglomerate beds and the prevalence of stream bedding indicate that the formation is of fluviatile rather than lacustrine origin. The original thickness can not be stated. Individual sections show 1,200 to 1,600 feet in localities where it is evident that the upper part has been removed. The Ellensburg formation carries a flora in which 15 specimens have been identified. Of these 12 or 13 are reported by Knowlton as occurring also in the Mascall beds of the John Day Basin, which are regarded as being upper Miocene.

L 10-11. JOHN DAY BASIN, OREGON, AND COLUMBIA PLATEAU.

Merriam[590c] describes the strata of the John Day Basin as follows:

Resting upon the Clarno formation and extending over the greater portion of the John Day Basin is a thick series of sediments which Marsh[a] called the deposits of the "John Day Lake." It has generally been referred to in geological and paleontological literature as the John Day beds. King[b] correlates this series with his Truckee beds as a part of the deposit of his Pah Ute Lake. In the statement regarding this correlation, King has, however, recognized Marsh's name, so that, if a correlation is attempted, Pah Ute should be displaced by John Day.

Nearly the whole of the John Day formation consists of ashy or tuffaceous materials. Only toward the top of the section do we find typical products of erosion. At Haystack, Spray, and in the lower end of Turtle Cove, good exposures show the highest portion of the series to be composed of 100 or 200 feet of hard, blocky tuff, below which is about the same thickness of sand and gravel. The gravels are in some places quite coarse, containing pebbles 4 or 5 inches in diameter. The sands sometimes show cross-bedding. Included in these deposits are worn

[a] Marsh, O. C., Am. Jour. Sci., 2d ser., vol. 9, 1875, p. 52.
[b] King, Clarence, U. S. Geol. Expl. 40th Par., vol. 1, p. 458.

fragments of bones and teeth, which probably represent forms similar to those in the beds immediately below.

Rhyolite flows are found toward the lower part of the Middle John Day at Bridge Creek, near the top of this division in Turtle Cove, and overlying what is probably Middle John Day on Pine Creek, about 3 miles northwest of Spanish Gulch.

The tuffs and ashes seem in some cases to have been worked over somewhat by air or water. At other points beds many feet thick have apparently been deposited directly, without much if any working over by either wind or water.

The source of the ash and tuff is as yet unknown. It probably came from vents not very distant from this basin of deposition.

Excepting the beds of sand and gravel near the top of the section, the stratification throughout the whole thickness of the John Day is very regular. Numerous beds of almost pure ash or tuff compose uniform, hard, and prominent layers, between which in the softer beds the regular deposition of thin layers is plainly indicated by delicate variations in color. Nodular layers, possibly produced in part by contained organic remains, are not infrequent in some localities, and small nodules are usually scattered through a large part of the Middle John Day.

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Without having accurately measured the John Day section, the writer would not be willing to consider the exposures north of the southern range of mountains as representing a thickness much greater than 2,000 feet. Perhaps it is not more than 1,500 feet thick. At Sheep Rock, near Picture Gorge, the whole section is shown rather sharply tilted, and all but the lower division would be included in the column between the cap rock and the level of the river. At Bridge Creek, also, the section includes the whole of the series. It may reach a thickness somewhat over 2,000 feet at that locality.

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Wherever the John Day is well exposed in the central and western portion of the basin, it seems to be divisible into three stages, which have been designated[a] the Lower, Middle, and Upper John Day.

The lower division consists usually of highly colored shale, which breaks down readily, forming characteristic mud-covered domes. These beds are in the main a deep red, with occasional alternating strata of buff or white ash. At Bridge Creek alternating beds of red, white, and green, occurring in a group of the typical hills of this division, form a striking feature of the landscape, the colored strata making sharply defined rings about the hills. At Clarno's Ferry numerous alternations of contorted and faulted red and white beds are splendidly exposed in prominent hills at the bottom of the section.

The beds of this group appear usually to show more deformation than those higher up in the series. This may be due in part to their being softer and having offered less resistance to disturbances than the more rigid strata above them.

The Lower John Day is almost barren of fossil remains at all points where it was visited and has never, so far as can be discovered, furnished many good specimens. Diligent search by the writer at several localities has been rewarded by the discovery of two or three fragments of rhinoceros teeth. An Oreodon skull was found at this horizon, many years ago, by Mr. L. S. Davis, but definite information regarding it is not now obtainable.

The lower division was estimated to be 250 to 300 feet thick at Clarno's Ferry. Its maximum thickness will probably exceed that limit. It is not impossible that the Lower John Day will some time be found to be separated by an unconformity from the middle division. Such fossil remains as have so far been found in it indicate, however, that it belongs to the John Day series.

The middle portion of the John Day section at Bridge Creek, Clarno's Ferry, and Turtle Cove consists of drab to bluish-green beds, sometimes forming rounded hills but more frequently

[a] Merriam, J. C., Science, new ser., vol. 11, Feb., 1900, p. 219.

exposed as steep, pinnacled, and ribbed bluffs. Nodular layers and thick beds with small nodules scattered through them are common in this group, while they are rare, if not entirely absent, in the lower division and are not common in the uppermost beds. The strata of this group are never so sharply contorted as those of the lower division, though they may stand at a fairly high angle and may show considerable faulting.

This stage has probably furnished more fossil remains than the upper division, partly because the remains are here frequently found in hard nodules, which have protected the bones and held them together.

At Bridge Creek a rhyolite flow is interbedded with the lower part of the Middle John Day or possibly separates it from the lower division. In Turtle Cove a similar flow is found at the top of this division and possibly separates it from the upper group. At many places, particularly in Turtle Cove, hard beds of white to greenish ash and tuff are intercalated between the softer and usually more fossiliferous strata.

The middle division is at least 500 feet thick in Turtle Cove and possibly as much as 800 to 1,000 feet at Bridge Creek.

At most John Day localities, including Bridge Creek, Turtle Cove, and the entire region of the North Fork, the uppermost beds in the section are buff tuffaceous or ashy deposits, sometimes with sand and gravels near the top. These beds show a thickness of at least 300 to 400 feet and perhaps much more in some localities.

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This division contains the only typical sands and gravels in the John Day, and the only known remains of fresh-water Mollusca occur here. Excepting a single leaf, the only plant remains known to occur in the series are in the upper division.

While it has not been possible for the writer to draw sharp lines between the divisions discussed, the lithologic characters are in general sufficiently well marked so that one is enabled to determine the horizon in the series to which beds in question belong.

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The John Day beds are usually slightly disturbed. They are generally tilted 5° to 10°. From the observations made by the writer, no definite system of folds could be made out, though there seem to be several which trend east and west. Faulting is not uncommon and in some places there has been much friction along the fault planes, so that the soft beds have been changed into hard slate bands several inches in thickness. Both the normal and reverse types of faults are represented. Toward the west end of Haystack Valley a break of unknown extent brings what are probably Middle John Day strata up to the level of the highest beds of the series. At another locality, some miles east of this point, numerous thrusts are beautifully shown in cliff sections. Along the North Fork two systems of fractures were noticed. One trends north and south and the other appears to cross it at nearly a right angle.

As has already been indicated, the series is evidently unconformable upon the Clarno.

In the whole of the region occupied by John Day north of the southern range of the Blue Mountains, it is covered by the Columbian lavas, being accessible only in the deep canyons, where it has been exposed by extensive stream corrasion. At every locality in the basin where the series can be seen, its relations to the overlying formations are beautifully shown. In several places, notably at Sheep Rock in the upper end of Turtle Cove, and on the main river below Spray, residual hills in the middle of the valley are capped by portions of the lower flows, which have served to protect the softer beds beneath.

The Columbia lavas are in some places seen to be decidedly nonconformable to the John Day. Near Haystack the fossil beds form a fairly sharp anticline below lavas which are almost horizontal. At Clarno's Ferry lava flows are seen at one locality to rest upon the middle beds, the typical upper divisions being absent.

The strata thus described are tabulated by Merriam and Sinclair [591] as follows:

Stratigraphic succession of the Cenozoic formations in the John Day Basin.

Age.		Section in the John Day Basin.		Correlatives.
Quaternary.		Terrace deposits with Equus and Elephas remains.		Later half of Quaternary.
		Erosion interval (tilting of the Rattlesnake and erosion of John Day Canyon).		Sierran (?).
Pliocene.		Rattlesnake formation (tuffs, gravels, ashy soil, and rhyolitic lavas).		Not determined.
		Unconformity (tilting and erosion of the Mascall).		
Miocene.	Later Miocene.	Mascall formation (tuffs, ashes, and possible gravels).		Pawnee Creek beds, Colorado; Deep River beds, Montana; Ellensburg formation, Washington.[a]
	Earlier Miocene.	Columbia lava (basalt and interstratified basaltic tuffs).		Yakima basalt, Ellensburg quadrangle, Washington. Harrison formation. Monroe Creek formation. Rosebud formation.
		Unconformity. Slight folding of the John Day. Interval of erosion.		
Oligocene.		John Day series.	Upper John Day (mainly buff-tinted tuffs; sands and gravels near top).	
			Middle John Day (drab and bluish-green tuffs).	
			Lower John Day (red, white, and green tuffaceous shales).	
Unconformity				
Eocene.		Clarno formation (shales, tuffs, andesitic and rhyolitic lavas). The Clarno has yielded an abundant flora, but no vertebrate remains have yet been found.	Upper Clarno beds (upper Eocene).	Payette formation, Idaho.[b] Manastash formation, Washington.[c]
			Lower Clarno beds (lower Eocene).	
Unconformity				
Cretaceous (marine).		Chico formation (sandstones and conglomerates).		Basal Chico at Texas Springs and near Horsetown, Cal.; Phoenix beds at '49 mines, Oregon.[d]

[a] Knowlton, F. H., Fossil flora of the John Day Basin: Bull. U. S. Geol. Survey No. 204, 1902, pp. 109–110.
[b] Idem, pp. 110–111.
[c] Smith, G. O., Prof. Paper U. S. Geol. Survey No. 19, p. 16.
[d] Stanton, T. W., note in Bull. Dept. Geology Univ. California, vol. 2, p. 294.

Osborn [623j] gives the following résumé of the Oregon Tertiary as a whole:

The known mammal fauna of Oregon, as determined partly by Cope and Wortman and more precisely as to levels by Merriam and Sinclair, is found on five levels, partly separated by volcanic overflows, as follows:

Rattlesnake	=upper Miocene	=Procamelus zone.
Mascall	=middle Miocene	=Merychippus zone.
Upper part of John Day	=transition, upper Oligocene, lower Miocene	=Promerycochœrus zone.
Middle (fossils numerous) and (?) lower parts of John Day.	=upper Oligocene, second phase	=Diseratherium zone.

The time of the beginning of the John Day deposition appears to correspond with that of the close of the Leptauchenia zone in the South Dakota region, namely, the upper Oligocene.

* * * * * * * * *

The volcanic materials of the John Day were chiefly wind blown, as described by Merriam;[a] there is little evidence of fluviatile conditions. The Mollusca are terrestrial or air breathing, with the exception of one locality which contains fluviatile Mollusca. The Testudinata, genus Stylemys, are of the Testudo or terrestrial type; no fluviatile types have been recorded. The so-called beavers (Castoridæ) are not the true river-living beavers (Peterson).

The known fauna of the John Day formation as a whole is chiefly of open-forest and savanna-living type. We note the entire disappearance of the ancient fauna, Creodonta-Hyænodontidæ, and do not observe the introduction or invasion from Eurasia of any new families of mammals. The major part of the John Day fauna is of upper Oligocene age, but in its latest phases it is perhaps transitional to lower Miocene. The fauna is thus broadly transitional between that of the White River group and the Arikaree formation.

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The lower John Day fauna is so little known that no deductions can be made from it, except that it appears to be closely related to that of the middle John Day. The faunistic comparison of the John Day formation therefore begins with the middle John Day, which is highly fossiliferous and slightly more advanced than that of the upper portion of the Brule clay and "Protoceras sandstones."

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The conclusion is that the middle John Day deposition partly overlaps and is partly sequent to the deposition of the upper part of the Brule clay and the "Protoceras sandstones."

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The upper part of the John Day formation, or Promerycochœrus zone, of the Mountain region of Oregon, as well as the Gering and Monroe Creek formation of Hatcher, the Gering or lower Arikaree of Darton, the Rosebud of Matthew, all in the plains region of South Dakota, may be regarded as covering the transition between the Oligocene and Miocene epochs, as these divisions are employed in France. They resemble chiefly the upper Oligocene of France.

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It is concluded that the upper part of the John Day, for the present, may be somewhat arbitrarily separated as the American upper Oligocene, while the partly contemporaneous and partly sequent plains formations may be termed lower Miocene.

The Columbia River basalt (Miocene) is the dominant formation of the Columbia Plateau. Overlying it in Washington are the strata described by Russell[684, 685] as lake beds and assigned by him to the John Day formation, but apparently of later age. Russell states in his later report:[685]

In my report of a reconnaissance in central Washington certain lacustral deposits are described which rest on the surface of the latest extensive lava flow of the Columbia system. This series of lake sediments consists principally of stratified clays, with thick strata of white volcanic dust, and in certain localities contains beds of coarse conglomerate. It is termed the John Day system, for the reason that it is thought to be an extension of a similar formation which occurs in John Day Valley, Oregon. The connection between these two areas has not been actually traced, however, and the correlation just suggested must be considered as provisional.

Beds of light-colored clay and of white volcanic dust, which have been referred to the John Day system, occur at the White Bluffs of the Columbia, 30 miles above Pasco, and are also well exposed in Naches Valley and near Ellensburg, in Yakima County. At these localities the impressions of the leaves of a large variety of plants and the bones of extinct animals have been obtained. The plant remains indicate that the shores of the ancient lake into which they were

[a] A contribution to the geology of the John Day Basin: Bull. Dept. Geology Univ. California, vol. 2, 1901, pp. 269–314.

blown or washed by tributary streams were clothed in a varied and beautiful flora, resembling, in a general way at least, the vegetation of the South Atlantic and Gulf States at the present day. In the ancient forest and about the shores of the old lake, now known as Lake John Day, a veritable menagerie of strange and in part gigantic beasts found a congenial home.

From the White Bluffs of the Columbia southward to the region described in this report there are no barriers, but the surface of the country rises gradually from the broad valley of the Columbia to the basaltic plateau of northeastern Washington. From studies made along the Columbia in 1892, I was led to the conclusion that Lake John Day extended far eastward and covered nearly all of southeastern Washington, even to the base of the Blue Mountains. This view is now known to have been in part erroneous. The sediments of Lake John Day are but poorly exposed to the east of Pasco and Wallula, and their extent in that direction, although not clearly shown, is certainly far short of the Blue Mountains and of the Idaho boundary. They cover the Eureka Flats, however, as is shown by a well 198 feet deep at Eureka Junction, which is all in strata similar to those exposed in the White Bluffs of the Columbia but does not reach the bottom of the formation. Fossil leaves were found in the rock removed in digging the well, similar to those obtained from other portions of the John Day system. With the exception of the rocks found at Eureka Junction, no exposures of the Lake John Day system have been recognized in the region treated in this report. The sediment of the old lake does not occur above the Columbia lava in the vicinity of Walla Walla, Dayton, and Starbuck, and its eastern shore must have been to the west of these localities.

The lacustral deposits described in the preceding section as being interbedded with the Columbia lava are of about the same age as the John Day system and were accumulated under similar conditions. They should perhaps be included in the same system, but further study is necessary before a conclusion in this connection can be reached.

Knowlton made a report on plants collected by Russell from an outcrop near Ellensburg, later placed in the Ellensburg formation by George Otis Smith. (See p. 826.) Regarding the correlation Knowlton[684a] concluded:

The leaves from near Ellensburg, Wash., are preserved in a moderately soft white chalky matrix, that is in general very similar to the well-known material from the auriferous gravels of California and the John Day Valley in Oregon. * * *

Of the ten species enumerated [for list see the work cited], seven, among which are the species most abundant in specimens and the most positive in identification, have been found in the auriferous gravels of California. Seven of the species have also been reported from the John Day Valley, Oregon, of which number three are common to the auriferous gravels. The new species (*Populus russelli*) has great affinities with Upper Miocene species of Europe.

From this examination it appears that there can be no doubt but that the plants from Ellensburg are similar in age to the auriferous gravels and the John Day Valley. The John Day Valley deposit has always been called Miocene. The auriferous gravels, on the other hand, were regarded by Lesquereux and others as Pliocene, but a recent examination of that flora based on extensive collections from Independence Hill, Placer County, Cal., seems to indicate that they also are probably upper Miocene in age.

L 12. WESTERN MONTANA.

Calkins, in an unpublished manuscript, has the following to say in regard to the Tertiary in the Philipsburg quadrangle, Montana, which applies equally well to adjacent areas of these rocks:

Rocks of Tertiary age apart from the intrusives occupy relatively small areas, chiefly in the valleys. The evidence at hand indicates that all these rocks are strongly unconformable. * * * They lie on various older formations indiscriminately, are not metamorphosed by the intrusions, and are much less deformed than the Cretaceous and older sediments. The quadrangle does not afford the best opportunity to determine the absolute age of the Tertiary formations, nor their relation to one another. * * *

In Philipsburg Valley and Willow Creek valley there are exposures of light-colored silty material shown by microscopic examination to be chiefly volcanic ash. These correspond in character to beds well exposed near New Chicago, north of the quadrangle, in which Douglass has collected vertebrate fossils that indicate a late Miocene age. * * *

The soft, pale-tinted, obscurely stratified volcanic ash beds, presumably of Miocene age, occur (1) at the north boundary of the quadrangle west of Flint Creek, (2) on Willow Creek near the west border of the quadrangle, and (3) in Philipsburg Valley with its southern continuation across the east fork of Rock Creek. These beds are perhaps the least resistant to erosion and the most poorly exposed in the quadrangle, being rarely uncovered except on steep slopes below the brinks of terraces capped by protecting gravel. Among the better exposures are some about 3 miles northwest of Philipsburg, whose whitish tint makes them visible from the town, and another in a gully about 1 mile north of Quinlan's ranch, at the head of Philipsburg Valley.

L-M 10. OLYMPIC PENINSULA, WASHINGTON.

The reconnaissance of the coast of the Olympic Peninsula in 1904 by Arnold [29c] led to the recognition of a formation covering parts of Oligocene and Miocene time, the Clallam formation. Arnold says:

Resting unconformably upon the Eocene and older rocks of the Olympic Peninsula is a series of conglomerates, sandstones, and shales rich in fossils and extensive in occurrence. The formation is well exposed in the region between Clallam Bay and Pillar Point, to the east, and for that reason is here named the Clallam formation. According to Dr. Dall, the fossils of the formation indicate that the basal portion of the series is Oligocene in age, while the upper part is certainly Miocene. Since the separation of the two members will necessarily have to be made on paleontologic grounds and will require a more detailed study of the material in hand than time has yet permitted, the term "Oligocene-Miocene series" will be used temporarily to designate the age of the beds. A portion of the formation is unquestionably the equivalent of the Astoria sandstones and shales occurring at the mouth of the Columbia River, 130 miles farther south.

All of the pre-Pleistocene deposits along Fuca Strait from Freshwater Bay to Cape Flattery, with the exception of the Eocene basalts and tuffs of Crescent Bay and the Pliocene conglomerate and sandstone of the Clallam Bay-Hoko River region, belong to the Oligocene-Miocene series, and at least the greater part and possibly the whole of the thick series of conglomerates, sandstones, and shales exposed in the Cape Flattery promontory, and also the sandstones and shales exposed in the hills south of the Bogochiel River, come under the same head. The thickness of this series as exposed in sections along the strait, which, by the way, virtually parallels the strike of the beds for most of the distance from Freshwater Bay to Neah Bay, is about 3,650 feet. The Waatch-Neah Bay section, which cuts directly across the strike of the great Cape Flattery monocline, exposes approximately 15,000 feet of conformable strata, most and possibly all of which may be Oligocene-Miocene.

The conglomerates of the series are usually quite coarse and hard and consist of pebbles and cobbles of quartzite, jasper, black slate, and occasional granitics. They are found mostly at the base and near the top of the series along the straits and in the middle of the series on the Cape Flattery promontory. The zone of conglomerate in the middle of the Cape Flattery section may be the equivalent of the basal conglomerates of the series as developed unconformably above the Eocene around Crescent Bay. If so, the sandstones at the base of the Cape Flattery section are older than any of the Oligocene-Miocene beds exposed on the strait. The base of the Cape Flattery section is unknown, as the lowest beds exposed in the section are separated from the subjacent rocks by a fault.

The sandstones of the Clallam formation are for the most part thin bedded, hard, and resistant to erosion and are extremely fossiliferous in certain localities, notably east of Clallam Bay. They are found at the base and near the top of the Cape Flattery section and below the upper conglomerates east of Clallam Bay.

The shale of the Oligocene-Miocene occurs principally in the middle of the formation along the strait. The lower part of the shale is thinly and plainly laminated, but higher up becomes almost massive clay. * * * The overthrusting of the beds exhibited at [one] locality is very unusual, as the strata along this portion of the coast ordinarily lie in low simple folds. The shale is gray in fresh exposures but becomes more or less oxidized upon exposure. Sandstone dikes, probably derived from interbedded sandstones, cut the shales in the region east of the mouth of the Pysht River, and near Gettysburg hydrogen sulphide gas was noticed escaping from cracks in the shale along the beach. * * * Fossils are abundant and beautifully preserved throughout the finer sediments of the series, at least two distinct horizons being recognized.

At least five recognizable faunas have so far been found in the Clallam formation. The oldest comes from the lowest clay shales of the series. [For lists see the work cited.]

Above the clay shale horizon is a series of medium-bedded to fine massive sandstones in which are found fauna apparently transitional from the clay shales to the coarse sandstones.

Still a third fauna [Miocene], later than the last, is represented by species found immediately east of Clallam Bay.

The fourth fauna is that found in sandstone layers interbedded with conglomerates in the upper parts of the formation.

The fifth fauna of the Oligocene-Miocene is that found at the mouth of the Sekiu River in beds the equivalent of the uppermost strata of the Cape Flattery section. The relation of this fauna to those [below it] is somewhat problematical, although it appears quite likely that the former is younger than most of the latter.

Correlations between the different fossiliferous localities of the Oligocene-Miocene series over the whole of the peninsula and Puget Sound region are comparatively easy, as are also correlations with certain of the Oregonian faunas such as those of the Astoria shales and sandstones, but when it comes to making direct correlations with the California or Alaskan faunas much difficulty is encountered. One of the greatest surprises the writer had in all of his work along the straits was his inability to find the characteristic upper Miocene fauna of the Sooke beds which are so well developed only 15 miles to the northward on Vancouver Island. With an almost unbroken series of Miocene faunas one would certainly expect to find the Sooke species somewhere among the lot, but such was not the case and no plausible explanation of their absence has so far presented itself.

L-M 11-12. LAKE BASINS OF WESTERN MONTANA.

The valleys which lie within the mountains of western Montana correspond throughout much of their extent with basins that are partly filled by sediments of Miocene and Pliocene age. The deposits were well described by Peale.[632] They were laid down in lakes, in large part at least, and comprise several types of sediment. The lowest are composed of material derived from the shores of the basins, from pre-Cambrian or Paleozoic rocks. They are succeeded by beds of volcanic ash, in part carried by wind and deposited in the lakes without admixture of foreign material, in part washed in from adjacent land surfaces. The sediments were locally covered by basalt. Peale's description applies to the Bozeman and Madison basins, in which the deposits exceed 2,000 feet in thickness.

Douglass[287] describes the general distribution of the Tertiary. In a later article[288] he distinguished the Sage Creek beds (Eocene?), White River formation

(Oligocene), and Fort Logan beds (upper Oligocene, John Day?). (See pp. 775–776.) The Miocene he assigned to the "Loup Fork," and recognized three divisions—Deep River beds (upper Deep River of Scott [717]), Flint Creek beds, and Madison Valley beds. Scott quotes from the first description by Grinnell and Dana (1875). (See Chapter XVI, p. 776.)

M 12-13. CYPRESS HILLS, SOUTHWESTERN SASKATCHEWAN.

McConnell [558a] gives the following notes on the Cypress Hills, in Saskatchewan:

The most interesting result of the geological examination of the district has been the discovery of an extensive area of Miocene beds, the first found in Canadian territory east of the Rocky Mountains. These beds cap all the more elevated parts of the range of uplands extending in a direction a little north of east, from the west end of the Cypress Hills to the east end of Swift Current Creek plateau, a distance of 140 miles. They have an average width of 15 miles, and cover altogether an area of nearly 1,400 square miles. They are unconformable to the beds below and in their western extension rest on the Laramie, but near East End Coulee they overlap it and are then underlain by the Fox Hill and Pierre. They have a general easterly dip of about 15 feet per mile, which is somewhat greater than that of the underlying beds, and in their eastern part are affected to some extent by the same depressed fold which has thrown the White Mud River Laramie area into a flattened form.

The Miocene beds are characterized by the great quantity of waterworn pebbles, derived from the quartzite formations of the Rocky Mountains, which are found in every part of the series. The pebbles are usually cemented together into massive beds of hard conglomerate but also occur distributed irregularly through or arranged in layers and lenticular beds in the sands and sandstones. The more massive conglomerate beds are found toward the western part of the area or around its outskirts. The associated beds, consisting of sands, sandstones, marls, and clays, are described in a previous part of the report. They are all very irregular, and seldom remain constant in composition for any distance along their strike.

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Under the general name of the South Saskatchewan gravels are included the pebble conglomerates and incoherent gravels and silty beds which are found, as valley or lake deposits, in different parts of the district and which, although destitute of organic remains so far as examined, are known by their relative position to be intermediate in age between the Miocene and Quaternary and to belong mostly to the period immediately preceding the latter. They are, however, not all contemporaneous and in one or two places afford evidence, by the admixture of Laurentian and quartzite pebbles toward the top, of a gradual blending with the lowest glacial beds. The deposit is usually confined to a single bed of conglomerate, varying in thickness from 2 up to 50 feet, composed of small quartzite pebbles, precisely similar to those found in the Miocene, and either consolidated by a calcareous or ferruginous cement, or with its constituents lying loose in a sandy matrix. In some places the conglomerate is overlain by a considerable thickness of sandy or silty beds.

Cope's report on the vertebrates [558b] is published as an appendix to McConnell's report.

N 8-9. GRAHAM ISLAND, QUEEN CHARLOTTE GROUP.

The Tertiary sediments of Graham Island are described by Ells [316a] as gray cross-bedded quartzose grits, having a calcareous cement and holding scattered pebbles; gray and black shales in thin beds; conglomerates; and lignites. The age of these sediments appears to be Miocene or later but is incorrectly shown as earlier Tertiary on the map of North America. (See also tabular view of formations of Queen Charlotte Islands, by G. M. Dawson, Chapter XII, p. 540.)

N 10. UPPER PEACE AND FRASER RIVERS, BRITISH COLUMBIA.

Under the title Lignite group Dawson [249b] described the occurrences of sandstone and shale which carry lignite beds and commonly underlie the basalt flows of the upper Fraser Valley, British Columbia. At Quesnel they have yielded a flora of Miocene or earlier age associated with insects.

N-O 4. ALASKA PENINSULA.

Atwood [42c] thus describes the Miocene of the Alaskan Peninsula:

Miocene sediments appear in Unga and Popof islands and at several places on the north and south sides of Alaska Peninsula. They consist of sandstones, shales, and conglomerates that represent off-shore, shallow-water deposition. An abundance of fossil material was procured and has been identified by Mr. Dall. At Coal Harbor, Unga Island, the Miocene strata conformably overlie the Kenai formation (upper Eocene), but at other localities the Miocene sediments appear to rest unconformably upon different formations and to have been restricted to local basins. They are but little disturbed.

One collection of fossil plants, from the Herendeen Bay district but from a lithologic unit that occupies a very small area, seems to indicate post-Miocene age. The most extensive post-Miocene formations consist of volcanic tuffs and basic lava flows. They are widespread on the mainland in the vicinity of the Balboa-Herendeen Bay district and cover many square miles in the islands to the south and in the region about Chignik Bay.

For Kodiak Island and Katmai Bay, see Chapter XVI (p. 784).

O 4. BRISTOL BAY.

On the east shore of Nushagak Bay, which enters Bristol Bay from the north, Spurr [771a] observed strata to which he gave the name Nushagak. He says:

The high bluffs which form the east shore of Nushagak Bay are composed of stratified gravels, coarse sands, arkoses, and clays, which in places are slightly consolidated, apparently being cemented by iron which has leached out of the arkoses. These beds, in general horizontal, are frequently distinctly flexed, sometimes dipping as much as 20°, and in places there is even considerable folding and distortion. The strata are often heavily cross-bedded and contain pebbles derived from a great variety of rock, some of which are striated, apparently from ice. This formation is exposed for a number of miles along the shore of Nushagak Bay and around Cape Etolin to Bristol Bay.

Overlying the folded clays and gravels which have been called the Nushagak beds are unconformable horizontally stratified clays and gravels which contain many pebbles and frequently large bowlders, often being striated by ice. Near Nushagak these upper beds occupy the tops of the bluffs, which are in places as much as 150 feet high, but where the bluffs become lower and the beds themselves become thicker they often come down to the beach line, so that the underlying unconformable series is not exposed. These upper beds must be referred to the Pleistocene, so that those which underlie are probably Tertiary. In this connection a note made by Dr. Dall[a] concerning fossils collected at Nushagak by C. W. McKay is of interest. According to this, fossils were collected in an "indurated clayey matrix," which evidently refers to the Nushagak beds just described. They include *Modiola multiradiata* Gabb, *Pectunculus patulus* Conrad, *Nucula tenuis* Lamarck, and *Serripes gronlandicus* Beck and determine the age of the clays and gravels in which they occur as Miocene.

Regarding the above Atwood states in a personal communication: "I have not been at this locality. The pebbles and bowlders striated by ice, which are reported

[a] Report on coal and lignite of Alaska: Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 1, 1896, p. 847.

as common in the Nushagak beds of Spurr, make me doubt their Tertiary age. I believe they must be younger."

O-P 9. DEASE AND UPPER LIARD RIVERS, BRITISH COLUMBIA.

Dawson,[258b] in a report on explorations in the Yukon district, describes a wide plateau cut on Tertiary rocks, which are unconformable to the underlying Paleozoic rocks.

Q 5-6. YUKON VALLEY.

Spurr [770a] distinguished two occurrences of Tertiary strata in the Yukon Valley—one as the Twelvemile beds and the other as the Palisade conglomerate. According to Brooks the former is now regarded as of Kenai (Eocene) age. Concerning the latter Spurr says:

On the left bank of the Yukon, about 35 miles below the mouth of the Tanana, cliffs of silt and gravel rise to a height of 150 feet. This locality has been named the Palisades, but on account of the occurrence in the silt of abundant bones of the mammoth and other large animals it is more popularly known as the "Boneyard." The silts also contain lignite beds and small land and fresh-water shells and are of Pleistocene age. About a mile below the beginning of the silt bluffs the height of the vertical exposure changes from 150 to 200 feet, the increase being apparently caused by a fault which is visible in the face of the bluffs and which upthrusts the down-river portion. The fault is a normal one, and the silts of the upstream side are seen to be upturned against the fault plane. On the downstream side of the fault there is brought up a lower and more consolidated bed which underlies the silts. This new bed is pure white, being composed of clean sand and well-washed pebbles. It is strongly cross-bedded and contains much woody matter—sticks, logs, etc.—in a condition between wood and lignite. Many of these woody layers are steeply inclined, being cross-bedded with the sandstone. This bed is very gently arched and has a barely perceptible dip downstream. It is partly indurated, so that while it yields with comparative ease to a pick, it is firm enough to stand in solid, nearly perpendicular cliffs and falls in great slabs.

In the materials collected from the woody layers Dr. Knowlton found fragments of dicotyledons, but none sufficiently distinct for identification. Many of the layers are full of finely preserved cones, which, according to Dr. Knowlton, appear to be the same as Heer's *Pinus macclurii*, and from these he infers that the age is Pliocene, or possibly Upper Miocene.

Q 7. UPPER YUKON.

Brooks[103b] states:

No beds have been identified on the Yukon which are positively known to belong to the Pliocene or Miocene. It seems probable, however, that some terrace deposits may be of late Tertiary age. Such interpretation of the facts in hand has been made by both Spurr and Collier.

McConnell [563] thus describes the occurrence east of the international boundary:

Beds referred to the Tertiary occur at several points around the outskirts of the gold district. A wide band follows the Yukon Valley above Dawson, on the northeast side, and continues on in a direction a little south of east to the Klondike, which it crosses a short distance above the mouth of Rock Creek. It then follows the Klondike River to the mouth of Flat Creek and probably underlies the belt of plateau country that borders the latter and extends through to the Stewart.

Exposures of these beds on Rock Creek and the Klondike River consist mostly of soft grayish sandstones, indurated clays and shales, and occasional beds of ironstone. A thick lignite seam is reported to outcrop on one of the branches of Rock Creek, and other seams occur along the band in its northwesterly extension. A seam, or group of seams, said to be 15 feet in thickness, is being worked on Cliff Creek, about 75 miles below Dawson, for the supply of that place.

A small area of dark sandstones, agglomerates, hardened clays, and shales was found on Last Chance Creek, a tributary of Hunker Creek, lying at angles on the schists. The sandstones contain small particles of carbonaceous matter, but no lignite was noticed.

Tertiary beds were also found along the southern boundary of the district on Indian River. The northern limit of this area follows Indian River Valley from Quartz Creek to a point above New Zealand Creek, and the band extends southward beyond the region examined. The beds lie in easy folds and consist mainly of soft light-grayish sandstone, dark coarse agglomeratic sandstone, soft dark shales, and, at one point, of heavy beds of coarse conglomerate. Fragments of fossil plants occur throughout the formation, but no determinable specimens were found.

Q 8. PEEL RIVER.

Camsell[128a] explored Peel River, a western branch of the Mackenzie which joins it at the head of the delta. He says:

The upper canyon of the Peel River is cut in a series of tilted black slates, often dipping upstream. The strata of which it is composed are alternately thick and thin bedded, containing concretionary nodules with crystals and veinlets of pyrite and some bituminous matter disseminated through the rocks. This formation extends for a distance of three-quarters of a mile below the mouth of the Wind River, where it is replaced and overlain by Tertiary clays and sandstones. The contact is not so well shown on the Peel River as it is on the Wind, though the unconformity between the two is plainly evident. These slates outcrop again 15 miles below in the lower canyon of the Peel River, so that they border the Tertiary rocks both to the east and to the west. A small outcrop of bituminous limestone, overlain by the red clay and sandstone of the Tertiary, is exposed 1 mile below the canyon on the south bank of the river.

When cut through by the Peel River, the Tertiary basin is 13 miles in width. The rocks of this basin consist of thick beds of soft sandstone, with some thin seams of lignite, overlain by more sandstone containing pebbles, with clay and some very thick beds of lignite. The whole series has been gently folded into a number of anticlines and synclines. One lignite bed near the top of the series is 30 feet in thickness and fairly persistent, appearing in two exposures 4 miles apart with a shallow syncline between. This bed rises in an anticline, the top of which has been truncated by later erosion, and beyond it dips again and disappears beneath the bed of the Bonnet Plume River.

Q 9–10. MACKENZIE VALLEY AND BEAR RIVER.

The "Bear River Tertiary" which outcrops along the Mackenzie above and below Fort Norman is described in some detail by McConnell,[560d] who quotes descriptions of the flora by Sir William Dawson.[265] The original publications should be consulted for details. McConnell states:

After reviewing the evidence afforded by the collections of fossil leaves and fruits which have been brought out by various explorers and examined by Heer and others, Sir William Dawson arrives at the following conclusion:

"The general conclusion indicated by the above facts is the strong resemblance of the flora of the Mackenzie River beds with that of the Laramie of other parts of Canada and the United States and also with the Tertiary of Greenland, Spitzbergen, Alaska, and the Hebrides. They thus confirm the inferences as to this similarity and as to the Lower Eocene age of the Upper Laramie stated by the author in 'The report on the forty-ninth parallel' in 1875, in subsequent 'Reports of the Geological Survey,' and in previous volumes of these Transactions."

The Bear River Tertiary basin, measured along the Mackenzie, has a length of about 40 miles. Its width was not ascertained, but Tertiary beds probably underlie the flat country which borders Bear River for 20 miles above its mouth. They can not extend more than 15 or 20 miles in a westerly direction, as a lofty limestone range runs parallel with the river at about that distance. The distribution of the beds is thus limited to an area 40 or 50 miles in length and 30 or 40 in width and may be considerably less.

The beds of this Tertiary basin are evidently lacustral in their origin and both in lithological character and stratigraphical position have a much closer resemblance to the Miocene (White River) of the Cypress Hills and neighboring areas than to the Laramie, with which their fossil flora correlates them. Like the Cypress Hills beds, they are characterized by their irregular deposition, by their slight induration, and by the large proportion of gravel and pebble beds which they contain, and a further degree of relationship is evidenced by the fact that they both rest unconformably on the beds beneath.

Knowlton, in a personal communication, states that the "Bear River Tertiary" of the Mackenzie Valley is the equivalent of the Fort Union of the United States and is lower Eocene.

R 5–6. ARCTIC COASTAL PLAIN, ALASKA.

In traversing the Colville Valley Schrader[708b] distinguished Oligocene and Pliocene strata of the region as the Colville series. For his description of the lower Colville (Oligocene) see Chapter XVI (pp. 792–793). In regard to the upper Colville (Pliocene) he states:

This portion of the section is practically free from indurated rock. It consists of nearly horizontally stratified beds of fine gray, slate-colored, or ash-colored calcareous silts, containing faunal remains. It is tentatively assigned to the Pliocene on the basis of fossils collected in place by the writer in the bluff (near its top) on the west side of the Colville about a mile north of the seventieth parallel. These have been reported on by Dr. Dall. [List follows.]

R–U 16–22. ARCTIC ARCHIPELAGO AND WESTERN GREENLAND.

Dawson[257b] in 1886 wrote of the "Arctic Miocene:"

The so-called Miocene of Greenland and Grinnell Land is now regarded as equivalent to the Laramie, or at least not newer than Eocene, by Mr. J. Starkie Gardiner, Sir William Dawson, and other paleobotanists. Our knowledge of the flora of the Banks Land beds is very slight, being confined to that of the structure of a few specimens of fossil woods * * * which have been reported on by Dr. C. Cramer, but, so far as it goes, it presents no features incompatible with the possible Laramie age of these deposits also.

The Tertiary plant-bearing sediments on the west coast of Greenland are described by White and Schuchert[902a] as conformable to the Cretaceous Patoot series.

The Patoot series, which appears lithologically and stratigraphically to be inseparable from the Atane series, contains at the same time many plants common in the upper part of the Amboy clays, with others allied more closely to the higher Cretaceous floras, such as that of the Laramie. The Patoot series may perhaps be safely interpreted as constituting a paleontological as well as sedimentary transition from the Atane series to the Tertiary. The thickness of the Atane and Patoot series (Senonian) is not less than 1,300 feet and may considerably exceed this.

The Tertiary clastics at Atanikerdluk attain a thickness of not less than 1,500 feet, not including the intruded basalts at least 200 feet thick. The horizon of most of the plants described by Heer as Miocene is assumed to be near the base of that series, the demarcation of which appears to be purely arbitrary.[a] It is more probable that the age of the plants now generally conceded by paleobotanists to be Oligocene may even be Eocene instead of Miocene. No remains of marine animals have as yet been discovered with these plants.

The Tertiary clastic zone appears to be thinner west of Atanikerdluk, and at Patoot and Atane it is presumably represented by the upper sandstone horizon 200 to 300 feet in thickness. At the western end of the peninsula its presence is established in the occurrence of "Atanikerdluk" plants. On the north coast east of Niakornat there may be a slight development of this zone, and it evidently is represented in the interior east of Kook.

Tertiary strata of unknown position occur in western Ellesmere Land. Schei[707a] says:

In the depressions between the mountains of Mesozoic sandstones abutting on Heureka Sound are in many places thick deposits of light quartz sand with embedded strata of lignite. The same is also the case in the lowlands east of Blaamanden and at the head of Stenkulfjord in Baumann Fjord. In addition to the lignite, masses of slaty clay were also found at the latter place, in which were well-preserved remains of *Sequoia langsdorfii, Taxodium distichum* var. *miocenum*, and some others, well-known witnesses to a southern vegetation in these regions in a geologically late period—that is, the Miocene.

Descriptions of the eruptive rocks follow in the original work.

[a] The conglomeratic sandstone at 1,000 feet above tide at Atanikerdluk, assumed by the writers to be the base of the Tertiary at that point, is the only hypothetical lithological bench mark observed in any section.

CHAPTER XVIII.

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