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DAVID WHITE, CHIEF GEOLOGIST

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CONTENTS.

	Page.
Geology of the pitchblende ores of Colorado, by Edson S. Bastin (published March 17, 1914)	1
Erosion and sedimentation in Chesapeake Bay around the mouth of Choptank River, by J. F. Hunter (published May 23, 1914)	7
Dike rocks of the Apishapa quadrangle, Colorado, by Whitman Cross (published June 13, 1914)	17
The composition of crinoid skeletons, by F. W. Clarke and W. C. Wheeler (published June 16, 1914)	33
Contributions to the stratigraphy of southwestern Colorado, by Whitman Cross and E. S. Larsen (published September 17, 1914)	39
A reconnaissance in the Canyon Range, west-central Utah, by G. F. Loughlin (published October 17, 1914)	51
The Montana group of northwestern Montana, by Eugene Stebinger (published October 14, 1914)	61
A deep well at Charleston, S. C., by L. W. Stephenson, with a report on the mineralogy of the water, by Chase Palmer (published December 31, 1914)	69
The stratigraphy of the Montana group, with special reference to the position and age of the Judith River formation in north-central Montana, by C. F. Bowen (published February 12, 1915)	95
The Cretaceous-Eocene contact in the Atlantic and Gulf Coastal Plain, by L. W. Stephenson (published February 27, 1915)	155
The history of a portion of Yampa River, Colo., and its possible bearing on that of Green River, by E. T. Hancock (published February 20, 1915)	183
The inorganic constituents of echinoderms, by F. W. Clarke and W. C. Wheeler (published February 27, 1915)	191
Index	197

ILLUSTRATIONS.

		Page.
PLATE I.	*A*, *B*, Camera lucida drawings of polished surface of pitchblende ore from the Wood mine, Quartz Hill, Gilpin County, Colo	4
II.	*A*, Camera lucida drawing of polished surface of pitchblende ore from the Calhoun mine, Quartz Hill, Gilpin County, Colo.; *B*, Microphotograph of polished section of pitchblende ore from the Wood mine, Quartz Hill, Gilpin County, Colo	5
III.	Map of the mouth of Choptank River, with Tilghman, Sharps, and James islands, showing different positions of the shore lines at the time of the first, second, and third surveys and areas of erosion and sedimentation	10
IV.	Relief map of south-central Colorado, showing relation of the Apishapa quadrangle to the Spanish Peaks center of eruption	18
V.	Photomicrographs of analyzed augite vogesite: *A*, With one nicol; *B*, With crossed nicols	22
VI.	Photomicrographs of analyzed hornblende-augite vogesite: *A*, With one nicol; *B*, With crossed nicols	24
VII.	Photomicrographs of analyzed plagioclase basalt: *A*, With one nicol; *B*, with crossed nicols	26
VIII.	La Plata sandstone on schist of Uncompahgre formation on north bank of Piedra River, Colo	44
IX.	Lake Bonneville beds at the mouth of Sevier Canyon, near Leamington, Utah	56
X.	Geologic map of area examined between Musselshell and Judith, Mont	104
XI.	Map showing approximately the trend of the Cretaceous-Eocene contact in the Atlantic and Gulf Coastal Plain	156
XII.	*A*, *B*, Contact between the Selma chalk (Upper Cretaceous) and Midway group (Eocene) at Old Canton Landing, Alabama River, Ala	162
XIII.	*A*, Fault involving the Cretaceous-Eocene contact at Old Canton Landing, Alabama River, Ala.; *B*, Exposure exhibiting the Cretaceous-Eocene contact on Macon-De Kalb road, 7½ miles south of Macon, Ala	163
XIV.	*A*, Cretaceous-Eocene contact in cut of St. Louis & San Francisco Railroad 1 mile east of New Albany, Miss.; *B*, Potholes in basal limestone of the Midway formation on the Rio Grande 1 mile below White Bluff, Maverick County, Tex	168
XV.	Map of Maverick County, Tex., showing the approximate trend of the Cretaceous-Eocene contact from the Rio Grande northward through the county	170

Page.
XVI. *A*, *B*, Cretaceous-Eocene contact on the Rio Grande at White Bluff, Maverick County, Tex......... 172
XVII. *A*, Contact between the Midway formation and overlying sandstone of Midway or Wilcox age on the Rio Grande in Maverick County, Tex.; *B*, Sandstone of Midway or Wilcox age in a prominent westward-facing bluff on the Rio Grande in Maverick County, Tex.............................. 173
XVIII. *A*, Basal limestone of Midway formation on southeast side of Elm Creek 11 miles south of Sabinal, Tex.; *B*, Eocene sandstone in bed of Hondo Creek 3½ miles south of Elstone, Tex......................... 178
XIX. *A*, Escondido formation in bed of Hondo Creek at Rock Crossing, Medina County, Tex.; *B*, Basal limestone of Midway formation on left bank of Hondo Creek in Medina County, Tex.................. 179
XX. Map showing the course of Yampa River, in Moffat County, Colo., from Green River east to 107° 30′ west longitude.. 184
XXI. Jointing in sandstone of Mesaverde formation: *A*, At the "Transfer," T. 2 N., R. 92 W., Meeker quadrangle, Colo.; *B*, In T. 4 N., R. 91 W., Monument Butte quadrangle, Colo.................... 188
FIGURE 1. Sketch map of Chesapeake Bay, showing the area studied and its relation to other parts of the bay. 8
2. Drainage map of a part of the Piedra Valley, Colo.. 42
3. Diagrammatic section along northwest side of Piedra Canyon, Colo............................... 45
4. Reconnaissance map of the Canyon Range, Utah, showing geologic formations....................... 52
5. View across North Fork of Yellowstone River, Canyon Range, Utah, looking northwest from Arbroath shaft... 53
6. Generalized sections along north and south sides of Fool Creek canyon, Utah...................... 55
7. Generalized section along north side of Oak Creek canyon, Utah................................... 55
8. Eocene conglomerate resting on upturned Mississippian (or older?) limestone at head of Yellowstone Canyon, Utah.. 56
9. Diagram showing probable relations of the marine and continental sediments of the Montana group in the northern Great Plains region, the top of the Colorado group being taken as a datum plane. 67
10. Diagram of well at Charleston, S. C., showing size of hole and length of casings inserted............ 70
11. Diagram indicating the terms used to designate paleontologic zones and the relation of these zones to formation units in the Chattahoochee region and the Carolinas................................ 87
12. Diagram showing correlation of Cretaceous portion of the Charleston well section in terms of the faunal zones recognized in the Cretaceous deposits of the eastern Gulf region................... 88
13. Generalized section of the Upper Cretaceous and Eocene series in west-central Alabama and east-central Mississippi.. 156
14. Generalized section from Troy, Ala., northward to Conecuh River.................................. 161
15. Sketch showing position of Cretaceous-Eocene contact and faulting at Old Canton Landing, Alabama River, Ala.. 162
16. Section showing Cretaceous-Eocene contact on Curls station road half a mile southwest of the courthouse at Livingston, Ala.. 163
17. Section showing Cretaceous-Eocene contact on Sucarnochee Creek 5 miles northwest of Livingston, Ala.. 164
18. Section showing Cretaceous-Eocene contact half a mile west of Giles, Kemper County, Miss....... 165
19. Profile section along the left bank of Rio Grande below White Bluff, Maverick County, Tex....... 172
20. Sketch map showing outcrop of Cretaceous-Eocene contact in portions of Uvalde and Medina counties, Tex.. 178

SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY, 1914.

GEOLOGY OF THE PITCHBLENDE ORES OF COLORADO.

By Edson S. Bastin.

The large amount of public interest that has recently been manifested in radium because of the apparent cures of cancer effected by certain of its emanations makes it desirable to place before the public as promptly as possible all available information in regard to the occurrence of the minerals from which radium may be derived. The following account of the mode of occurrence of pitchblende at Quartz Hill, in Gilpin County, Colo., is therefore published in advance of a much larger report on the same region in which many other types of ore deposits will be considered. The field studies were made in the fall of 1912. As the geologic relations at Quartz Hill differ in important particulars from those at foreign localities, a summary of the genetically important features of the principal European occurrences is included for purposes of comparison. My thanks are due to Mr. Frank L. Hess, of the Geological Survey, for generously placing at my disposal additional specimens for study.

SOURCES OF URANIUM IN THE UNITED STATES.

The quantity of uranium ore mined in the United States is exceedingly small and in 1913 appears to have been equivalent to about 38 short tons of uranium oxide (U_3O_8), or approximately 32 tons of metallic uranium.[1] This is considerably larger than the production in 1912, which was equivalent to about 26 short tons of uranium oxide, or in 1911, which was equivalent to about 25 short tons. Practically the entire production of 1911 and 1912 and about half that of 1913 went to foreign countries. Of this tonnage nearly all came from sandstones of the high plateau regions of southwestern Colorado and southeastern Utah, in which the uranium occurs disseminated as the canary-yellow mineral carnotite ($2UO_3.V_2O_5.K_2O.xH_2O$) or its calcium-bearing equivalent tjuyamunite ($2UO_3.V_2O_5.CaO.xH_2O$). The small remaining portion of uranium ore mined in the United States, amounting in 1912 to only 275 pounds, was uraninite, or pitchblende, a complex uranate of variable composition to which a definite chemical formula can not yet be assigned. This mineral occurs in two distinct ways—in small amounts in granite pegmatites, notably in North Carolina, and in intimate association with metallic sulphides in certain mineral veins of Quartz Hill, near Central City, Gilpin County, Colo. The mines from which pitchblende has been obtained are all located on Quartz Hill and include the Calhoun, Wood, Kirk, German, Belcher, and Alps mines. For many years a small and sporadic production has come from this group and has been used mainly for specimens and for experiments. Quartz Hill is not only the one important locality in the United States where pitchblende occurs in mineral veins but one of the few in the world.

PRINCIPAL FOREIGN OCCURRENCES OF PITCHBLENDE.

In preparing the following summary of the principal foreign occurrences, the writer has so far as possible consulted original sources. The chief localities outside of the United States at which pitchblende has been found in mineral veins are the western part of the Erzgebirge, near the German-Austrian boundary, and the Cornwall district in England. A brief summary of the geologic occurrence of uranium minerals is also given in a recent article by P. Krusch.[2]

[1] Hess, F. L., Preliminary statement of the production of uranium and vanadium: U. S. Geol. Survey Press Bulletin, January, 1914.

[2] Über die nutzbaren Radium-Lagerstätten und die Zukunft des Radium-Marktes: Zeitschr. prakt. Geologie, vol. 19, pp. 83-90, 1911.

THE ERZGEBIRGE.

Types of deposits.—Muller[1] recognized in and near the granite batholiths of the western Erzgebirge in Bohemia and Saxony four types of ore deposits, which he classified as follows:

A. Older ore-forming period:
  1. Veins of the tin type.
  2. Veins of the pyritic lead-zinc type.

B. Younger ore-forming period:
  3. Veins of the cobalt-silver type.
  4. Veins of the iron and manganese type.

Deposits of types 1 and 2 are connected by transitions. The tin ores are confined to the granite and its immediate vicinity, while the pyritic lead-zinc veins are a little farther removed from the granite batholiths. The veins of types 3 and 4 are later than those of types 1 and 2.

At Joachimsthal, in Bohemia, and at Schneeberg, Annaberg, and Johanngeorgenstadt, across the border in Saxony, the veins of principal economic importance belong to Müller's cobalt-silver type (No. 3). It is with the veins of this type that the pitchblende is characteristically and exclusively associated.

Joachimsthal, Bohemia.—According to Stěp and Becke[2] the ores of the cobalt-silver type in the Joachimsthal district may be further subdivided into two classes—cobalt-nickel-arsenic ores and rich silver ores. In my opinion the ores of the first class represent the primary ore deposition, and those of the second class are in all probability the result of sulphide enrichment acting on the primary ore. The pitchblende, with its accompanying gangue minerals, quartz and dolomite, has rarely been observed in actual contact either with the rich silver ores or with the cobalt-nickel-arsenic ores. Usually the uranium and its gangue minerals have as metallic associates only variable amounts of pyrite and chalcopyrite, which appear to be in part earlier and in part later than the pitchblende. In a few places, however, the pitchblende, quartz, and dolomite coat ore containing cobalt or nickel minerals (smaltite, chloanthite, or niccolite), and therefore apparently are later than those minerals. The relation of the uranium ores to the rich silver ores can be inferred only from museum specimens in which ruby silver or proustite occurs in vugs in the pitchblende ore and in minute veinlets traversing it. It appears fairly well established, therefore, that the uranium ores of Joachimsthal were deposited somewhat later than the nickel-cobalt-arsenic ores but before the development of rich silver sulphides, which in these deposits were probably formed by enrichment due to the action of meteoric waters. The deposits are now controlled by the Austrian Government.

Annaberg, Saxony.—In the Annaberg region also the cobalt-silver type of ore is economically the most important, and its veins in many places cut or even materially displace the earlier tin, copper, and pyritic lead-zinc veins. According to Müller[3] the pitchblende is characteristically though nowhere abundantly associated with the cobalt-silver type of veins. It usually forms compact spherulitic or grapelike masses, some of which have shell-like or concentric structure, as a coating on siderite and fluorspar. Rarely it forms layers as much as 7 centimeters thick.

The primary minerals of the cobalt-nickel veins are, according to Müller, barite, fluorite, quartz, siderite, rammelsbergite ($NiAs_2$), niccolite, chloanthite, smaltite, native bismuth, tetrahedrite, stibnite, chalcopyrite, pyrite, reddish sphalerite, and berthierite ($FeS.Sb_2S_3$). The pitchblende, together with siderite, calcite, and some pyrite and chalcopyrite, is later than the cobalt-nickel group of minerals but earlier than the rich silver minerals whose origin, in my opinion, may be attributed with much probability to downward enrichment.

Johanngeorgenstadt, Saxony.—In the Johanngeorgenstadt district, which has been described by Viebig,[4] the most valuable uranium ores also belong genetically with Müller's cobalt-silver type, but they are characterized by an unusual abundance of native bismuth and bismuth compounds and are valuable mainly as a source of that metal and only subordinately for the

[1] Müller, Hermann, Die Erzgänge des Annaberger Bergrevieres, Erlauterungen zur Specialkarte des Königreichs Sachsen, p. 66, Leipzig, 1894.

[2] Stěp, Josef, and Becke, F., Das Vorkommen des Uranpecherzes zu St. Joachimsthal: K. Akad. Wiss. Sitzungsber., vol. 113, pp. 585–618, Wien, 1904.

[3] Müller, Hermann, op. cit., pp. 94, 98–100.

[4] Viebig, W., Die Silber-Wismutgänge von Johanngeorgenstadt in Erzgebirge: Zeitschr. prakt. Geologie, vol. 13, pp. 89–115, 1905.

nickel, cobalt, or silver they carry. The principal primary minerals of these veins are arsenopyrite, cobaltite, chloanthite, native bismuth, quartz, dolomite, siderite, calcite, and rarely barite and fluorite. The pitchblende is invariably associated with the veins of this type. It is in part disseminated and in part in solid crusts or bands some of which reach a thickness of 6 to 8 centimeters. Kidney-shaped and concentric forms are common. Characteristic metallic associates are fine-grained galena and chalcopyrite and native bismuth, small masses of these minerals being locally inclosed in the pitchblende ore. The common gangue mineral is an iron-manganese carbonate. In other parts of the Erzgebirge the pitchblende is irregularly distributed in nests, but in the Gottes Segen Spat mine, in this region, it occurs in considerable quantities and with much regularity.

Schneeberg, Saxony.—In the Schneeberg district, according to Müller,[1] pitchblende is a characteristic though not an abundant accompaniment of the cobalt-silver type of veins. Its kidney-shaped or rounded shell-like masses are ordinarily associated with chalcopyrite, galena, and brown carbonate. Müller regarded the pitchblende and its accompanying minerals as of slightly later formation than the primary cobalt and nickel minerals and earlier than the rich silver minerals.

CORNWALL DISTRICT, ENGLAND.

In and near the granite batholiths of Cornwall occur not only tin and copper lodes but also, usually at a greater distance from the granite, younger lodes of two types—(1) those containing uranium and nickel ores and (2) iron-manganese lodes.[2] In the vicinity of Bodmin, for example, there occur certain lodes containing arsenic and copper minerals and smaller quantities of uranium, cobalt, and nickel ores. These lodes cross the tin and copper lodes that are the main mineral resources of the district and are therefore somewhat younger, although it is believed that all the lodes are genetically connected with the granitic intrusives of the region.

In the St. Austle Consols mine, according to Williams,[3] uranium minerals have been found in certain small veins that cross the main tin-copper lode. The associates of the uranium minerals in the cross veins are locally copper ores but more commonly ores of nickel and cobalt. The uranium minerals also occur on the sides of the veins.

At Dolcoath, according to Pearce,[4] pitchblende occurred "associated with native bismuth and arsenical cobalt in a matrix of red compact quartz and purple fluorspar." At South Tresavean it occurs with "kupfer-nickel, native silver, and rich argentiferous galena." "I believe," says Pearce, "in all the localities I have named, it was found in little veins crossing the lodes" (that is, the tin lodes).

At the South Terras or Uranium mine, in Cornwall,[5] "The uranium lode * * * is said to vary in width from 3 to 5 feet, but the uranium ore is confined to a leader a few inches in width, consisting partly of pitchblende and calc and copper uranites with copper pyrites, mispickel, and galena, and small quantities of nickel, cobalt, and chromium ore in a veinstone of quartz and green garnet rock."

PITCHBLENDE IN THE QUARTZ HILL DISTRICT, COLO.

GENERAL GEOLOGIC RELATIONS.

The predominant rocks of Quartz Hill and neighboring parts of Gilpin County are pre-Cambrian igneous and sedimentary rocks and Tertiary intrusive rocks in the form of dikes and stocks.

The oldest pre-Cambrian rocks are those of the Idaho Springs formation, predominantly a quartz-mica schist, which is believed to be a metamorphosed sediment. This schist is intruded by

[1] Müller, Hermann, Der Erzdistrikt von Schneeberg in Erzgebirge, in B. von Cotta's Gangstudien, vol. 3, pp. 129-138, 1860.
[2] Ussher, W. A. E., Barrow, G., and MacAlister, D. A., The geology of Bodmin and St. Austell: Geol. Survey England and Wales Mem., Expl. Sheet 347, p. 134, 1909.
[3] Williams, R. H., Notice of the occurrence of nickel and cobalt at St. Austle Consols mine, near St. Austle, Cornwall: Roy. Inst. Cornwall Thirty-ninth Ann. Rept., pp. 32-34, 1857.
[4] Pearce, Richard, Note on pitchblende in Cornwall: Roy. Geol. Soc. Cornwall Trans., vol. 9, pp. 103, 104, 1875.
[5] Ussher, W. A. E., Barrow, G., and MacAlister, D. A., op. cit., p. 157.

pre-Cambrian granites of at least two ages—an older granite that has been dynamometamorphosed to a granite gneiss and a younger granite that has not been notably dynamometamorphosed and is commonly massive. Granite pegmatite offshoots from both these granites are numerous and in places intrude the Idaho Springs formation so intimately as to produce an injection gneiss. Where the Idaho Springs formation lies near or is inclosed by considerable bodies of granite rock, it has commonly been contact-metamorphosed to a hornblende schist.

All the pre-Cambrian rocks are intruded by dikes and stocks of monzonite porphyry and of bostonite porphyry (entirely orthoclase). These are believed to be of Tertiary age.

The mineral veins of the vicinity are the result of combined fissure filling and replacement along a series of fractures characterized by easterly to northeasterly strikes and commonly by steep dips. The veins cut both the pre-Cambrian rocks and the Tertiary intrusives. On the basis of mineral composition they can be divided into two types, which may be designated the pyritic type and the lead-zinc type. They have been worked principally for their precious-metal content, though yielding also considerable amounts of copper and lead.

The principal primary minerals of the pyritic type are pyrite and quartz; chalcopyrite and tetrahedrite are almost invariably present in subordinate amounts, and enargite, fluorite, and rhodochrosite occur here and there. The primary minerals commonly present in the veins of the lead-zinc type are galena, sphalerite, pyrite, chalcopyrite, quartz, and calcite. Some parts of the district are characterized solely by one or the other of these types of mineralization, but in many of the veins both types are present. In such veins it has been demonstrated by repeated exposures that the lead-zinc type is somewhat later than the pyritic type and that the minerals of the former commonly line vugs or fractures in those of the latter. It is believed, however, that the lead-zinc mineralization followed close upon the heels of the pyritic mineralization, and that the two types represent merely successive epochs in one great vein-forming period. Although the mineral veins cut the monzonite prophyry dikes and stocks, it is believed that both came from a common deep-seated source, the ore-bearing solutions following the monzonite intrusion after a short interval.

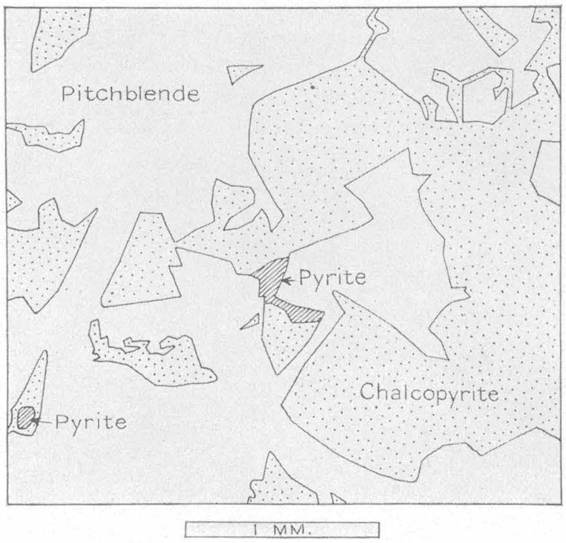
Sulphide enrichment in the upper portions of many veins of the lead-zinc type has developed secondary silver minerals in considerable abundance, and such veins are known as "silver veins," their principal value being in that metal.

PITCHBLENDE ORES.

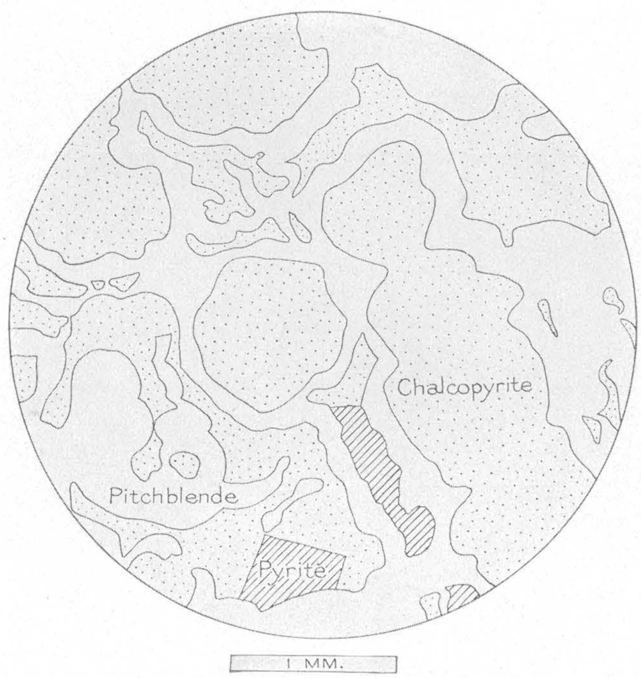
Although few opportunities were afforded for studying the richer pitchblende ores in place, because of suspension of mining at most of the mines, numerous specimens presented to the Survey by men interested in these mines were polished and studied under the reflecting microscope and found to show clearly the relations of the pitchblende to the sulphides which accompany it in the veins.

In a number of specimens it is evident that the pitchblende crystallized contemporaneously with chalcopyrite, pyrite, and probably gray quartz. A specimen from the Wood mine, obtained through the courtesy of Mr. W. C. Denison, when polished and studied presented the appearance shown in Plate I. Some of the intergrown chalcopyrite and pitchblende show angular outlines, as indicated in Plate I, *A*, but more commonly the pitchblende areas are ringlike in cross section with chalcopyrite occupying the center of the ring and inclosing it, as indicated in Plate I, *B*. Pyrite and gray quartz, apparently contemporaneous with the pitchblende and chalcopyrite, are present in small amounts. Specimens from the Wood and German mines in the mineral collections at the State Capitol in Denver show chalcopyrite and pitchblende so intimately intergrown as to leave little doubt of their contemporaneous crystallization. In other specimens from the Wood mine botryoidal pitchblende has cores of pyrite and is in places fringed with pyrite, as shown in Plate II, *B*. To summarize, the manner in which the minerals are intergrown in several specimens shows conclusively that pitchblende crystallized contemporaneously with chalcopyrite and probably with minor amounts of pyrite and gray quartz.

In other specimens the relations between pitchblende and sulphides are entirely different. A specimen of rich ore from the Calhoun mine, obtained through the courtesy of Mr. Hugh C.



A.



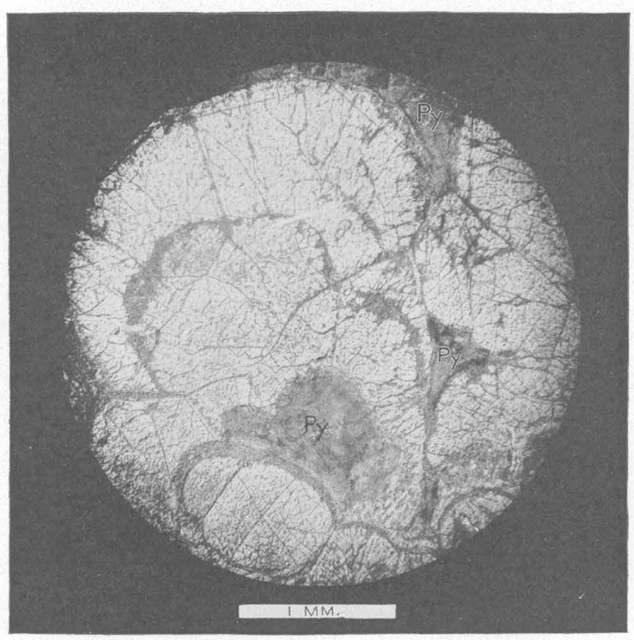
B.

CAMERA LUCIDA DRAWINGS OF POLISHED SURFACE OF PITCHBLENDE ORE FROM THE WOOD MINE, QUARTZ HILL, GILPIN COUNTY, COLO.

Showing contemporaneous growth of pitchblende, chalcopyrite, and pyrite. In *B*, drawn from another part of the same specimen as *A*, the pitchblende areas show rounded outlines.

A. CAMERA LUCIDA DRAWING OF POLISHED SURFACE OF PITCHBLENDE ORE FROM THE CALHOUN MINE, QUARTZ HILL, GILPIN COUNTY, COLO.

Showing pitchblende traversed by later veinlets of sphalerite, pyrite, and galena.



B. MICROPHOTOGRAPH OF POLISHED SECTION OF PITCHBLENDE ORE FROM THE WOOD MINE, QUARTZ HILL, GILPIN COUNTY, COLO.

Showing botryoidal forms characteristic of much of the pitchblende. Py, Intergrown pyrite.

Brown, consists principally of pitchblende, but this mineral is sharply cut by veinlets one-eighth inch or less in size, composed of sphalerite, pyrite, and some galena. An enlarged view of some of the smaller veinlets as seen under the reflecting microscope is shown in Plate II, *A*. Another specimen from this mine shows pitchblende in botryoidal forms fractured and traversed by minute veinlets consisting predominantly of pyrite, chalcopyrite, and dark-gray quartz, but containing some galena and sphalerite. In the more shattered portions fragments of pitchblende lie in a matrix of these sulphides. A specimen from the Calhoun mine, obtained from Mr. Percy R. Alsdorf, shows altered schist traversed across its foliation by a $\frac{1}{8}$-inch to $\frac{3}{16}$-inch veinlet of pitchblende. A polished section shows that the pitchblende has in places been shattered and that fragments of it lie in a matrix of galena, sphalerite, chalcopyrite, and gray quartz, while other parts are traversed by minute veinlets of galena. It is clear, therefore, that there has been some sulphide mineralization subsequent to the deposition of the pitchblende.

The pitchblende ores of Quartz Hill are believed to represent merely a local and unusual variation in the main sulphide mineralization of this region—a variation of the same order as the occurrence of enargite in a neighboring group of veins near South Willis Gulch. I found no evidence to support Rickard's opinion[1] that the pitchblende mineralization is genetically connected with the intrusion of the granitic rocks, whose age is pre-Cambrian; on the contrary, I believe that, together with the sulphides that accompany them, they are genetically related to the Tertiary monzonite intrusives.

The significance of the contrasting and apparently contradictory modes of association of the pitchblende with the sulphide minerals becomes apparent when it is recalled that the Central City district is in general characterized by two types of mineralization, an earlier pyritic mineralization and a later lead-zinc mineralization. It is believed that the pitchblende was deposited during the earlier or pyritic mineralization, that it was afterward fractured, and that the fractures thus formed were filled by sulphides of the later or lead-zinc mineralization.

The general geologic relations and the absence of characteristic high-temperature minerals in the deposits of Quartz Hill, as well as in those of Cornwall and the Erzgebirge, indicate that the pitchblende was deposited under conditions of moderate temperature and pressure. Unlike the European pitchblende, however, the pitchblende of Quartz Hill is not associated with nickel and cobalt minerals, which so far as known have never been found in that region even in small quantities. The occurrence of pitchblende in pegmatite as well as in mineral veins of the type here described shows that the mineral may also form under conditions of high temperature and pressure.

[1] Rickard, Forbes, Pitchblende from Quartz Hill, Gilpin County, Colo.: Min. and Sci. Press, June 7, 1913, pp. 851-856.

EROSION AND SEDIMENTATION IN CHESAPEAKE BAY AROUND THE MOUTH OF CHOPTANK RIVER.

By J. FRED. HUNTER.

INTRODUCTION.

With the unfolding of geologic knowledge during the last century the processes of denudation, transportation of sediments, and sedimentation have become better understood, and to some extent their relative effects in bringing about the present configuration of the earth's surface have been determined. The nature of these processes has been studied in many parts of the globe, but owing to the large size of the units affected and the slowness of the processes there has been little opportunity to collect quantitative data. Indeed, the data available are very largely conjectural, their degree of accuracy being only that of good guessing. However, with the advent of accurate topographic and hydrographic surveys, the first steps toward actual measurements of some of the many interesting surficial changes that are in progress have been taken, and it only remains for time and additional observations to afford opportunities for comparison. Resurveys, particularly by the United States Coast and Geodetic Survey, of parts of the eastern coast of the United States at different intervals have shown in many places marked changes of both shore line and sea bottom, as on Cape Cod, on Nantucket Island, and in Delaware Bay. Comparisons of this kind have so far been incidental to work in engineering and coast surveying, so that there has been little opportunity for the selection of localities particularly adapted to studies of erosion and sedimentation.

Chesapeake Bay, which is really a large tidal river, is favorable for such investigations, in that it has a drainage basin of moderate size and retains a large part of the sediments brought in from that basin by its tributary rivers. Moreover, this bay, since the memorable explorations of Capt. John Smith in 1608, has been of much interest to explorers and map makers. The classic map made by Smith was followed by many others of varied character, such as Herman's "Map of Virginia and Maryland" (1670) and Griffith's "Map of Maryland" (1794), both of which were the standard maps of their time and marked great advances in the cartographic knowledge of the bay.[1] In the course of the general economic development of this region further data as to the limits and character of Chesapeake Bay and its tributaries continued to accumulate as the result of the work both of governmental bureaus and of private concerns until in the fourth decade of the last century the need began to be felt for a thorough topographic and hydrographic study of the bay. In 1845 the United States Coast and Geodetic Survey began such a study, and by 1848 had surveyed the entire bay and prepared charts on the scale of 1:20,000 showing with accuracy the shore lines and the depths of water. In 1900 it was deemed necessary to make a similar study of the bay in connection with the work of the Maryland Shell Fish Commission, and by 1903 a second set of charts had been completed by the Coast Survey, on the same scale and showing the same detail as the earlier charts. Both sets of charts are accurate and are unique in covering so well so large and important an area at dates removed from each other

[1] For an interesting detailed history of the explorations and surveys of Chesapeake Bay, see Mathews, E. B., The maps and map makers of Maryland; Maryland Geol. Survey. vol. 2, pt. 3, 1898.

by an interval of more than half a century. Even a cursory examination of the corresponding charts of the two periods shows important changes in the position of the shore line and of the bay bottom.

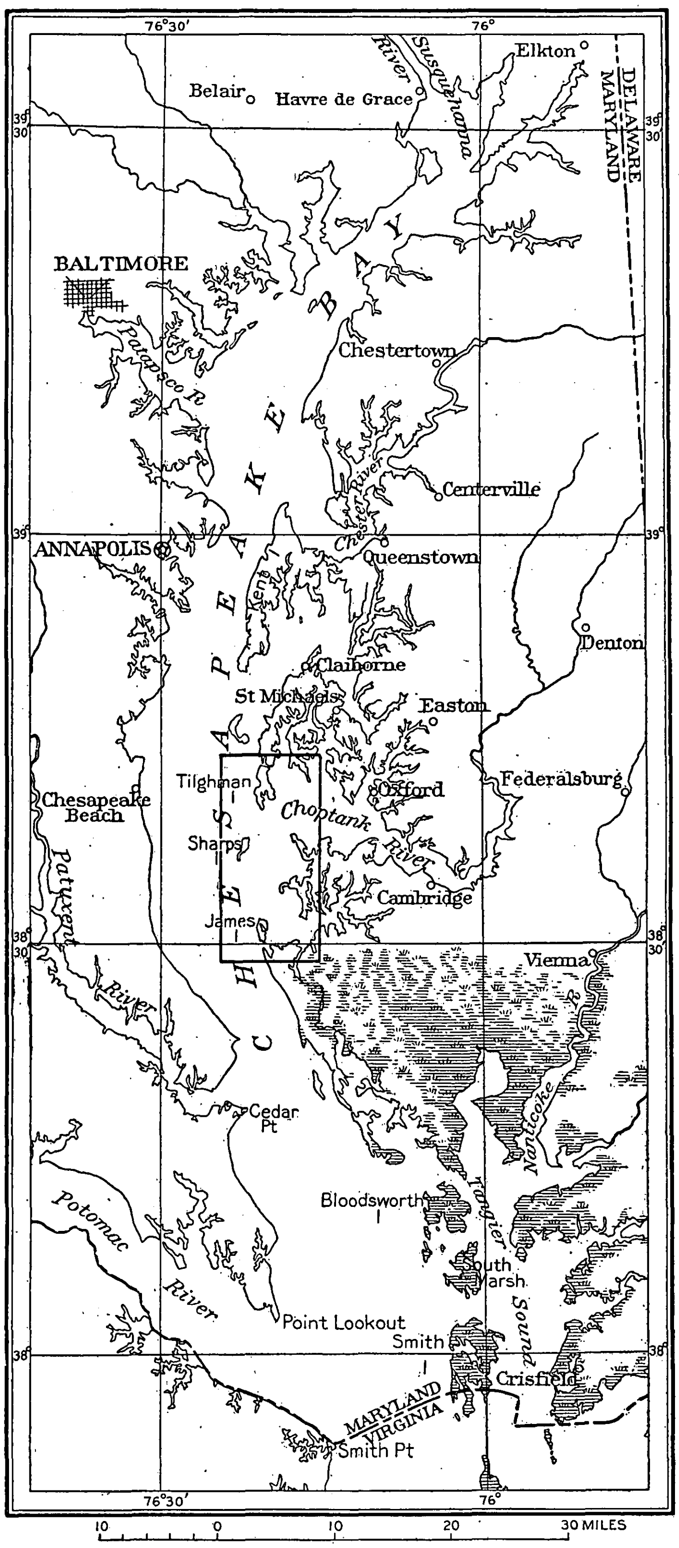


FIGURE 1.—Sketch map of Chesapeake Bay, showing the area studied and its relation to other parts of the bay.

Mr. Charles Yates, of the United States Coast and Geodetic Survey, who has spent a number of years on Government survey work in Chesapeake Bay and to whom the writer is indebted for a number of facts used in the preparation of this paper, has repeatedly urged a study of the processes of erosion and sedimentation as brought out by a comparison of these charts. Owing to the great mechanical labor and the long time necessary for such an investigation, the writer has contented himself with the study of a very small test area on the eastern shore of the bay around the mouth of Choptank River, including Tilghman, Sharps, and James islands and the adjacent mainland, with the purpose of ascertaining the advisability and possible results of a more elaborate study of the entire bay. (See fig. 1.) The test area, which is situated about midway of the length of the bay, is representative of that portion of it which has suffered change sufficient to be noted by cursory examination of the two sets of charts. Moreover, it lies in an intermediate position, north of which the change in shore lines has been effected chiefly by erosion and south of which there has been a very large amount of marsh building. This small area affords an excellent opportunity to establish certain local rates of erosion and sedimentation, but of course gives no data for many of the larger and more general conclusions that would be expected from a study of the entire bay. For example, the relation of sedimentation to land waste as studied by Humphreys and Abbot in the Mississippi River basin and by Mellard Reade, Élie de Beaumont, Archibald Geikie, and others in river basins of Europe and elsewhere, suggests itself as a subject for an investigation that could hope to bear fruit only if pursued on the larger scale.

SURVEYS OF THE AREA DISCUSSED.

The earliest adequate sketch of the mouth of Choptank River is on Herman's "Map of Virginia and Maryland" (1670). Although the map shows much distortion, the chief land features of the area here discussed are represented about as they exist to-day except that James Island (called James Point) had a broad connection with the mainland. Griffith's "Map of Maryland" (1794) shows the land features as they are now, James Island, strange to say, being widely separated from the mainland, although a chart of the Coast Survey prepared in 1848 shows a narrow isthmus between the two. A singular though probably not very significant fact in view of the primitive methods of surveying and the moderate degree of accuracy of the two early maps is that on each of them Tilghman Island is represented as having an outline very different from its present shape and as being separated from Sharps Island by a considerable stretch of water. This fact is interesting in view of the current belief of the inhabitants in a very recent land connection between the two islands. Although these maps are of interest in view of the changes that are known to be taking place, no reliance can be put on their accuracy.

Besides the topographic and hydrographic surveys of 1847–48 and 1900–1901, a plane-table survey of the shore lines of James and Sharps islands, the southern portion of Tilghman Island, and Cook and Hills points was made by Mr. Yates and the writer in December, 1910, with the aid of the charts and triangulation stations of the Coast and Geodetic Survey. The United States Geological Survey has published topographic and geologic maps covering the area,[1] which is located partly in the Choptank and partly in the St. Marys quadrangle.

TOPOGRAPHY AND GEOLOGY.

Two principal topographic and geologic features are represented in this area. One of these is the plain or terrace occupied by the Talbot formation, which is the lowermost and at the same time the youngest of the Pleistocene Columbia group. Although elsewhere this terrace may rise to 40 feet above sea level, it does not reach more than 10 feet in the area under discussion. It is built up chiefly of clay marl and sand, with scattered patches of gravel, and in most places it is terminated by a low scarp cut by the waves, though locally it slopes gently to the water's edge. The other principal feature is the tidal marshes which occupy the remaining but much smaller part of the area not covered by the Talbot formation. They consist of low-lying, swampy land which at high tide may be largely submerged. They are composed mainly of the same materials as the Talbot but contain also an abundant growth of swampy sedge or grass which aids in filling up the depressions by serving as obstructions that retain the mud and by furnishing a perennial accumulation of vegetable débris. The living and dead plants form a thick network through the clay marl and peat, which, thus reinforced at the water's edge, offer great resistance to the cutting of the waves.

CHANGES IN SHORE LINE.

JAMES ISLAND.

Loss in area.—James Island is the southernmost of the trio of islands (James, Sharp, and Tilghman islands) which stand in a line across the mouths of Choptank and Little Choptank rivers and front on the bay. It is crudely wedge-shaped and is nearly cut in two by an inlet that crosses it diagonally. It is next to Tilghman Island in size, being nearly 2 miles long and three-quarters of a mile wide and having a present area of 490 acres. Although now deserted except for a few families the island had at one time a much larger population, as shown by the presence of about 20 houses, a schoolhouse, and a church. The land nowhere rises above 10 feet in elevation, and the shore scarps in places attain 7 feet.

A comparison of the maps of 1848 and 1900 shows some remarkable changes in this island. (See Pl. III.) The narrow isthmus, probably no more than a sand bar, which connected the island with the mainland in 1848 had disappeared in 1900, when 0.28 mile of water separated the two land bodies. At the time of the survey in 1900 the west shore had receded to a point

[1] Shattuck, G. B., and Miller, B. L., U. S. Geol. Survey Geol. Atlas, St. Marys folio (No. 136), 1906. Miller, B. L., U. S. Geol. Survey Geol. Atlas, Choptank folio (No. 182), 1912.

500 yards beyond the head of the inlet of 1848. The inlet had been filled in and the sand bar separating it from the bay had shifted bodily eastward. In area the island had decreased from 975 acres in 1848 to 555 acres in 1901. It had thus suffered a loss of 420 acres, or 43 per cent, in 53 years, showing a mean annual loss of nearly 8 acres. During the succeeding 9 years it was cut down to 490 acres, an average of over 7 acres being cut away each year, the total loss for the period being 65 acres, or 12 per cent. During the 62 years covered by the study, 485 acres, or nearly half the island, had disappeared, an average of 7.8 acres, or about 0.8 per cent of the original area, being carried away each year. However, as the island becomes smaller and the coast line shorter, this average annual loss will be reduced.

Linear cutting.—As in the other islands, almost the entire cutting has taken place on the northern and western shores, the eastern strand line remaining practically stationary during the entire period. The cutting of the outer shores is doubtless due to the strong bay currents and storm waves which sweep these shores, eroding and carrying away great quantities of sediment. However, the rate of cutting has differed notably in different parts of the shores, owing in large measure to unequal resistance of the land material. In general, where the land is comparatively high and where the shore material consists of the clays and marls of the Talbot formation, the cutting goes on most rapidly. In such places the low cliffs offer favorable conditions for erosion. The marly clay, being undercut by the waves, crumbles down in clods or lumps of various sizes. This process of breaking down is helped and to some extent regulated by joints and narrow clay seams, probably formed by the percolation of water dashed back on shore. In many places the shore has numerous angular and rounded reentrants, in some of which are fashioned small caves that may extend to a distance of several feet. The presence of trees on the shore, especially where it is high, may hasten the retreat of the strand line. As the waves cut away the earth from around their roots they fall over into the water, carrying a quantity of soil with them and loosening still more of it where they formerly stood.

The low-lying marl land is much more resistant to erosion than the higher clay scarps. The salt marshes formed by this type of shore deposit support a dense growth of sedge and grass, whose roots are matted together in the clay and sand. This vegetation serves to hold the fine material blown and washed over it, and the marsh is thus built up. At the same time the waves are unable to cut this reinforced material rapidly. Out of these facts comes the explanation of a rather curious and interesting phenomenon. The map of 1901 showed that the only remains of the north end of the James Island of 1848 was a small island situated on the spot which was formerly an arm of the diagonal inlet but which was later filled with marsh material. That water in the midst of land in 1848 should become land in the midst of water in 1901 is a remarkable result of the greater resistance of the marsh-built land. Similar phenomena have been noted elsewhere in the course of the study; in fact, wherever the shore has been of tide-marsh formation the erosion has been comparatively slight.

Another interesting feature of the change in James Island is the shifting of the sand bar that separates the waters of the bay from the head of the inlet. The waves probably add about as much sand as they carry away, the accretions being largely carried over into the inlet basin. Thus the bar seems to be moving slowly eastward. It is probable that in time the bar will be broken through, as was the bar between the island and the mainland. Once open the channel would be widened and the rate of erosion of the resulting two islands accelerated.

No less striking than the loss in area suffered by the island during the last 62 years is the amount of linear advance of the bay. A comparison of the first two maps shows that the average amount of erosion on the north and west coasts of the island during the period from 1848 to 1901 was nearly a quarter of a mile and the annual average was 24 feet. That the rate is fairly constant is shown by the fact that during the nine years succeeding 1901 the average annual rate was 23 feet. At this rate the island, whose maximum width is 0.66 mile, should disappear in about 150 years. This estimate is almost exactly the same as another reached by a consideration of the annual areal loss per mile of eroded shore line. Although this agreement is interesting, the result is little more than a guess, as numerous other factors may enter to disturb the present conditions and rate of erosion.

MAP OF THE MOUTH OF CHOPTANK RIVER, WITH TILGHMAN, SHARPS, AND JAMES ISLANDS

Showing positions of the shore line at the time of different surveys, together with areas of erosion and sedimentation

Prepared by J. F. Hunter from charts of the U. S. Coast and Geodetic Survey and original surveys

Scale $\frac{1}{62,500}$

1 0 1 2 Miles

1 0 1 2 Kilometers

1914

SHARPS ISLAND.

Loss in area.—Sharps Island, the smallest of the three under discussion, stands directly at the mouth of Choptank River, unprotected on any side from the action of the waves. Less than a generation ago it was a summer resort and supported a number of people throughout the year. The north end was well wooded and the island was a favorite ground for hunting ducks and small game. The days of its prosperity are now but a memory, and the life of the island is a thing of the past. The trees have disappeared save for a meager half dozen; the houses have been washed away except for the large hotel which stands alone in the center of the island, a crumbling monument to the activity of other days; the site of an artesian well has been transgressed by the waves so that it now presents the unique feature of a well in the midst of the waters of the bay. The survivors of the piling that made up the long pier which formerly invited the voyager only add to the melancholy of the deserted and dreary scene.

Impressions and hearsay are not the only evidence of remarkable changes in the island, for the story told by comparison of the three maps of 1848, 1900, and 1910 is equally noteworthy. In 1848 the island contained 438 acres; in 1900 the surprisingly small area of 91 acres, or but 21 per cent, had survived. There had been an average annual loss of 6.7 acres, or 1.5 per cent. Owing to the decrease in the length of shore line the amount of erosion annually during the period from 1900 to 1910 dropped to an average of 3.8 acres, which, however, was 4 per cent of the total area of 1900. The area of the island in 1910 was 53 acres, showing a loss of 88 per cent in 62 years, an average annual loss of 6.2 acres, or 1.4 per cent.

Linear cutting.—The maximum erosion on Sharps Island, as on James Island, has been on the west and north sides, the east and south sides having remained substantially unchanged. An interesting feature is the continuance of the sand spit on the south end until after 1900, when the pier was washed away. Since then the spit has moved around to the southeast corner of the island, inclosing a small pond. The northern part of the island is made up of material of the Talbot formation and rises out of the water as much as 7 feet. Here the erosion has been enormous, the water advancing 0.35 mile in 52 years and 0.57 mile in 62 years. The average encroachment on the north and west coasts during the 52-year interval was 0.32 mile, or at the rate of 32 feet a year. During the 10 years between 1900 and 1910 the bay advanced 0.21 mile on the north shore, or at the remarkable rate of 110 feet a year. The loss on the west coast, however, was much less, averaging about 21 feet a year during the period.

The marshland of the southern part of the island is withstanding the force of the waves much more effectively than the rest of the island and will doubtless be the last to disappear. It may be interesting in this connection to venture a prediction, based on the facts at hand, as to the time of final disappearance of the island. By platting the length of the island as ordinates against the time interval between surveys, it is evident that the rate of erosion has greatly increased in the last 10 years. If the rate of that interval were to continue the island would disappear before 1930. However, it is obvious from the general study that the erosion was unusually intense during this period and furthermore that when the marshland is reached the rate will decrease. On the basis of the rate of encroachment during the 52-year interval and the maximum width of 0.28 mile, the time of disappearance would be put at 1947. From a consideration of the annual areal loss per mile of shore line subject to erosion, one-half the remaining exposed shore line being used as a basis, the average annual loss will be 1.67 acres. By this method the date of the island's entire submergence would be put at 1942. At the rate during the last 10 years on the west coast, the estimated date would be a little later, probably about 1950 to 1955.

From general considerations the writer feels that it is fairly safe to predict that Sharps Island will be entirely gone by 1950 and that it is not beyond the range of possibility that the island will disappear before 1940. The higher land to the north will doubtless be cut away first, and in 15 years, if the average yearly rate persists, the house will be reached. In 20 years probably little will be left but the low-lying marshland.

37183°—15——2

TILGHMAN ISLAND.

Tilghman Island is the largest and most northerly of the three islands under discussion. It is over 3½ miles long and has an area of more than 3 square miles, providing homes for many prosperous farmers and fishermen. At its north end are located the towns of Tilghman and Avalon, with a population of several hundred people. It is separated from the mainland by a narrow strait called Knapp Narrows.

This island has suffered much less erosion in proportion to its area than either of the other two. The eastern coast, as in the other islands, remained essentially unchanged during the 63 years from 1847 to 1910. Extensive erosion has taken place along the western coast, except in the protected portion in Pawpaw Cove, a semicircular indentation midway of the island.

During the 53 years between 1847 and 1900 the area of Tilghman Island decreased from 2,015 to 1,686 acres, a total loss of 329 acres, or over 16.3 per cent. The maximum encroachment of the sea has been on the southern cape (Blackwalnut Point), which has receded a quarter of a mile in 63 years. The average annual encroachment of the sea on the western shore during the 53-year period was 10 feet, the estimate excluding the shore of Pawpaw Cove, which has not changed. This is a much lower rate than those effective on the corresponding coasts of the other islands. Only the southern portion of the west coast was surveyed in 1910, but here the erosion has been rather rapid, averaging 29 feet a year for the 10-year period beginning with 1900.

That Tilghman Island will have a much longer life than the other two islands is manifest. By considering as before the mean annual areal loss per mile of exposed shore line and using one-half the remaining westerly exposed shore line as a basis, it would seem that the island will not disappear in its watery grave for at least 570 years. However, this estimate must be regarded only as a very rough approximation.

Although the earliest maps show a large stretch of water between Tilghman and Sharps islands, many of the residents recount the tales told by their forbears of a generation or two ago concerning the proximity and even the connection of the two islands. It may be interesting in this connection to point out the fact that during the 63 years from 1847 to 1910 the average annual widening of the intervening water area was 0.01 mile. As the islands in 1910 were 3.38 miles apart, the time of their separation, if this rate of widening has prevailed continuously, would be about 340 years ago, or about 1570. This is a hundred years earlier than the date of the oldest map, that of Herman, which shows a considerable stretch of intervening water.

SHORES AROUND THE MOUTH OF THE CHOPTANK.

This discussion so far has considered chiefly the shores exposed to the waves of Chesapeake Bay. It may be worth while for comparison to note the changes that have taken place on points affected more particularly by the currents of Choptank and Little Choptank rivers. Cook Point, which lies almost due east of Sharps Island, has been remarkably eroded. During the 53-year interval from 1847 to 1900 this point suffered a loss of 108 acres, or about 17 per cent of its area, thus losing about 2 acres each year. On the northwest coast of the point, where the erosion has been greatest, the water has encroached as much as 0.2 mile in 63 years, or at the rate of 16 feet a year. This rate, however, is a maximum—not an average for the coast line. An interesting feature is the increase of the rate during the 10 years from 1900 to 1910, when the maximum cutting amounted to 0.06 mile, or 32 feet a year. Except at the extreme end there has been comparatively little change on Cook Point. On the west side of the point a pond inclosed by a sand bar is filling up, and is a further example of strongly resisting marsh material. On Hills Point, south of Cook Point, there has been considerable erosion along the northwesterly exposed shores. The average rate here is about 15 feet annually, although the point of maximum cutting may show nearly twice that much. The spit at the end of this point is remarkable for its persistence throughout the 62 years. Farther south the west shore of Ragged Point was cut away to a distance of 0.14 mile in 52 years, or at the considerable rate of 14 feet a year. Nelson Point, on the north side of the Choptank and east of Tilghman Island, suffered a very considerable loss in the 53-year interval before 1900. The former point receded nearly a quarter of a mile, while farther north the neck was cut through by the currents, leaving the former southern part of the peninsula an island.

In general the erosion inside the rivers has been less than on the shores exposed to the action of the bay, although at a few favorable points the cutting has been equally great. As might be expected, the numerous inlets which in part make up the devious shore line of this area showed but little change at the end of the 53-year period. Except at the localities already mentioned, the shore does not show any large losses, the maximum probably being 300 or 400 feet. Moreover, nowhere in the area under discussion has any considerable amount of gain been made by the building up of land. However, south of the area studied large delta deposits are constantly growing and will add a very interesting chapter to the history of the bay.

CHANGES IN SEA BOTTOM.

GENERAL STATEMENT.

Comparison of the surveys of 1847–48 and 1900–1901 not only showed very appreciable changes in the position of the shore lines of the bay but also more or less shifting of the sediments on the sea bottom, as indicated by the differences in soundings for the two periods. Many of these differences are so slight as to come within the limit of error and of the personal equation of the hydrographers. At the same time, in the study of a large area such as the entire Chesapeake Bay, many of these small differences might rightly be taken into account, for any errors would probably tend to compensate rather than to accumulate. However, over a considerable area the results would without doubt be negative; that is, they would show no change. The area here discussed is entirely too small to obtain any very substantial or important conclusions. Nevertheless, a few facts may be worthy of note and may suggest further and better methods for the study of the larger problem.

The method here pursued was to draw, from the Coast Survey charts, hydrographic contours representing depths of 6, 12, 18, and 30 feet below mean sea level for the two periods. By suitably designating the two sets of contours, the areas of cut and of fill could by a little inspection be distinguished. As an intermediate step the area over which a recent contour had shifted was hachured differently according as it had moved toward what was higher ground, thus showing a scouring, or toward what was lower ground, thus showing a shoaling. This greatly facilitated the mapping of the areas subject to erosion and to sedimentation.

AREAS OF EROSION.

The largest and most important area of scouring is that west of Tilghman and Sharps islands. In fact, except for a small area directly north of the mouth of Choptank River and an area west of James Island, the slopes of the bay have experienced fairly uniform cutting. Almost everywhere, however, the erosion has been greatest near the shore, while at a depth of 30 feet the contours show but little change. In the vicinity of the 6 and 12 foot contours the difference in depth for the two dates very rarely reaches 6 feet, while the average would probably be much less.

Another area of extensive erosion is that north and west of James Island, at the mouths of Choptank and Little Choptank rivers, where there has been a deepening of more than 6 feet near shore and uniformly less toward the deep channel. An interesting and rather unexpected area of scour is that west of Ragged Point and southeast of Hills Point, but the amount of change here is somewhat smaller than in the other areas mentioned. Smaller areas of scour are scattered with little regularity over the region, the exact causal relations in many of them not being entirely evident.

AREAS OF DEPOSITION.

The areas of deposition are fewer and somewhat more interesting than the areas of erosion. They indicate local checking of the movements of the currents, which may have resulted from a variety of causes. Perhaps the most interesting example of shoaling is that between Tilghman and Sharps islands, where more than 6 feet of sediment has been laid down in places, the maximum amount being found between the 12 and 18 foot contours. Here Choptank River, flowing westward, probably meets, for a large part of the time at least, a strong inshore current from the bay. The velocity of the river waters is thus diminished and deposition results. On the opposite (south) side of the channel scouring has taken place, thus indicating an acceleration of the river current on that side, except close to the shore, where, strange to say, the soundings show slight deposition. As the river flows on and reaches the broad stretch of water between Sharps Island and the shores of Trippe Bay, its velocity is again decreased, owing to the increase in area of cross section, with the result that deposition occurs on both sides of the channel.

North of the mouth of the river there is an area in which the movement of the water is modified, owing to the junction of the bay and river currents. Here there is, for this reason, a small area of deposition. The cause of the shoaling west of James Island is not immediately apparent, although it may lie in the diversion of the strong river current in a southeasterly direction by the bay currents, a portion of the water being thus backed up against the island and east of the main channel. Other areas of deposition are those east of James Island and on the east side of the Little Choptank between Ragged Point and Hills Point.

Approximately 34 per cent of the area covered by water in the territory under discussion has been affected by erosion or by sedimentation. Of this portion about 80 per cent, or approximately 26 per cent of the total area under water, has been subjected to scouring during the 52-year interval from 1848 to 1900. It appears from a study of profiles and contours that the vertical elements in the areas of erosion and in the areas of sedimentation are approximately equal. Now, inasmuch as but 20 per cent of the area subject to change showed shoaling while 80 per cent showed scouring, and as the vertical element is approximately the same in each case, it becomes evident that the equivalent of at least 60 per cent of the sediments affected in the area must have been carried farther down the bay. The areas subjected to erosion aggregate 35 square miles and those subjected to sedimentation 9 square miles, making an excess of 26 square miles eroded. By taking 1½ feet as a reasonable average for the amount of vertical change, the total quantity carried out of the area and down the bay would approximate 0.007 cubic mile. Of course, no estimate is possible as to the amount transported through this area from points beyond its borders. However, it is apparent that a study of the entire bay would yield interesting data on the amounts of material eroded and deposited in different portions of it. If to such data could be added an estimate of the amount of sediment carried past any point in the bay during the 52-year interval, an approximate estimate could be made of the total land waste of the basins drained by the tributary streams above this point. Such a result would be of fundamental importance to geologists in the consideration of the phenomena of denudation.

SUMMARY.

The quantitative results of the study can best be presented by the following table:

Results of erosion at mouth of Choptank River.

	Date of surveys.	Area (acres).	Interval between surveys (years).	Loss per year (acres).	Average advance of water on eroded coasts. For the period (miles).	Average advance of water on eroded coasts. Annually (feet).
James Island	1848	976				
	1901	555	53	7.9	0.24	24
	1910	490	9	7.3	.04	23
Sharps Island	1848	438				
	1900	91	52	6.7	.32	32
	1910	53	10	3.8	[a] .21 [b] .04	[a] 110 [b] 21
Tilghman Island	1847	2,015				
	1900	1,686	53	6.2	.09	9
	1910		10		[c] .06	[c] 29
Cook Point [d]	1847					
	1900		53	2		
	1910		10		[e] .2 [f] .06	[e] 16 [f] 32
Hills Point	1848					
	1910		62		.18	15
Ragged Point	1848					
	1900		52		.14	14

[a] North shore.
[b] West shore.
[c] Only the south end of Tilghman Island was surveyed in 1910.
[d] Owing to the shape of Cook Point the maximum linear cutting was measured rather than the average.
[e] For 63 years.
[f] For 10 years.

The most interesting feature of the study is the rapid destruction of the three islands. Sharps Island is disappearing most rapidly and will probably be entirely effaced before 1950. The remarkable rate of cutting during the last 10 years on the north end of this island, amounting to 110 feet a year, is worthy of note. Observation shows that practically all the erosion has been on the west and north sides of the islands; that is, on the shores which are most open to the attack of the southerly bay currents and the westerly winds and their waves. In general the cutting has been greatest along the shores having low scarps made up of the clays and marls of the Talbot formation and least along those of the low-lying tidal marshes. For this reason the land now being formed will in many places outlive the older and higher portions. Most of the projecting points within the entrance to the Choptank show considerable change, although much less than the shores of the bay proper. No building up of the land is going on within the area studied, although farther south extensive delta deposits are being laid down.

A study of the submarine changes shows rather extensive scouring along the eastern shore of the bay proper and less extensive though equally intensive shoaling at places within the river mouth. The equivalent of approximately 60 per cent of the total amount of the sediments subject to change in the area is carried farther down the bay. A very rough estimate of the quantity of material carried away from the area is 0.007 cubic mile, but owing to the fact that this material comes from several different basins and that the amount of sediment transported through the area is unknown no idea as to the rate of land waste could be obtained.

In conclusion, while the present work should be regarded only as a test investigation of the erosion and sedimentation in Chesapeake Bay, it is demonstrated by the comparison of the two surveys of 1848 and 1900 that very significant changes both in the topography and in the hydrography of the region have taken place. Although the data here set forth are chiefly of local importance, it is hoped that the study may suggest certain methods that are applicable to a complete study of the bay. Such a study of the changes during an interval of over 50 years would present some idea as to the land connections and distribution not only of the past but likewise of the future. It would also give quantitative data on the rate of erosion and of sedimentation and, if carried far enough, should furnish new and significant data on the rate of land waste in the surrounding basins. Finally, if the study of this small area shall lead to a more extensive investigation as to the quantitative relations of these fundamental geologic processes, the purpose of the work will have been fulfilled.

DIKE ROCKS OF THE APISHAPA QUADRANGLE, COLORADO.

By Whitman Cross.

INTRODUCTION.

Location and field work.—The Apishapa quadrangle, the geographic relations of which are shown by Plate IV, is situated on the plains south of Arkansas River, in Colorado, about 24 miles east of the mountain front. The geology of the Pueblo, Walsenburg, Spanish Peaks, and Elmoro quadrangles, adjoining it on the northwest, west, southwest, and south, respectively, has been described in folios of the Geologic Atlas.[1] G. K. Gilbert, assisted by F. P. Gulliver and G. W. Stose, took up the survey of the Apishapa area in 1894. The Apishapa folio was completed by Stose and was issued in 1913. The rocks to be described in this paper were collected by Gilbert and his assistants, the present writer never having visited the area. The following description of the occurrence of the rocks has been kindly furnished by Mr. Stose.

Occurrence of the rocks.—Forty-three dikes have been observed in the Apishapa quadrangle. They are mostly vertical in position and trend as a rule nearly west, or somewhat to the south of west. The greater number are from 4 to 10 feet wide, but a few reach a width of 20 feet or more.

The trend of the dikes and the character of the dike rocks demonstrate clearly that they belong to the outer zone of the system of dikes radiating from the Spanish Peaks center, to the southwest. Near this center similar dikes cut the Eocene Huerfano formation, and in the Apishapa quadrangle the latest Cretaceous formation present is penetrated by some of the rocks here described. While the dikes are therefore possibly of late Eocene age, they may be considerably younger. Fragments of the dike rocks are found in the earliest terrace deposits of the quadrangle.

The dikes are most numerous, naturally, in the southwestern part of the quadrangle—the part nearest to the Spanish Peaks. The most thickly intruded tract is an elliptical upland area southeast of Bonita Cordova ranch, where 12 dikes occur within a strip about 1 mile wide. In a few places dikes were observed to intersect one another, but the relative ages were not determined, though the identification of specimens has shown that in most of these places the intersecting dikes are made up of different rocks. In Graston Butte, the dike hill east of North Rattlesnake Butte, a long branching dike of basalt is cut by a shorter one of augite vogesite.

Where the dikes penetrate shale the shale has been indurated, as a rule for several feet from the contact, and erosion has left the dike and the indurated wall rock projecting above the surface of the soft shales. No noticeable mineral change has occurred in the baked shale. A similar effect is locally found where dikes cut limestone.

The most conspicuous of these dike ridges are Mica Butte and Blue Hill. Graston Butte, east of North Rattlesnake Butte, and some others, unnamed, are nearly as large but are less conspicuous because they are less isolated.

Where the dikes cut the Dakota sandstone or the Timpas limestone (Cretaceous), they are generally attacked more readily by weathering and erosive agencies than the wall rocks and therefore are indicated by crevices or channels traversing the sedimentary formations.

[1] Gilbert, G. K., U. S., Geol. Survey Geol. Atlas, Pueblo folio (No. 36), 1897. Hills, R. C., idem, Elmoro folio (No. 58), 1899; Walsenburg folio (No. 68), 1900; Spanish Peaks folio (No. 71), 1901.

Several dikes contain xenoliths of foreign rocks brought up from lower levels and derived partly from sediments traversed by the dikes and partly from the pre-Cambrian complex below. The pre-Cambrian rocks are granites, gneisses, and schists, similar to those of the Greenhorn Mountains, to the west. No fusion or notable metamorphism of these xenoliths was observed.

General character of the rocks.—All the Apishapa dike rocks are very dense and dark in the unaltered state. The rock most easily determinable in hand specimens is a minette. Two diabases are dark gray and with a hand lens one can recognize feldspar and pyroxene in them. The largest group is that of the homogeneous-appearing aphyric aphanites; these grade into melaphyres (in the field meaning of the term) exhibiting more or less abundant and distinct small olivine and augite phenocrysts. Biotite tablets as much as 1 centimeter in diameter are sporadically developed in some rocks.

A few specimens are characterized by round or irregular white grains of analcite. Although in two specimens these grains appear like phenocrysts, it is believed that they are the filling of small pores. In one rock a fibrous zeolite occurs beside analcite partly filling vesicles. Calcite and chlorite are associates of the analcite in some rocks.

Microscopical study shows that the rocks belong to a series of lamprophyres ranging from minette to basalt. That the basalt is but one extreme of the series is shown by the gradation through several occurrences into alkali feldspar rocks carrying abundant biotite and brown hornblende, with augite and more or less olivine. The analyses to be presented confirm this characterization. The dikes of the adjacent quadrangles furnish many other lamprophyric varieties, according to Hills, making the gradation still more striking.

The Apishapa dike rocks will be described under the names minette, augite minette, tinguaite, olivine-bearing augite vogesite, augite-hornblende vogesite, sodic diabase, and olivine-plagioclase basalt.

PETROGRAPHY.

MINETTE.

Description.—The single dike of normal minette occurs west of the lower or north end of the canyon of Apishapa River. It trends east-west and is 10 feet or more in average width. Material from a point about 5 miles west of the river has a reddish or gray-brown color due to numerous leaves of glistening biotite, many of which are 2 or 3 millimeters across. A rude parallel arrangement of the biotite flakes causes a marked schistosity. The matrix is pale pinkish in tone, owing to the presence of minute biotite scales and limonite pigment. No phenocrysts of feldspar or augite can be detected.

Under the microscope the rock is seen to be a mass of interlacing leaves of fresh biotite, which form perhaps one-third of the whole, with a matrix consisting principally of clear alkali feldspar in blades, many of them arranged in sheaf-like bundles. Besides these predominant constituents, apatite is notably abundant in colorless cross-jointed prisms, the smaller of which are included in the biotite. A prismatic mineral, presumably diopside, was once an abundant element but is now almost wholly decomposed, chlorite and calcite in a very fine aggregate of indistinct outline taking its place. Magnetite is scattered through the rock in dustlike particles surrounded by limonitic stain. The feldspar is principally orthoclase, with which is associated some soda-rich plagioclase, probably oligoclase-albite.

Calcite occurs not only as one of the alteration products of the prismatic mineral but also in minute scales and irregular particles scattered through the mass. No calcite grains with distinct cleavage have been seen. The amount of calcite corresponding to the CO_2 found by analysis is much greater than the estimate from microscopical examination. This discrepancy is explained by the presence of minute seams of calcite parallel to the schistosity, representing a deposit from circulating solutions. These seams do not appear in the thin sections.

RELIEF MAP OF SOUTH-CENTRAL COLORADO, SHOWING RELATION OF THE APISHAPA QUADRANGLE TO THE SPANISH PEAKS CENTER OF ERUPTION.

The Apishapa quadrangle is outlined in white.

Chemical composition.—An analysis of the rock just described, made by George Steiger in the laboratory of the Geological Survey, is given in column 1 below and is accompanied by analyses of similar rocks:

Analyses of minette and related rocks.

	1	2	3	4	5	6
SiO_2	32.32	52.26	50.81	40.71	50.41	41.57
Al_2O_3	8.16	13.96	15.13	19.46	12.30	9.75
Fe_2O_3	9.46	2.76	2.40	7.46	5.71	4.06
FeO	4.10	4.45	3.52	6.83	3.06	4.47
MgO	5.97	8.21	10.64	6.21	8.69	8.65
CaO	12.60	7.06	4.96	11.83	7.08	11.10
Na_2O	.69	2.80	1.01	1.80	.97	1.57
K_2O	5.97	3.87	7.01	3.26	7.53	6.10
H_2O+	4.09	1.34	3.07	1.53	1.80	2.30
H_2O-	1.03	1.53	....	....	.46	1.54
TiO_2	4.55	.58	1.71	....	1.47	2.36
CO_2	6.30	.49	Trace.	.74	....	1.24
P_2O_5	3.78	.52	.62	....	.46	4.05
S	.26	....	....	....	....	....
MnO	.13	.14	Trace.	.18	.15	.25
BaO	.36	.23	....	....	.23	.44
SrO	.24	....	....	....	....	.11
	100.01	100.25	100.88	100.01	100.42	[a] 99.90
Less O	.13					
	99.88					

[a] Including ZrO_2 0.02, Cl 0.04, F 0.23, Cr_2O_3 0.04, NiO 0.02, V_2O_3 0.04, FeS_2 0.06, and deducting 0.11 O for F, Cl.
1. (Augite) minette, Apishapa quadrangle, Colo. George Steiger, analyst.
2. Augite minette, Sheep Creek, Little Belt Mountains, Mont. W. F. Hillebrand, analyst; rock described by L. V. Pirsson, U. S. Geol. Survey Twentieth Ann. Rept., pt. 3, p. 531, 1900.
3. Augite minette, Plauensche Grund, near Dresden, Saxony. B. Doss, analyst; Min. pet. Mitt., vol. 11, p. 27, 1890.
4. Minette, Franklin Furnace, N. J. L. G. Eakins, analyst; described by J. P. Iddings, U. S. Geol. Survey Bull. 150, p. 238, 1898.
5. Syenitic lamprophyre, Two Buttes, Colo. W. F. Hillebrand, analyst; described by W. Cross, Jour. Geology, vol. 14, p. 165, 1906.
6. Apatite minette, northwest bank Columbia River, opposite Northport, Wash. W. F. Hillebrand, analyst; described by F. L. Ransome, Am. Jour. Sci., 4th ser., vol. 26, p. 337, 1908.

Analysis No. 1 shows low silica and alumina, corresponding to the dominance of biotite; potash is strongly in excess over soda; and phosphoric acid is very high, in agreement with the abundance of apatite. The decomposition of the pyroxene and especially the infiltration of calcite account for the high carbonic acid. It must be assumed that the biotite is rich in magnesia, and probably a large part of the titanic acid is to be found in the mica, as no ilmenite or titanite has been detected.

A comparison with other analyses of minette, after all due allowance has been made for the calcite present, shows the Apishapa rock to be unusually femic. While good analyses of minette are rare, the few found in literature are of rocks much richer in silica, alumina, and magnesia. None of those cited is so comparatively rich in potash. The Colorado rock has also a larger amount of titanic acid than the others. It is exceeded in phosphoric acid contents only by the apatite-rich minette of Washington (No. 6). The Washington rock is also rich in titanic acid, and it seems not improbable that these two minettes were, when unaltered, closely allied rocks.

In general mineral and chemical character this minette is about as closely related to the peculiar lamprophyric rock (prowersose) from Two Buttes, Colo. (No. 5), as it is to any of the analyzed minettes. That rock is richer in orthoclase and diopside and poorer in biotite than the minette. It has also much less normative apatite and ilmenite. The Two Buttes rock was described as "a syenitic lamprophyre allied to minette."

Classification.—The described characters of this rock clearly place it under minette in the qualitative system. It was no doubt originally an augite-bearing minette, though perhaps approaching the pure biotite variety. The rarity of minette free from augite or hornblende has been commented on by Rosenbusch.[1]

The position of this rock in the quantative system may be approximately determined in spite of its high content of carbonic acid, for, as has been pointed out, the greater part of the

[1] Rosenbusch, H., Mikroskopische Physiographie der massigen Gesteine, 4th ed., p. 666, 1907.

calcite is not due to decomposition of rock constituents. The norm and systematic position of the rock are as follows:

Norm and systematic position of minette from Apishapa quadrangle, Colo.

or	35.58	Class: $\frac{Sal}{Fem}=\frac{42.28}{38.18}=1.11$, salfemane, III.
ab	6.29	
C	.41	
en	1.70	Order: $\frac{L}{F}=\frac{0}{41.87}=0$, perfelic, gallare, 5.
fo	9.24	
mt	.23	
hm	9.28	Rang: $\frac{K_2O'+NaO'}{CaO'}=\frac{76}{0}=\infty$, peralkalic, 1, orendase.
il	8.66	
ap	9.07	
	80.46	Subrang: $\frac{K_2O'}{Na_2O'}=\frac{64}{12}=5.33$, dopotassic, (1) 2 (unnamed).
Calcite	14.30	
H_2O, etc.	5.38	Symbol: III.5.1.(1)2.
	100.14	

Unless more soda has been removed than there is discernible reason to suppose this is one of the most distinctly potassic rocks known. But the degree of alteration, as well as the transitional position of the rock shown by the ratio $K_2O:Na_2O$, renders it inappropriate to name the subrang from this occurrence. The minette from Washington (No. 6) contains both nephelite and leucite and a large amount of diopside in its norm. It seems evident that the Apishapa rock may have contained so much pyroxene that normative lenads would have appeared if the analysis had been made on fresh material.

AUGITE MINETTE AND TINGUAITE.

Mica Butte, situated west of Apishapa River, in the southern portion of the quadrangle, is traversed by an east-west dike, the single specimen of which at hand exhibits two distinct rocks, one cutting the other in very intricate fashion. No recorded observations give further data on the field relations. The specimen consists chiefly of a brown, fine-grained, plainly biotite-bearing rock, much brecciated, and penetrated by dull pale-green tongues of apparently crystalline character. A poikilitic fabric is indicated in both parts by the cleavage luster of large feldspar grains, some nearly 1 centimeter across. The chadacrysts[1] are irregularly distributed through the orthoclase and all other primary constituents occur in this manner.

From the name given to the butte where this dike occurs it may be inferred that biotite is developed in much of the rock in larger crystals than in the specimen. The green material, of tinguaitic character, is so different from the minette that some considerable development must also be assumed for it.

Under the microscope the minette part of the specimen is found to consist of biotite, augite, alkali feldspar, apatite, magnetite, and brown glass. Fresh feldspar grains of various sizes inclose many augite and apatite needles of perfect crystal form and wholly irregular orientation. Some of the augite prisms betray the presence of the ægirite molecule by color and pleochroism but retain a large extinction angle. Smoky glass acts like the feldspar as matrix for the other minerals in many spots. Titanite is present in a few large grains penetrated by apatite needles.

This augite-bearing minette gives reason for the suppositon that the altered prismatic mineral of the other minette described was augite, but the latter rock is much richer in biotite than the specimen from Mica Butte.

The tinguaitic material, injected in fine veinlets all through the minette, varies greatly in texture and in the degree to which it is mixed with the minette minerals, especially biotite. Some narrow arms are coarse grained and consist of alkali feldspar, ægirite, apatite, titanite, magnetite, and glass. In such parts the ægirite occurs in irregular bunches or interstitial grains between the larger and more abundant alkali feldspars.

[1] Chadacrysts are the crystals or grains inclosed in the oikocryst, or "host": Iddings, J. P., Igneous rocks, vol. 1, p. 202, 1909.

In other tongues there is a felt of ægirite needles in a fine granular mass of feldspar, and here augite of the same habit is more or less mingled with ægirite, as is also more or less biotite, in minute flakes. Sodalite or noselite in regular crystals is variably developed in some veinlets.

While this occurrence of tinguaitic character is worthy of note, the lack of observations as to its occurrence and the inadequate material at hand for its study make further description at this time undesirable.

OLIVINE-BEARING AUGITE VOGESITE.

Description.—The most abundant variety of these Apishapa dike rocks is made up principally of augite, olivine, magnetite, apatite, and a colorless matrix, which in most rocks consists mainly of alkali feldspar but in some is in part a glass. Biotite is a very common and brown hornblende an occasional constituent of small quantitative importance. All these rocks appear to be domafic[1] in general character, but the analysis of a typical rock of this group shows that the salic molecules actually predominate in the norm and they probably do so also in the mode.

Most of these vogesites are dopatic or perpatic microphyres, megaphenocrysts of olivine, augite, or biotite being rare. Both olivine and biotite sporadically reach dimensions of 1 centimeter or more. Under the microscope it is seen that olivine is commonly and augite occasionally developed in prominent phenocrysts. But the porphyritic texture is locally obscured by the seriate development of augite from the largest to the minutest particles. In a few specimens white grains of analcite are conspicuous, but these are believed to be the filling of small vesicles, and though possibly formed immediately after the consolidation of the magma, the analcite is not properly a phenocryst.

Augite is the most abundant constituent of these rocks, possibly exceeding 35 per cent in some dikes. It is pale green in color, prismoid in form, and generally of euhedral or subhedral development. In size it ranges from microphenocrysts several millimeters long to minute particles requiring a high-power lens for their identification. It is almost invariably unaltered.

Olivine was probably present in all these rocks, and in many of them it is still fresh, but in a few it is entirely altered to a chloritic or pilitic aggregate. Biotite is seldom lacking among the minute particles of the groundmass, and here and there hornblende of similar brown color is associated with it.

The brownish color of the base in some rocks is found by high magnification to be due mainly to minute scales of biotite or short prisms of hornblende, and in others it is caused by ferritic globulites. Both hornblende and biotite may be developed in equant grains of similar appearance. Magnetite occurs in many small and nearly uniform grains, but is less abundant than might be expected in such basic-looking rocks. Apatite is variable in amount but is unusually abundant in most dikes.

The felsic[2] element of these rocks plays the part of a base holding the mafic constituents. It is holocrystalline in a few rocks, partly crystalline in some, and almost or quite hyaline in others. In the most distinctly crystalline form it is anhedral and granular and consists of apparent alkali feldspar having a refractive index always distinctly less than that of balsam. More commonly the base exhibits but faint polarization and has a pale-brownish color when examined with low power. Under high magnification the mass often appears fibrous, the fibers being outlined by pale-brownish globulites between them.

The rock of this group, of which an analysis is given on page 22, is represented in Plate V. Plate V, *A* shows the appearance in ordinary light. Olivine in large crystals is represented by white areas having a rough surface. Augite is developed in clouded prisms corresponding to the olivines in size and also in many small prismoids and grains. The white irregular base is

[1] *Mafic* applies to the whole group of ferromagnesian minerals developed in rocks and to rocks in which such minerals dominate. It is distinct from *femic*, which applies properly only to normative nonaluminous ferromagnesian molecules. Cross, Iddings, Pirsson, and Washington, Jour. Geology, vol. 20, p. 561, 1912.

[2] *Felsic*, a term complementary to mafic, has been proposed for the group of modal feldspar, feldspathoids, and quartz, to which the normative term *salic* is often incorrectly applied. Cross, Iddings, Pirsson, and Washington, idem.

alkali feldspar, some of the radiating and branching groups of needles being visible in the center of the figure. Biotite is here very subordinate and its small flakes can not be distinguished from magnetite in the photograph.

Plate V, *B* brings out the rather prominent bundles of alkali feldspar needles and the irregularly granular, anisotropic character of the rest of the white base of Plate V, *A*.

In a few of these augite vogesites there is some isotropic or very faintly polarizing substance that plays the same textural part as the feldspar aggregate of the rock illustrated by Plate V. Some alkali feldspar accompanies this base, which is supposed to be glass. It is clouded by minute brownish particles.

In several rocks there is also another isotropic substance, of dusty appearance and low refractive index, which is usually associated with chlorite and calcite and is believed to be secondary analcite.

Indications of plagioclase are entirely lacking in most of these olivine-bearing augite vogesites. Nephelite is possibly present in small amount in the very fine grained base, which consists largely of alkali feldspar, but it nowhere assumes a distinctly recognizable form.

Chemical composition.—An analysis of a fresh typical olivine-bearing augite vogesite is given in column 1 below, together with analyses of chemically analogous rocks, for comparison.

Analyses of olivine-bearing augite vogesite and related rocks.

	1	2	3	4	5	6	7
SiO_2	44.31	44.39	44.87	43.64	42.80	44.66	44.52
Al_2O_3	14.10	13.12	14.05	13.12	12.49	12.97	14.28
Fe_2O_3	4.75	4.19	2.03	6.40	4.32	3.84	6.36
FeO	6.02	7.38	7.79	5.52	6.06	7.55	5.39
MgO	7.80	9.54	8.87	9.36	7.62	9.35	7.13
CaO	9.66	9.55	9.76	9.52	10.43	8.82	10.20
Na_2O	3.74	4.17	4.65	3.89	4.33	4.24	3.76
K_2O	2.83	2.22	2.31	2.18	2.75	2.78	2.59
H_2O+	3.29	1.96	.62	.49	4.92	.69	3.53
H_2O-	.88	....	....	.16	....	.48	
TiO_2	2.10	2.40	4.71	4.55	2.36	2.76	2.04
P_2O_5	.53	.93	.27	.74	1.77	1.10	.56
S	.10	....	.23	....	....	....	....
MnO	.18	....	.07	....	....	.20	....
BaO	.10	....	....	....	....	....	....
SrO	.10	....	....	.03	....	....	....
	100.49	100.18	[a]100.23	99.60	99.85	[b]99.71	100.36
Less O	.05						
	100.44						

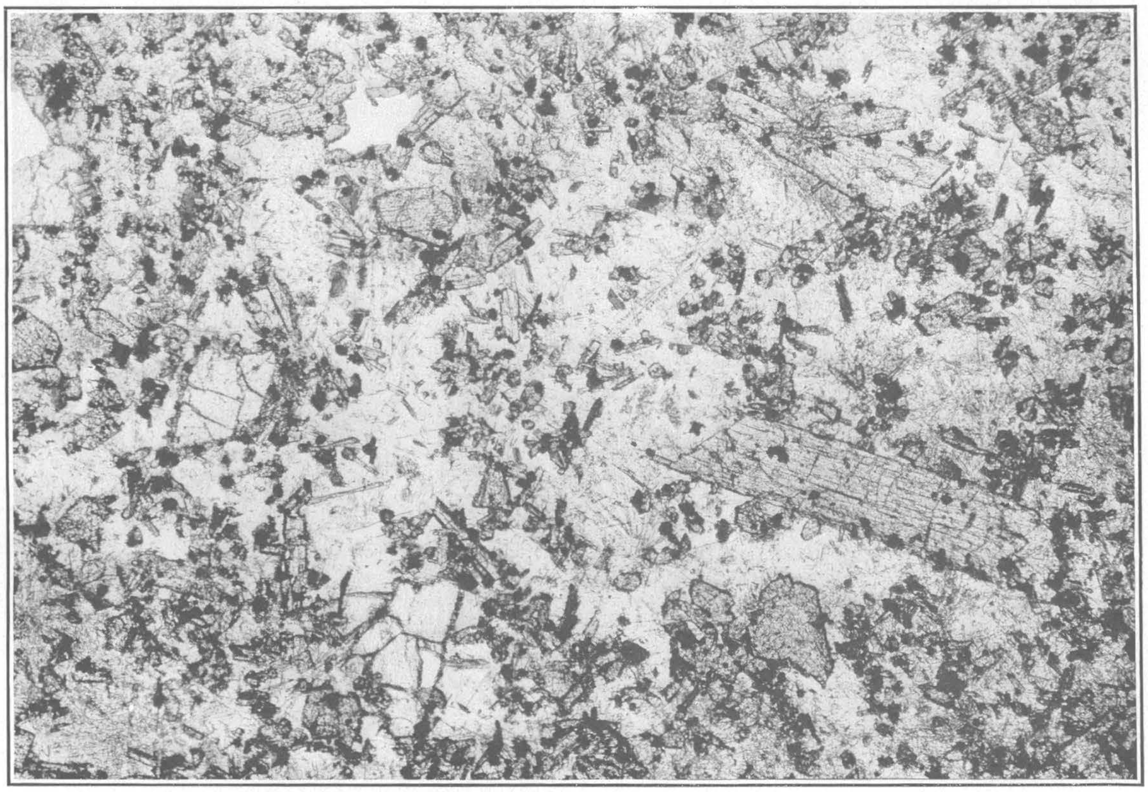
[a] Including CO_2, 0.16. [b] Including Cr_2O_3, 0.01, and NiO, 0.26.

1. Olivine-bearing augite vogesite, dike south-southeast of Dripping Spring, Apishapa quadrangle, Colo. Analyst, George Steiger.
2. Feldspar basalt, Friedrichstolln, Der Meissner, Allendorf, Hesse. Cited by F. Beyschlag, Erläuterungen zur geologischen Spezialkarte von Preussen, Blatt Allendorf, p. 47, 1886.
3. Essexite, Haselbach, Passau, Bayrischer Wald, Bavaria. Analyst, G. Vervuert. Described by A. Frentzel, Geogn. Jahresheften, vol. 24, p. 162, 1911.
4. Nephelite basanite, La Garrinada, Olot, Spain. Analysis and description by H. S. Washington, Am. Jour. Sci., 4th ser., vol. 24, pp. 233-240, 1907.
5. Leucite basalt, Hertinghausen, Hesse-Nassau, Germany. Analyst, Dittrich. Described by R. Bernges, Neues Jahrb., Beil. Band 31, p. 633, 1911.
6. Basalt (trachydolerite), Sverre Fjeld volcano, Bock Bay, Spitzenbergen. Analyst, Dittrich. Described by V. M., Goldschmidt, Videnskapsselsk. Skr.-naturv. Kl., 1911, No. 9.
7. Nephelite basanite. Jesserken Berg, Bohemian Mittelgebirge. Analyst, C. Fr. Eichleiter. Described by G. Irgang, Min. pet. Mitt., vol. 28, pp. 55-57, 1909.

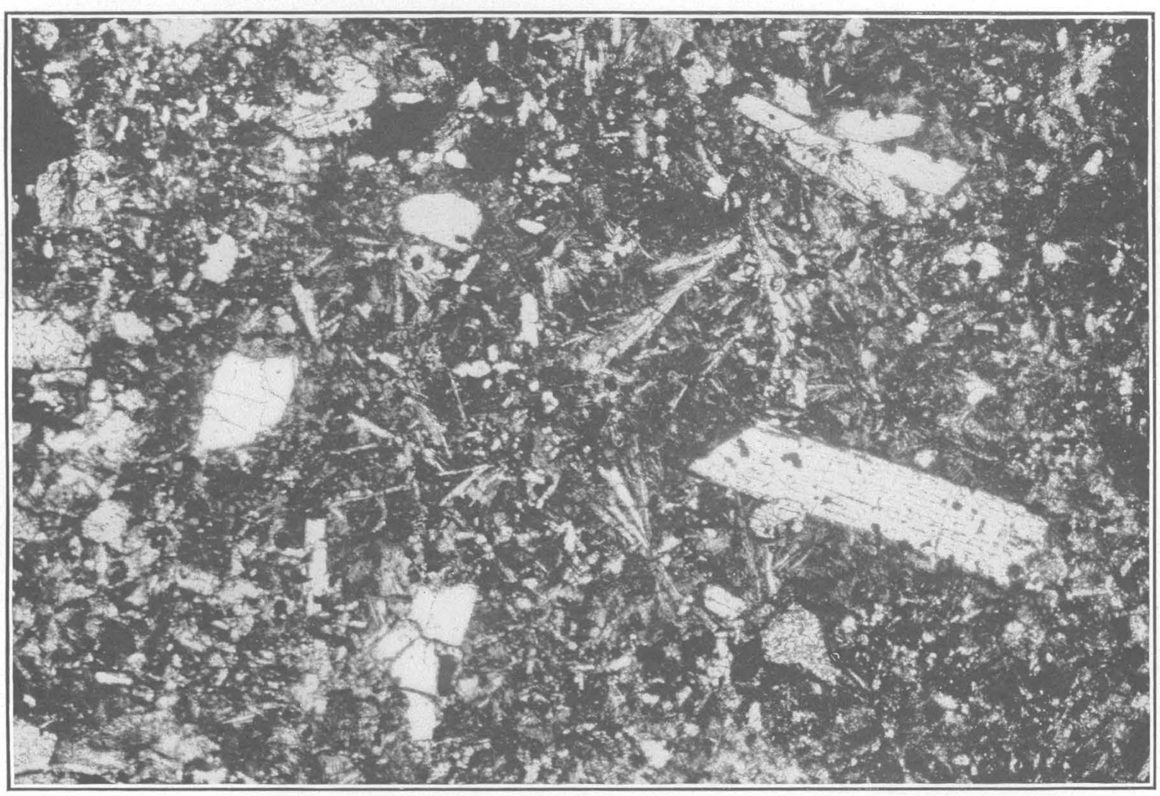
The agreement in chemical character among these rocks is notable, yet the names assigned to them show how greatly the conditions of consolidation affect the mode. The seemingly small variations of the different oxides have in fact an important effect on the normative or potential mineral character of these magmas, as appears from the table of norms given below. Titanic acid is notably high.

Classification.—The norms of the rocks whose analyses have been quoted will be found in the table below. Those for the cited rocks of this and succeeding tables have been calculated by H. S. Washington.[1]

[1] Dr. Washington has kindly given me free access to the extensive material he has compiled for a new edition of his invaluable tables of rock analyses, now nearly ready for publication.



A.



B.

PHOTOMICROGRAPHS OF ANALYZED AUGITE VOGESITE.

A, With one nicol; *B*, with crossed nicols. Magnified 51 diameters.

Norms of olivine-bearing augite vogesite and related rocks.

	1	2	3	4	5	6	7
or	16.68	12.79	13.34	12.79	16.12	16.68	15.57
ab	7.60	10.74	7.07	15.58	7.86	9.96	10.48
an	13.07	10.56	10.84	11.95	6.95	7.51	14.18
ne	13.20	13.49	17.46	11.08	15.34	13.92	11.64
di	25.32	24.12	28.23	23.76	26.46	23.12	25.68
ol	8.08	13.25	9.78	8.68	6.81	13.66	4.93
mt	6.96	6.03	3.02	4.64	6.26	5.57	9.23
il	4.00	4.56	8.97	8.66	6.38	5.32	3.95
hm				3.20			
ap	1.24	2.35	.67	1.68	4.02	2.69	1.34

The position of the Apishapa rock (No. 1) in the quantitative system is determined by the following data:

Class: $\frac{\text{Sal}}{\text{Fem}}=\frac{50.55}{45.60}=1.11$ =III, salfemane.

Order: $\frac{\text{L}}{\text{F}}=\frac{13.20}{37.35}=0.376=6$, portugare.

Rang: $\frac{K_2O'+Na_2O'}{CaO'}=\frac{91}{47}=1.936=2'$, monchiquase.

Subrang: $\frac{K_2O'}{Na_2O'}=\frac{30}{61}=0.49={}'4$, monchiquose.

The other rocks have the following symbols:

2....III.6.2.4	4....III.6.2'.4	6....III.6.2.4
3....III.6(7).2.4	5....III.6'.2.4	7....III.6.2(3)'.4

The Apishapa rock comes well within the central parts of the salfemane class and its lendofelic order, portugare. It is domalkalic but intermediate toward the alkalicalcic rang limburgase. As to subrang it is dosodic but intermediate toward the sodipotassic shonkinose. With regard to the femic elements it is dopolic, prepyric, premiric, and premagnesic, and in these respects the rocks compared with it are closely analogous.

In the mineralogic or qualitative system the Apishapa rock must be called an olivine-bearing augite vogesite, for it has no plagioclase. Manifestly its feldspar is highly sodic and hence the rock is not a typical vogesite.

Bearing the name vogesite, the Apishapa rock parts company with its chemical analogues so far that no suggestion of close similarity with them is conveyed by their current names.

Comparison of norm and mode.—In the vogesite from Colorado norm and mode do not agree at all closely in some important respects. That rock is purely of an alkali feldspar type, yet it has more normative anorthite than most of the chemically analogous rocks containing plagioclase. It has a large amount of normative nephelite but little in the mode, while the reverse is true of augite and olivine. No doubt the augite contains much of the lime and alumina of the normative anorthite, and the abnormative amounts of olivine and augite release some silica, which presumably served to decrease the nephelite and increase the albite of the rock.

It is interesting to note that the rocks compared with this vogesite also exhibit differences of norm and mode. The basalt of the Meissner (No. 2) is a well-known rock cited by Rosenbusch, Zirkel, and others as typical of the doleritic basalts of intersertal texture, without mention of nephelite as a constituent. Beyschlag, however, notes that among the petrographers who have studied the Meissner basalt Senft and Möhl have reported nephelite, a determination which he regards as requiring confirmation. The quoted analysis of the Meissner basalt seems clearly to be the most reliable of those cited by Beyschlag, but he unfortunately gives no special description of the material analyzed. Alkali feldspar is present, though not in large amount, in a section of rock from the Meissner given to me many years ago by Prof. Zirkel, but I have not been able to find nephelite in it. The norm of the Meissner basalt shows that it has potential nephelite, and if conditions in some parts of the mass were favorable to its development nephelite might well assume locally an important rôle.

The essexite (No. 3) of the above table has abundant andesine, though its normative anorthite is less than that of the vogesite. In spite of the name essexite Frentzel does not mention nephelite as a constituent, although 17.46 per cent is shown in the norm. The nephelite basanite of La Garrinada (No. 4) has abundant labradorite and some nephelite, but orthoclase is not mentioned by Washington. The leucite basalt (No. 5) has so much glass that its holocrystalline mode can not be safely inferred, but its abnormative leucite is certainly not due to low silica or high potash contents.

The basalt of Bock Bay (No. 6) appears from the full description of Goldschmidt to have nephelite in its groundmass, though in particles so minute that he regards the determination as questionable. Although containing practically the same potash and more soda than the vogesite, this basalt has no determinable alkali feldspar. With less lime and much less normative anorthite than the vogesite, it has considerable plagioclase, richer in soda than in lime.

The nephelite basanite of Jesserken Berg (No. 7) presents curious relations of norm and mode, particularly when compared with the vogesite (No. 1) and the basalt of Spitzbergen (No. 6). It is a sanidine-bearing nephelite-hauyne basanite with oligoclase as its lime-soda feldspar, yet it has nearly twice as much normative anorthite as the basalt from Spitzbergen and is not so rich in the alkali molecules. It agrees closely with the vogesite in chemical composition but has both plagioclase and lenads much more prominently developed.

HORNBLENDE-AUGITE VOGESITE.

Description.—A group of vogesites differing but little from the group just described in megascopic appearance is characterized by an abundance of camptonitic brown hornblende, equaling or exceeding augite in amount, with biotite of the same brown color, and a variable development of plagioclase, which is always subordinate to alkali feldspar. Olivine is or was a constituent of less importance than in the other group, and it is commonly decomposed to a pilitic aggregate, while the other mafic silicates are fresh. Apatite and magnetite are abundant.

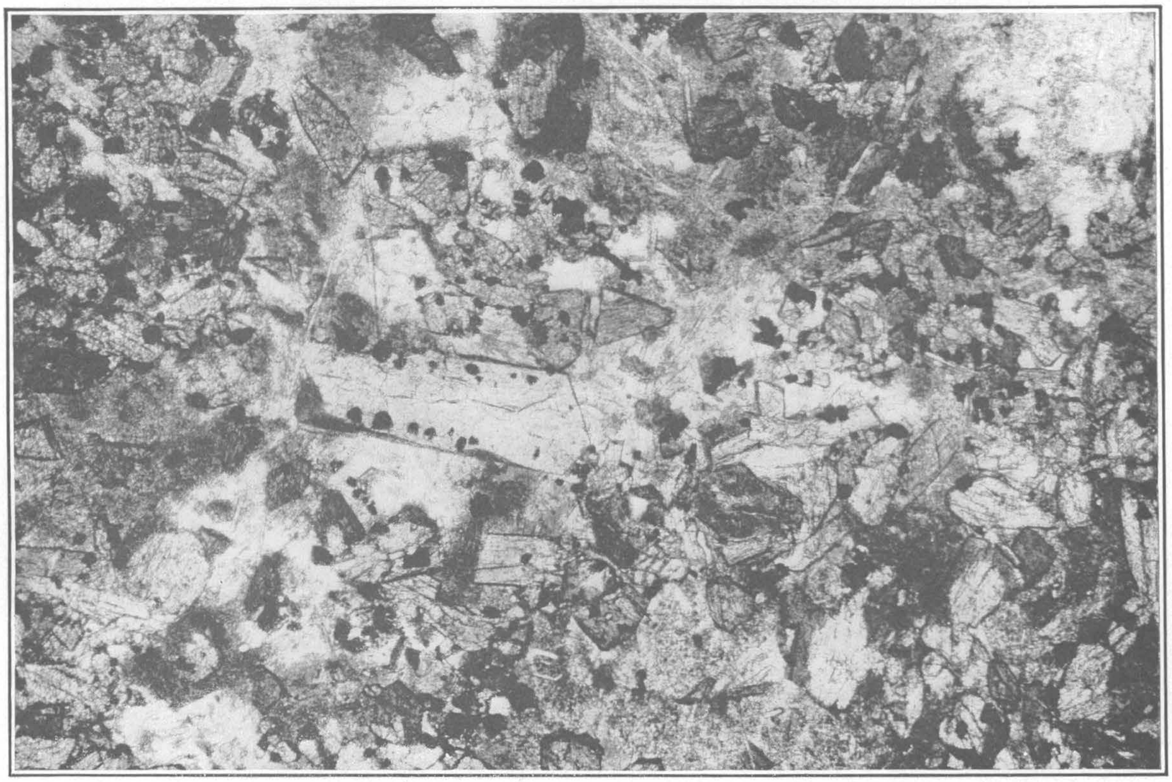
Some of these vogesites are unevenly panautomorphic, granular except for the alkali feldspars, and so coarse that their texture can almost be recognized by the unaided eye. Others are microphyres, and in these hornblende and biotite are chiefly or wholly in the groundmass, while a part of the augite appears in distinct microphenocrysts along with olivine.

The mafic silicates predominate somewhat, but feldspars are more abundant than they seem to be, because of the occurrence of the alkali feldspars as the matrix. Plagioclase is most commonly developed in stout crystals of imperfect form and is labradorite or andesine.

Analcite occurs in round phenocrystic grains and some of it seems as if it might be primary, but this is questioned because small pores of the same size containing chlorite, calcite, and sometimes analcite are present in the same rocks.

Plate VI reproduces photomicrographs of the hornblende-augite vogesite of which an analysis is submitted below. This rock came from a dike 3 miles west of the upper end of Apishapa Canyon and east of Mica Butte. Plate VI, *A*, taken in with one nicol, shows the general texture very well. The large prism to the left of the center and nearly all other prisms and grains of the same shade of gray are augite. Many darker-gray crystals are brown hornblende, which is intergrown with augite at one end of the large prism and in many other crystals. Three decomposed olivine crystals appear near the center. Biotite is very subordinate in this rock. The black grains of Plate VI, *A*, are all magnetite, and several long needles of apatite appear in the left-hand portion. The feldspathic base is resolvable only in polarized light between crossed nicols. Plate VI, *B*, brings out the multiple twinning (albite and pericline laws) of a stout crystal near the upper border, and albite twinning appears in a few other grains but is less easily distinguished in the illustration. Some clear alkali feldspar needles, which are also visible in *A*, appear more sharply defined in *B*, lying in a fine aggregate of feldspathic character.

Chemical composition.—The augite-hornblende vogesite of a dike 4 miles west of Apishapa Canyon has the composition given in column 1 on page 25, according to an analysis by George Steiger. Analyses of some of the most closely allied rocks are given for comparison.



A.

B.

PHOTOMICROGRAPHS OF ANALYZED HORNBLENDE-AUGITE VOGESITE.

A, With one nicol· *B*, with crossed nicols. Magnified 51 diameters.

Analyses of augite-hornblende vogesite and related rocks.

	1	2	3	4	5
SiO_2	43.49	43.58	50.35	44.20	44.82
Al_2O_3	12.76	11.46	15.76	13.96	14.06
Fe_2O_3	5.92	3.40	2.32	3.19	4.56
FeO	5.18	9.13	7.30	8.41	7.27
MgO	9.23	10.80	7.40	8.03	8.60
CaO	10.54	9.88	10.12	9.79	9.56
Na_2O	2.40	2.18	2.75	3.66	3.69
K_2O	2.53	2.13	3.89	2.35	2.30
H_2O+	3.05	2.40	.45	.76	.30
H_2O-	1.86	.47		.12	.05
CO_2					
TiO_2	2.10	3.32	.30	4.10	4.25
P_2O_5	.75	.95	.39	.62	.67
S	.11				
Cl		Trace.			
FeS_2					
NiO				.14	
MnO	.10		.35	.51	None.
BaO	.13				
SrO	.12				
	100.52	99.70	101.38	99.84	100.13

1. Augite-hornblende vogesite, Apishapa quadrangle, Colorado.
2. Limburgite, Woodend, Macedon, Victoria, Australia. Skeats and Summers, Geol. Survey Victoria Bull. 24, p. 28, 1912.
3. Olivine monzonite. Smalingen, Fahlun, Sweden. Analyst, L. Schmelck. Described by W. C. Brögger, Die Eruptivgesteine Kristianiagebietes, vol. 2, p. 46, 1895.
4. Nephelite basanite, Cruzcat, south of Olot, Spain. Analysis and description by H. S. Washington, Am. Jour. Sci., 4th ser., vol. 24, pp. 233-240, 1907.
5. Nephelite basanite, Montsacopa, near Olot, Spain. Analysis and description by H. S. Washington, loc. cit.

This type is more basic than the vogesite described above, having less silica, alumina, and alkalies and more magnesia and lime, but these differences are not enough to obscure the general similarity of the two rocks. The cumulative effect of the differences is best appreciated by a comparison of the norms of the two rocks.

Classification.—The norms of the hornblendic vogesite and the correlated rocks are as follows:

Norms of augite-hornblende vogesite and related rocks.[a]

	1	2	3	4	5
or	15.01	12.23	22.8	13.90	13.34
ab	11.00	13.10	11.0	9.43	14.15
an	16.40	15.29	18.3	14.73	15.01
ne	5.11	2.84	6.5	11.64	9.37
di	23.48	21.99	23.6	24.28	21.86
ol	9.48	17.79	13.1	11.11	9.73
mt	8.58	4.87	3.5	4.64	6.73
il	3.95	6.38	.6	7.75	8.06
ap	1.78	2.35	1.0	1.34	1.68
	94.79	96.84	100.4	98.82	99.93
Rest	5.62	2.87	.5	.88	.35
	100.41	99.71	100.9	99.70	100.28

[a] The norms of Nos. 2 to 5 are as calculated by Dr. Washington. Nos. 4 and 5 differ slightly from those originally published by him (loc. cit.).

The position of the vogesite in the quantitative system is indicated by these data:

Class: $\frac{\text{Sal}}{\text{Fem}}=\frac{47.52}{47.27}=1.+=\text{III}$, salfemane.

Order: $\frac{\text{L}}{\text{F}}=\frac{5.11}{42.41}=0.120+=5(6)$, portugare-gallare.

Rang: $\frac{K_2O'+Na_2O'}{CaO'}=\frac{66}{59}=1.12=3$, camptonase-limburgase.

Subrang: $\frac{K_2O'}{Na_2O'}=\frac{27}{39}=0.69=3'$, ourose-kentallenose.

The symbols of the analogous rocks are:

2.... III. 5′. 3. 3(4).
3.... III. 5(6). 3. 3.
4.... III. 6.(2)3.4.
5.... III.′6.(2)3.4.

The Apishapa rock is near the center of the salfemanes and by its low nephelite falls in the perfelic order gallare, but it is transitional to portugare, in which the hornblende-free vogesite comes. Through low alumina and consequent lower anorthite this vogesite is alkalicalcic and through less preponderant soda it is sodipotassic.

Kentallenose and ourose have even fewer known representatives than monchiquose and the Apishapa rock has few very close analogues, as the above table shows.

The motex [1] of this rock places it in the mineralogic system as a lamprophyre of dominant alkali feldspar with hornblende, augite, and olivine as its mafic silicates. By the appearance of plagioclase the rock approaches the monzonitic series of lamprophyres.

Comparison of norm and mode.—In this rock, as in the olivine-bearing vogesite, the most notable discrepancy between norm and mode is in the lime feldspar. With 16.4 per cent normative anorthite the rock has but little plagioclase, while its nearest chemical analogues are characterized by plagioclase.

OLIVINE-PLAGIOCLASE BASALT.

Description.—The basalts of the Apishapa quadrangle are dark, dense rocks, differing from the vogesites because of their more distinctly crystalline appearance, due to the development of feldspar. Yet these rocks are so fine grained that only a few crystals of olivine, augite, or plagioclase can be clearly recognized by the unaided eye even in the coarsest specimens.

The microscope shows that the olivine, augite, plagioclase, magnetite, and apatite have a development like that most commonly found in typical basalts of dense and nearly holocrystalline texture. Olivine exhibits a tendency to form small phenocrysts, while augite and plagioclase are less commonly prominent in this way. But a seriate gradation from largest to smallest grains diminishes or destroys the porphyritic appearance. The ophitic relation of plagioclase and augite is seldom pronounced.

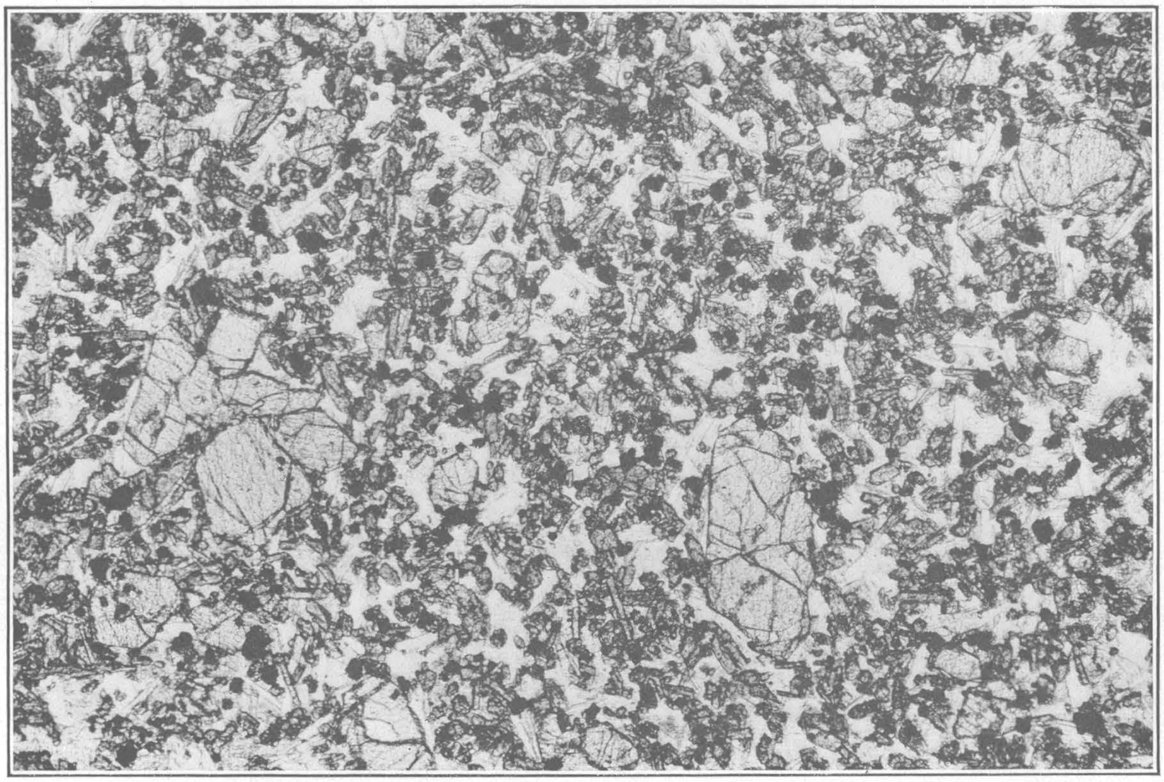
Biotite in small leaves is sparingly present in some of these basalts. Brown hornblende has not been noted. The interstitial feldspar is orthoclase or an alkali feldspar containing both potash and soda. In some dikes this alkali feldspar is almost lacking and in others it has a development similar in character though not in importance to that in the olivine-bearing augite vogesite. Glass is present in some dikes in clear colorless areas penetrated by mineral grains or prisms, but does not assume the rôle, common in basalts, of a base of smoky color and globulitic interpositions.

Plate VII, *A*, represents the appearance of the basalt of which an analysis is given below, as seen in ordinary light. The large phenocrysts of rough surface are olivine. Augite appears only in the prismoids and grains of much smaller size but forms a large part of the rock. The interstitial white areas represent abundant plagioclase laths and irregular grains of plagioclase or alkali feldspar, which are not readily distinguished except when seen in polarized light. The greater part of the black areas represent dark-brown biotite and the remainder magnetite.

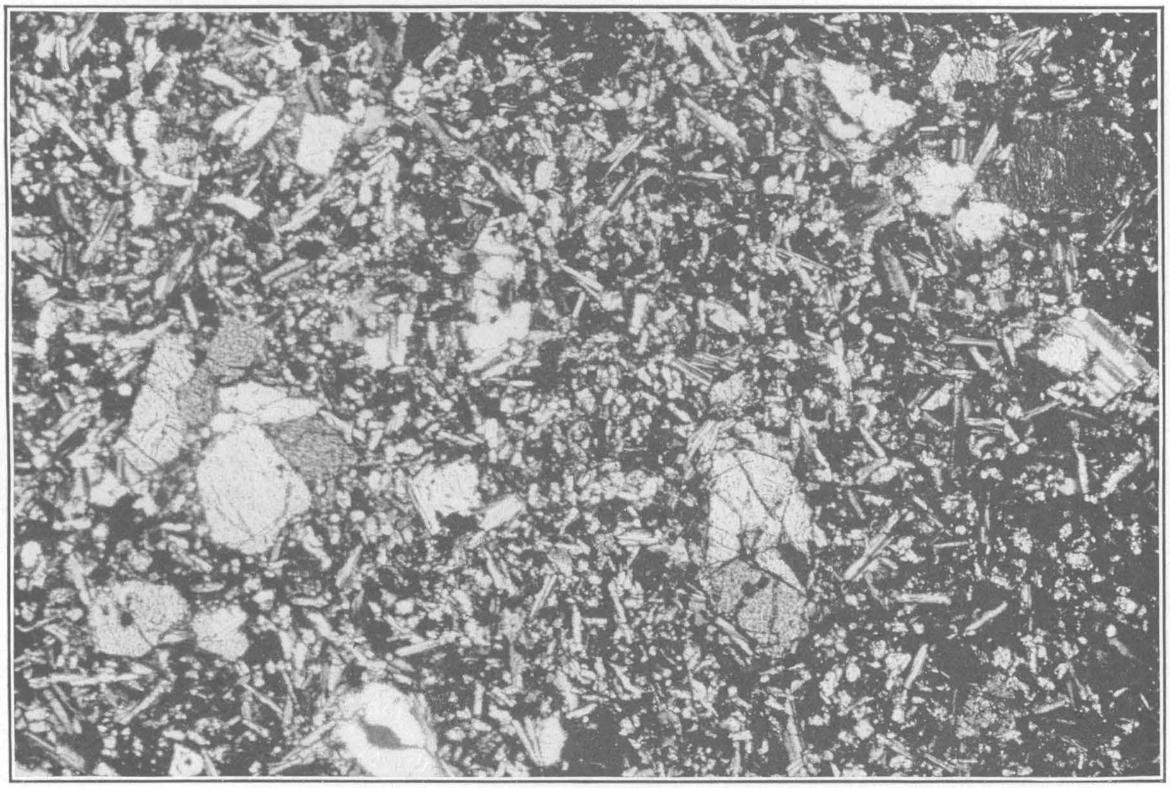
Plate VII, *B*, represents the same area as seen in polarized light, the plagioclase laths being here much more distinct.

Chemical composition.—The chemical analysis of the basalt is given in the subjoined table, together with those of the nearest chemical analogues of which I have found mention:

[1] *Motex* is a convenient term by which to refer to the mode and texture of any rock. See H. S. Washington, Am. Jour. Sci., 4th ser., vol. 24, p. 230, 1907.



A.



B.

PHOTOMICROGRAPHS OF ANALYZED PLAGIOCLASE BASALT.

A, With one nicol; *B*, with crossed nicols. Magnified 51 diameters.

Analyses of olivine plagioclase basalt and related rocks.

	1	2	3	4	5	6
SiO_2	44.64	44.29	44.78	45.80	43.76	45.15
Al_2O_3	12.82	12.62	12.76	13.41	11.58	12.93
Fe_2O_3	3.64	3.61	5.42	6.89	4.39	5.26
FeO	8.34	8.84	8.34	5.69	7.57	6.88
MgO	10.05	10.06	10.17	12.82	12.97	11.35
CaO	10.09	9.23	10.23	9.91	9.64	9.97
Na_2O	3.39	3.25	3.56	3.57	3.03	2.90
K_2O	1.76	1.82	1.81	1.41	1.84	1.76
H_2O+	1.20	.21	1.42	...	.47	.32
H_2O-	.36	.09	...	...	...	.29
CO_2	...	...	.93	...	.38	...
TiO_2	1.99	4.92	.25	...	3.41	2.65
P_2O_5	.90	.57	.92	.46	.45	.73
SO_3	...	.05	...	...	.14	...
ZrO_2	...	.02	...	...	...	...
S	...	...	...	...	.15	...
NiO	...	...	...	...	...	.01
MnO	.16	(a)	...	...	...	.16
BaO	.14	.06	...	...	...	...
SrO	.09	.04	...	...	...	...
	99.57	99.68	100.59	99.96	99.78	100.36

a Not determined.

1. Olivine-plagioclase basalt dike 8 miles east-northeast of North Rattlesnake Butte, Apishapa quadrangle, Colorado. Analyst, George Steiger.
2. Nephelite basanite, Las Planas, south of Olot, Catalonia, Spain. Analysis and description by H. S. Washington, Am. Jour. Sci., 4th ser., vol. 24, p. 217, 1907.
3. Basalt, Hünenberg, Blatt Melsungen, Prussia. Analyst, Steffen. Described by F. Beyschlag, Erläuterungen zur geologischen Spezialkarte von Preussen, Blatt Melsungen, p. 20, 1891.
4. Basalt, Wostray, near Milleschau, Bohemia. Analyst, J. Hanamann. Cited by J. E. Hibsch, Min. pet. Mitt., vol. 24, p. 274, 1905.
5. Basalt, Matavuna, flow of 1905-6, Savaii, Samoan Islands. Analyst, Heuseler. Described by A. Klautsch, Preuss. geol. Landesanstalt Jahrb., vol. 27 (1907), p. 174, 1910.
6. Basalt, Mount Terang, Camperdown district, Victoria, Australia. Analyst, A. A. Topp. Rock described by H. J. Grayson, Geol. Survey Victoria Mem. 9, p. 22, 1910.

The basalt of the Apishapa quadrangle has a composition similar to that of the vogesites but is slightly richer in magnesia and richer in soda relative to potash. The total of the alkalies is high and the silica low for an average feldspar basalt.

Classification.—The norms of the basalt of the Apishapa quadrangle and the analogous rocks are as follows:

Norms of olivine-plagioclase basalt and related rocks.

	1	2	3	4	5	6
or	10.56	11.12	10.56	8.34	11.12	10.56
ab	12.58	15.20	14.67	13.10	8.91	14.67
an	14.18	14.18	13.62	16.12	12.79	16.96
ne	8.52	6.82	8.24	9.37	8.80	5.40
di	24.53	22.02	21.04	23.89	25.41	22.14
ol	16.24	14.10	18.62	18.16	17.78	15.75
mt	5.34	5.34	7.89	9.98	6.50	7.66
il	3.80	9.42	.48	...	6.54	5.02
ap	2.12	1.34	2.12	1.01	1.01	1.68
	97.87	99.54	97.24	99.97	98.86	99.84
Rest	1.56	.47	3.54	.00	1.14	.62
	99.36	100.01	100.78	99.97	100.00	100.46

The quantitative classification of No. 1 is shown by the ratios cited below:

Class: $\frac{\text{Sal}}{\text{Fem}}=\frac{45.84}{52.03}=0.881=\text{III}$, salfemane.

Order: $\frac{\text{L}}{\text{F}}=\frac{8.52}{37.32}=0.228={}'6$, portugare.

Rang: $\frac{K_2O'+Na_2O'}{CaO'}=\frac{74}{51}=1.45={}'3$, limburgase.

Subrang: $\frac{K_2O'}{Na_2O'}=\frac{19}{55}=0.345=4$, limburgose.

The symbols of the rocks express the degree of normative resemblance between them.

1.... III.'6.'3.4.	3.... III.'6.(2)3.4.	5.... III.6.(2)3.4.
2.... III.(5)6.'3.4.	4.... III.6.3.4.	6.... III.5(6).3.4.

The classification by motex places the Apishapa rock among the olivine-plagioclase basalts. That it is not a typical feldspar basalt is shown in the discussion of norm and mode.

Comparison of norm and mode.—While the mode of the basalt of the Apishapa quadrangle is more nearly normative than those of the associated vogesites, in that anorthite is at least more fully developed in plagioclase, its norm contains a considerable amount of nephelite which probably does not appear in the mode. This nephelite shows the basalt to belong potentially with the nephelite basanites rather than with the common basalts falling in auvergnose or camptonose. The potential significance of this normative nephelite is fortunately illustrated in striking manner by the nephelite basanite of Las Planas (No. 2 of table), which is very near to the basalt of the Apishapa quadrangle in chemical composition but has less normative nephelite.

The basalts of Hünenberg (No. 3) and Wostray (No. 4) are not described in detail in the publications cited, but presumably they contain no recognized nephelite.

The lava of Matavuna volcano (No. 5) is, according to Klautsch, largely vitreous, but it contains labradorite, both in small phenocrysts and in microlites. Klautsch points out a chemical similarity between this lava and the nephelinite of Katzenbuckel and the nephelite basanite of Hundeskopf.

The basalt of Mount Terang (No. 6) is also largely glass, but shows some augite and feldspar.

SODIC DIABASE.

Three dikes of the Apishapa quadrangle have a general diabasic character in that the specimens from them are largely augite-plagioclase rocks with ophitic texture more or less distinctly developed. They are of very simple mineral composition, and their principal characteristic is the highly sodic character of the plagioclase. This appears to be oligoclase or oligoclase-albite, no andesine or labradorite having been noticed.

The rock nearest to common diabase in texture forms a dike 7 miles south-southeast of Dripping Spring. It is a gray fine-grained ophitic rock in which the fabric is more evident to the unaided eye than in any other dike of the quadrangle, yet few of its largest feldspar and augite crystals exceed 1 millimeter in length. The plagioclase crystals are more nearly euhedral than the augite crystals and often penetrate them, but the augite grains are not large enough to emphasize the ophitic fabric.

Plagioclase predominates over augite, to which the other constituents, embracing biotite, titaniferous magnetite, apatite, and probably some monoclinic alkali feldspar, are all decidedly subordinate. Chlorite, calcite, and analcite (?) are the noteworthy secondary minerals. Of these, chlorite seems to represent, in part, a former prismatic constituent, of much less abundance than augite, which is tentatively thought to have been hypersthene, for augite does not undergo visible alteration to chlorite in these rocks, nor does the brown hornblende of other dike rocks of the region. Olivine is not present and the long prisms replaced by chlorite are of a form not assumed by olivine in the associated rocks.

Plagioclase, the principal constituent of the rock, occurs in tablets of multiple alibitic twinning, appearing very "dusty" in ordinary light, but it is really not much decomposed. Its refractive index in most sections is near that of Canada balsam but is prevailingly lower, and the maximum extinction from the trace of albite twinning plane is about 7°. It seems probable that oligoclase-albite is the term best expressing the composition. Some monoclinic alkali feldspar is probably present, but none was definitely identified. A colorless, isotropic mineral of low refraction occurs in small amount, in association especially with calcite and chlorite, and is referred to analcite.

One of these diabasic rocks forms a dike running east from the mesa 5 miles west of Dripping Spring. It is similar in texture and grain to the rock just described and differs from it in composition mainly in the character of the plagioclase, which is more distinctly oligoclase. Biotite and hornblende of the same deep-brown color are equally abundant, but are far subordinate to pale-green augite.

RELATIONS OF THE APISHAPA ROCKS TO THE SPANISH PEAKS.

The dikes of the Apishapa quadrangle belong to a great system of radial dikes, with associated sills, which surround the Spanish Peaks, an eruptive center situated 25 miles southwest of the border of the quadrangle. (See Pl. IV.) The rocks of this center and of the dikes and sills, so far as they occur in the Spanish Peaks, Walsenburg, and El Moro quadrangles, have been described in a general way by R. C. Hills, in the folios dealing with these areas. No chemical analyses accompanied the descriptions by Hills. The description of the Apishapa rocks and especially the four analyses presented in this paper indicate in some measure the interest attaching to the rocks of this remarkable center of associated differentiates. A summary of the data given by Hills will make this still clearer.

At the Spanish Peaks there are three great stocks penetrating Eocene beds. The rocks of these masses are called by Hills granite porphyry, augite granite porphyry, and augite diorite. The granite porphyry is described as containing abundant large phenocrysts of orthoclase and quartz and some plagioclase. The groundmass is rich in quartz, partly in micrographic intergrowth with feldspar, presumably orthoclase. No mafic constituents are mentioned as present in this rock, but it grades within a narrow transition zone into the augite granite porphyry, which is characterized by both augite and biotite. Augite diorite is a collective name for somewhat different rocks variably rich in augite, biotite, hypersthene, plagioclase, orthoclase, and quartz.

On the map of the Spanish Peaks quadrangle Hills represents 240 dikes. A large and perhaps equal number are said to occur in the unmapped area west of the center of eruption. At 10 or 15 miles from the peaks begins a zone marked by thin sills of rocks like those which occur in dikes, and in several places dikes and sills are visibly connected. In the Walsenburg quadrangle 70 dikes and 20 sills were mapped, most of which belong to the Spanish Peaks system. Ten dikes and several sills occur in the El Moro quadrangle, south of the Apishapa.

The dike and sill rocks are referred by Hills to five principal groups, which at their intersections exhibit certain rather definite age relations. In the folio legends these groups are designated "early monzonite porphyry" (76 dikes), "early lamprophyre" (10 dikes), "late monzonite porphyry" (13 dikes), "late lamprophyre" (88 dikes), and "basalt" (34 dikes).

The monzonite porphyries carry both plagioclase and alkali feldspar in large amount. In the earlier group the mafic constituents are augite and brown hornblende, while in the later group these minerals are less prominent than biotite. Quartz is present in the groundmass of some of the later porphyries.

The lamprophyres exhibit great variety in composition both as to feldspars and as to mafic silicates. They range "from a near approach to the syenites, at one extremity, through the hornblende vogesites and monzonites, to the camptonitic varieties, at the other." A basic variety of the earlier group, "containing but little hornblende, shows an abundance of biotite, with more or less augite and olivine as phenocrysts, and magnetite in the groundmass." Some of the later lamprophyres are ophitic in fabric.

Under "basalt" Hills groups various rock types, some of which he says are nearly related to certain lamprophyres through abundance of hornblende and biotite and the presence of alkali feldspar. There are, however, some "normal basalts," which constitute the only exceptions to "the general statement that alkali feldspars in varying proportions range through the Spanish Peaks rocks from one end to the other." No minette is mentioned by Hills as occurring in either one of the quadrangles surveyed by him. It is evident that the Spanish Peaks area is a rich field for detailed petrographic work.

DISCUSSION OF RESULTS.

It is clear that the chemical and mineral characters of the Apishapa dike rocks illustrate some of the most puzzling and important problems of petrology. But while this is true, the great complex of associated rocks at and about the Spanish Peaks must be thoroughly studied, with adequate chemical analyses of many types, before the significance of the facts observed in this small number of rocks can be fully appreciated.

The Apishapa rocks have a considerable range in chemical composition, but very much less than is exhibited in the great series to which they belong. Those analyzed are all low in silica, but vary as to their bases from the potash-rich minette to a basalt with soda strongly dominant over potash. Lime and magnesia are very prominent, and titanic acid appears to be one of the notable chemical features.

The mafic silicates, augite and olivine, are abundant in nearly all the rock varieties; biotite is also common and is the leading constituent in the minette, and brown hornblende is strongly developed in several types. Of the felsic silicates alkali feldspar is characteristic of the greater number of the rocks and plagioclase is quantitatively important in relatively few.

The modal development of the rocks requires most of them to be classified in the current system as alkali feldspar rocks. The vogesites are soda-rich, and so apparently are the diabasic types. Even in some of the basalts alkali feldspar is abnormally developed. The persistence of alkali feldspars is probably the most notable modal feature of the whole series of intrusive rocks about the Spanish Peaks.

The prominence of the alkali feldspars must undoubtedly lead petrographers accustomed to refer all igneous rocks to either an alkalic or a calcic series to assign these rocks to the former category. But even the small group in the Apishapa quadrangle has some basalts with little alkali feldspar, and it seems altogether probable that the series ranges in fact from alkali-rich rocks to those of normal basaltic character—that is, to rocks which are intrinsically equivalent to typical basalts of the calcic, subalkalic or "Pacific series." As has been pointed out in the preceding pages, there has been some prevalent condition in the Apishapa region which has brought the alkali feldspars into great prominence and obscured for most rocks their potential anorthite. It is true of many rocks of the Apishapa quadrangle, and presumably also of the large series about the Spanish Peaks, that they are not so strongly alkali-rich rocks as they seem to be from their mode.

This brings us to the problems of greatest general and theoretical interest presented by the rocks under discussion. It has been shown that the nearest known chemical analogues of the vogesites and the associated basalt are for the most part rocks of notably different modes. This is most striking in the case of the olivine-bearing augite vogesite. These rocks emphasize anew the fact that for magmas of intermediate chemical composition, containing all the common bases in considerable quantities, there is a great possible range in the minerals which may develop on crystallization. Aside from the evident problems of classification under these circumstances, there is the more fundamental question as to the genetic significance of the observed relations. Are these facts capable of interpretation as expressing other definite natural relations, if not a dependence of mineral upon chemical characters? Are the several mineral combinations possible from such magmas as those of the Apishapa district due to conditions attending their differentiation in various regions, or are they due to variable conditions of consolidation, or to both?

For the Apishapa rocks the point of most critical interest relates to the conditions that prevented normative anorthite from entering into plagioclase, as it more commonly does in rocks of similar chemical composition, and to the place at which these conditions were effective. In the olivine-bearing augite vogesite 13 per cent of normative anorthite has been taken into other minerals, most of it going undoubtedly into augite. Such entrance of anorthite molecule into augite is common enough, but the conditions under which it takes place are not yet determined.

In his study of the variation in mineral composition of the rocks of Yogo Peak, Pirsson[1] shows that in a series of rocks ranging from granite porphyry to shonkinite, lime and alumina enter into augite apparently in proportion as magnesia acquires a molecular dominance over lime in the magmas. In a shonkinite, with 9.2 per cent MgO and 9.7 per cent CaO, there is but 10 per cent of plagioclase to 35 per cent of aluminous augite.

[1] Pirsson, L. V., chapter on petrography in Geology of the Little Belt Mountains, Montana, by W. H. Weed: U. S. Geol. Survey Twentieth Ann. Rept., pt. 3, p. 567, 1900.

Such a control by magnesia does not exist in the Apishapa rocks, for it is in the olivine-augite vogesite with lowest actual and relative magnesia that the anorthite is entirely suppressed and in the basalt with highest actual and relative contents in magnesia that plagioclase is most abundant. Nor is it a question of the amount of normative anorthite, for the hornblende-augite vogesite, with 16.40 anorthite, has little plagioclase, while the plagioclase basalt has but 14.18 anorthite, only 1 per cent more than appears in the norm of the plagioclase-free vogesite.

Ignoring the disturbing effect of assimilation of foreign substances and assuming that the formation of a series of magmatic differentiates in a given region is a result of certain forces, known or unknown, characteristic of that region, we must also recognize that in the course of eruption and crystallization these magmas come under the influence of pressure and temperature differing from those of the site of deep-seated differentiation, causing more or less pronounced reactions. When we consider also the possibilities of the absorption by the magma of various potent substances while passing from one place to another, it seems scarcely overdrawn to say that a magmatic solution may become the plaything of conditions quite unrelated to those of the place of its origin, that these independent conditions may vary in one district from time to time, and that they surely must vary from one province to another, when magmas of the same chemical composition are involved.

When a large series of eruptions or intrusions of various differentiates has occurred in one province it is conceivable that the conditions attendant on consolidation, though independent of those regulating differentiation, may have been so constant as to permit the development of some highly characteristic mineral features of the rock series. But the fact that conditions of crystallization may vary in one region during a long series of eruptions and are not the same, unless by fortuitous coincidence, in different regions where the magmas may have been similar must lead to caution in extending over the whole world the generalizations that apply to one area.

THE COMPOSITION OF CRINOID SKELETONS.

By F. W. Clarke and W. C. Wheeler.

INTRODUCTION.

That many rocks, now raised far above sea level, were once marine sediments and that living organisms contributed to their formation are among the commonplaces of geology. It is also known that radiolarians, diatoms, and sponges form siliceous deposits; that calcareous rocks are derived in part from corals and mollusks; and that crustacean and vertebrate remains are largely phosphatic. These facts are established in a broad, general way, but they need to be studied in greater detail, so that the function of each class of organisms may be more exactly known. An investigation of this kind is reported in the following pages. The special problem covered by it was suggested by Mr. Austin H. Clark, of the United States National Museum, who furnished the specimens for analysis.

EXISTING CRINOIDS.

In 1906 H. W. Nichols[1] published a number of analyses of marine invertebrates, and in one of them, a crinoid; *Metacrinus rotundus*, from Japan, he found 11.72 per cent of magnesium carbonate. This analysis attracted Mr. Clark's attention, and at his request two other analyses of crinoids were made in the laboratory of the United States Geological Survey by Chase Palmer, who also found that they contained abundant magnesia. These analyses, which were published and discussed by Mr. Clark,[2] will be considered in detail later. They at once suggested that crinoids generally might be highly magnesian and so play an important part in the formation of magnesian limestones.

In order to settle this question Mr. Clark supplied us with 22 specimens of recent crinoids, representing 19 genera and covering a wide range of localities. These were analyzed by Mr. Wheeler, and the analyses confirmed the original supposition. All the specimens contained magnesium carbonate in notable proportions but varying in a most remarkable manner. The data obtained are in detail as follows, beginning with the list of the specimens studied:

1. *Ptilocrinus pinnatus* (A. H. Clark). *Albatross* station 3342, off the Queen Charlotte Islands, British Columbia. Latitude 52° 39′ 30″ N., longitude 132° 38′ W. Depth of water, 2,858 meters; temperature, 1.83° C. Mean of two analyses.
2. *Florometra asperrima* (Clark). *Albatross* station 3070, off the coast of Washington. Latitude 47° 29′ 30″ N., longitude 125° 43′ W. Depth, 1,145 meters; temperature, 3.28° C.
3. *Psathyrometra fragilis* (Clark). *Albatross* station 5032, Yezo Strait, Japan. Latitude 44° 05′ N., longitude 145° 30′ E. Depth, 540–959 meters; temperature, 1.61° C.
4. *Pentametrocrinus japonicus* (P. H. Carpenter). *Albatross* station 5083, 34.5 miles off Omai Saki Light, Japan. Latitude 34° 04′ 20″ N., longitude 137° 57′ 30″ E. Depth, 1,123 meters; temperature, 3.39° C.
5. *Capillaster multiradiata* (Linné). *Albatross* station 5137, Philippine Islands near Jolo, 1.3 miles from Jolo Light. Latitude 6° 04′ 25″ N., longitude 120° 58′ 30″ E. Depth, 36 meters; no temperature record.
6. *Pachylometra patula* (Carpenter). *Albatross* station 5036, Philippine Islands, North Balabac Strait, 15.5 miles from Balabac Light. Latitude 8° 06′ 40″ N., longitude 117° 18′ 45″ E. Depth, 104 meters; no temperature record.
7. *Catoptometra ophiura* (Clark). Same locality as No. 6.

[1] Field Columbian Mus. Pub. 111, p. 31.

[2] U. S. Nat. Mus. Proc., vol. 39, p, 487, 1911.

8. *Hypalocrinus naresianus* (Carpenter). *Albatross* station 5424, Philippine Islands, 3.4 miles off Cagayan Island, Jolo Sea. Latitude 9° 37′ 05″ N., longitude 121° 12′ 37″ E. Depth, 612 meters; temperature 10.22° C.

9. *Parametra granulata* (Clark). *Albatross* station 5536, Philippine Islands, between Negros and Siquijor, 11.8 miles from Apo Island. Latitude 9° 15′ 45″ N., longitude 123° 22′ E. Depth, 502 meters; temperature, 11.95° C.

10. *Craspedometra anceps* (Carpenter). *Albatross* station 5157, 3.3 miles from Tinakta Island, Tawi Tawi group, Sulu Archipelago. Latitude 5° 12′ 30″ N., longitude 119° 55′ 50″ E. Depth, 32 meters; no temperature record.

11. *Ptilometra mülleri* (Clark). Sydney Harbor, New South Wales, Australia. Latitude 33° 15′ S., longitude 151° 12′ E., approximately.

12. *Hathrometra dentata* (Say). *Fish Hawk* station 1033, off Marthas Vineyard, Mass. Latitude 39° 56′ N., longitude 69° 24′ W. Depth, 329 meters; temperature about 7.8° C.

13. *Bythocrinus robustus* (Clark). *Albatross* station 2401, Gulf of Mexico, southeast of Pensacola. Latitude 28° 38′ 30″ N., longitude 85° 52′ 30″ W. Depth, 255 meters; no temperature record.

14. *Crinometra concinna* (Clark). *Albatross* station 2324, north of Cuba. Latitude 23° 10′ 35″ N., longitude 82° 20′ 24″ W. Depth, 59 meters; temperature, 26.17° C.

15. *Isocrinus decorus* (Wyville Thomson), stem. Off Habana, Cuba. Latitude 24° N., longitude 82° W., approximately.

16. Same as No. 15, arms.

17. *Endoxocrinus parræ* (Gervais), stem. Off Habana.

18. Same as No. 17, arms.

19. *Tropiometra picta* (Gay). Rio de Janeiro, Brazil. Latitude, 25° 54′ S., longitude, 44° W., approximately.

20. *Promachocrinus kerguelensis* (Carpenter). Shores of the Antarctic Continent in the vicinity of Gaussberg. Latitude 67° S., longitude 90° E., approximately. Depth, 350–400 meters; temperature, −1.85° C. Salinity of water, 3.3 per cent.

21. *Anthometra adriani* (Bell). Same locality as No. 20. Nos. 20 and 21 were collected by the German South Polar Expedition.

In the following table the actual analyses are given. The symbol "R_2O_3" represents the sum of ferric oxide and alumina, and "Loss on ignition" covers carbon dioxide, water, and organic matter, the last being often very high. At the foot of each column the CO_2 calculated to satisfy the bases is given. The deficiencies in summation are mainly due to inclosed or adherent salt, an inevitable impurity, as was proved in the analyses of two samples, Nos. 15 and 17.[1] Analysis No. 1 is the mean of two concordant analyses of separate samples.

Analyses of crinoids.

	1	2	3	4	5	6	7	8	9	10	11
SiO_2	1.64	0.04	1.11	0.37	0.16	0.12	0.04	0.07	0.40	0.15	0.17
R_2O_3	1.07	.39	1.01	.71	.62	.63	.79	.09	.50	.19	.19
MgO	3.08	3.60	3.12	3.76	4.77	4.94	4.64	4.44	4.48	5.13	4.17
CaO	40.65	40.37	34.20	38.50	38.12	41.34	40.75	45.86	41.79	42.77	38.91
P_2O_5	.11	.21	Trace?	.40	Trace.	.43	.33	Trace.	Trace.	.11	.17
Loss on ignition	51.45	53.75	60.04	55.25	54.61	51.36	51.80	48.32	51.44	50.28	54.61
	98.00	98.36	99.48	98.99	98.28	98.82	98.35	98.78	98.61	98.63	98.22
CO_2 needed	35.23	35.48	31.37	34.01	35.19	37.51	36.81	41.27	37.77	39.17	34.90

	12	13	14	15	16	17	18	19	20	21
SiO_2	3.17	0.40	0.04	0.03	0.09	0.04	0.15	0.02	0.02	0.23
R_2O_3	.31	.31	.25	.07	.19	.20	.26	.35	.45	.37
MgO	2.49	4.56	4.75	5.08	4.70	5.09	5.04	4.51	3.02	3.27
CaO	26.12	47.08	41.78	45.67	42.77	45.42	43.41	39.57	40.68	42.49
P_2O_5	.23	Trace.	Trace.	Trace.	Trace?	Trace.	Trace.	.10	Trace.	Trace.
Loss on ignition	65.25	47.17	50.33	47.54	50.59	48.58	50.00	53.64	54.53	52.22
	97.57	99.52	97.15	98.39	98.34	99.33	98.86	98.19	98.70	98.58
CO_2 needed	22.73	41.93	38.00	40.40	38.71	41.29	39.65	36.05	35.18	37.08

In order to make these analyses more instructive it is necessary to recalculate them into such form as to show the composition of the true crinoid skeleton—that is, to eliminate the highly variable organic matter of the original specimens. On doing this and recalculating to 100 per cent, we find that they assume the following form:

[1] No. 15 contains 1.27 per cent of water-soluble salts and No. 17 contains 0.21 per cent. These raise the summations to 99.66 and 99.54 per cent, respectively.

Revised analyses of crinoids.

	1	2	3	4	5	6	7	8	9	10	11
SiO_2	2.01	0.05	1.57	0.48	0.21	0.14	0.05	0.08	0.47	0.24	0.21
R_2O_3	1.31	.48	1.41	.91	.78	.74	.95	.10	.59	.22	.24
$MgCO_3$	7.91	9.44	9.25	10.15	12.69	12.20	11.68	10.16	11.08	12.34	11.13
$CaCO_3$	88.48	89.45	87.77	87.34	86.32	85.81	86.46	89.66	87.86	86.93	87.94
$Ca_3P_2O_8$	.29	.58	Trace?	1.12	Trace.	1.11	.86	Trace.	Trace.	.27	.48
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

	12	13	14	15	16	17	18	19	20	21
SiO_2	5.73	0.42	0.05	0.03	0.10	0.04	0.17	0.02	0.02	0.28
R_2O_3	.56	.33	.30	.08	.21	.21	.29	.43	.57	.44
$MgCO_3$	9.36	10.09	11.69	11.69	11.42	11.62	11.96	11.77	7.86	8.23
$CaCO_3$	83.47	89.16	87.96	88.20	88.27	88.13	87.58	87.51	91.55	91.05
$Ca_3P_2O_8$	.88	Trace.	Trace.	Trace.	Trace?	Trace.	Trace.	.27	Trace.	Trace.
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

With these analyses the two made by Mr. Palmer may be advantageously compared, although they were not quite so elaborate. The data are as follows:

22. *Heliometra glacialis* var. *maxima*. Iwanai Bay, northeastern part of the Sea of Japan, latitude 43° 01′ 40″ N. Depth, 315 meters; temperature, surface 20.5° C., bottom 1.5° C.

23. *Metacrinus rotundus*. Eastern Sea, off Kagoshima Gulf, southern Japan, latitude 30° 58′ 30″ N. Depth, 278 meters; temperature, surface 27.8° C., bottom 13.3° C.

In No. 22, which contained much organic matter, Mr. Palmer found 2.68 per cent MgO (=5.61 $MgCO_3$) and 40.03 CaO (=71.48 $CaCO_3$). In No. 23, with no organic matter, he found 4.89 MgO (=10.29 $MgCO_3$) and 49.95 CaO (=89.19 $CaCO_3$). Assuming that the crinoid skeletons consist essentially of carbonates, and recalculating to 100 per cent, we have as the content of magnesium carbonate in these crinoids—

No. 22, 7.28 per cent.
No. 23, 10.34 per cent.

These figures fit in well with the others and even by themselves suggest a relation between temperature and the magnesia content of crinoids. In the following table the entire series is arranged in the order of ascending $MgCO_3$, with the accessory data as to latitude and locality conveniently abbreviated. In this table the two analyses of Endoxocrinus are averaged together, and so also are the two of Isocrinus.

Magnesium carbonate in crinoid skeletons.

No.	Locality.	Latitude.	Depth (meters).	Temperature (°C.).	Per cent $MgCO_3$.
22	Northern Japan	43° N.	315	1.5	7.28
20	Antarctic	67° S.	375	−1.8	7.86
1	British Columbia	52° 39′ N.	2,858	1.8	7.91
21	Antarctic	67° S.	375	−1.8	8.23
3	Northern Japan	44° N.	(?)	1.6	9.25
12	Massachusetts	39° 56′ N.	329	7.8	9.36
2	Washington	47° 29′ N.	1,145	3.3	9.44
13	Gulf of Mexico	28° 38′ N.	255	(?)	10.09
4	Southern Japan	34° N.	1,123	3.4	10.15
8	Philippines	9° 37′ N.	612	10.2	10.16
23	Southern Japan	30° 58′ N.	278	13.3	10.34
9	Philippines	9° 15′ N.	502	12	11.08
11	Australia	33° 15′ S.	(?)	(?)	11.13
15, 16	Cuba	24° N.	(?)	(?)	11.56
7	Philippines	8° N.	104	(?)	11.68
14	Cuba	23° 10′ N.	59	26.2	11.69
19	Brazil	25° 54′ S.	(?)	(?)	11.77
17, 18	Cuba	24° N.	(?)	(?)	11.79
6	Philippines	8° N.	104	(?)	12.20
10	.....do	5° 12′ N.	32	(?)	12.34
5	.....do	6° N.	36	(?)	12.69

From the foregoing table it is perfectly clear that the proportion of magnesium carbonate in crinoids is in some way dependent on temperature. Temperature, however, is not entirely dependent on latitude. Depth of water has also a distinct influence. The crinoids from relatively shallow depths in the Tropics are highest in their magnesian content; those from the Antarctic and the far north are lowest. The proportion given for No. 12, from the coast of Massachusetts, is probably too low, for the specimen as analyzed contained over 6 per cent of silica and sesquioxides—evident impurities, due to adherent mud from which the delicate structure could not be wholly freed. If these are rejected, the $MgCO_3$ is raised from 9.36 to 10 per cent, which gives the crinoid a better and more probable rating.

So far as we are aware such a peculiar relation between temperature and composition as is here recorded has not been previously observed. To recognize it is one thing; to account for it is not so easy. At first we supposed that it might possibly be due to a difference in the form of the more abundant carbonate—the less stable aragonite in the warm-water forms and calcite in the crinoids from colder regions. But tests by Meigen's reaction proved that the organisms were all calcitic, and so this supposition had to be abandoned.

Mr. A. H. Clark, who is an authority on the crinoids, has stated to us that they are exceptionally well suited to a study of the kind recorded here, "for the skeleton is always entirely internal and protected from the surrounding water by living tissue; so that whatever alteration it may undergo after its original deposition can not be influenced by the water in which it lives." He has also pointed out that the crinoids from warm regions have the most compact skeletons; the compactness being in general proportional to the temperature and also to some extent dependent upon the size of the individual. Heliometra, for example, is the largest of the crinoids, its skeleton is one of the least compact, and its magnesian content is lowest among all the species examined. Structure as well as temperature seems to be correlated with the proportion of magnesia in the crinoids, but the chemical explanation of the facts is yet to be found.

Only one other group of marine organisms, so far as is now definitely known, is conspicuous for its relative richness in magnesium carbonate, namely, the calcareous algæ, as shown in an investigation by Högbom.[1] In 11 analyses of algæ belonging to the genus Lithothamnium he found magnesium carbonate in proportions varying from 3.76 to 13.19 per cent. No temperature relation, however, appeared in his series of analyses. The highest figure was obtained in a specimen from the Arctic Ocean, the next highest in one from Bermuda, and the lowest in one from the Java Sea. Three analyses of fossil algæ gave even lower magnesia than was found in the living forms. The average proportion was near that found among the crinoids. It is highly desirable that both groups of organisms should be studied more completely and with every precaution against error. Crinoids from European, especially Mediterranean waters, from the coasts of Africa and South America, and from the Indian Ocean might be analyzed to much advantage. One caution, however, is needed: only alcoholic material should be used. Specimens preserved in formalin, which tends to become acid, are of doubtful value in a research of this kind. All the crinoids studied in the present investigation had been preserved in alcohol.

FOSSIL CRINOIDS.

In order to make this investigation more systematic it seemed desirable to analyze a number of fossil crinoids, so as to determine whether any definite and regular changes could be traced in passing from the recent to the ancient organisms. For the material studied we are indebted to the kindness of Mr. Frank Springer, who selected the material with great care so as to cover a range of horizons from the Lower Ordovician up to the Eocene. The 10 crinoids chosen are described in the list on page 37, and the analyses which follow were made in the same way as those of the modern species.

[1] Neues Jahrb., 1894, vol. 1, p. 262.

1. *Pentacrinus decadactylus* (D'Orbigny), stem. Eocene, Vincenza, Italy.
2. *Millericrinus mespiliformis* (Goldfuss), stem. Upper Jurassic, Kelheim, Bavaria.
3. *Pentacrinus basaltiformis* (Miller), stem. Middle Lias (Lower Jurassic), Breitenbach, Wurttemberg, Germany.
4. *Encrinus liliiformis* (Lamarck), stem. Triassic, Braunschweig, Germany.
5. *Graphiocrinus magnificus* (Miller and Gurley), complete crown. Pennsylvanian (upper Carboniferous), Kansas City, Mo.
6. *Dorycrinus unicornis* (Owen and Shumard), calyx and stem. Lower part of Burlington limestone, Mississippian (lower Carboniferous), Burlington, Iowa.
7. *Megistocrinus nodosus* (Barris), plates. Middle Devonian, Alpena, Mich.
8. *Eucalyptocrinus crassus*, plates. Silurian, western Tennessee.
9. Crinoid sp.?, stem. Trenton limestone, Middle Ordovician, Kirkfield, Canada.
10. *Diabolocrinus vesperalis* (White), plates and stem. Lower Ordovician, Tennessee.

Analyses of fossil crinoids.

	1	2	3	4	5	6	7	8	9	10
SiO_2	0.99	2.84	1.55	0.24	3.07	6.92	10.39	29.11	2.56	4.07
R_2O_3	2.64	.28	2.59	.43	2.18	.64	.87	1.73	.31	1.95
FeO	1.36	None.	....	None.	1.32	None.	1.19	.27	None.	.88
MnO	.13	None.	....	Trace.	.15	Trace.	.16	.04	Trace.	.04
MgO	.78	.38	.84	9.44	.78	.38	1.21	.58	.91	.79
CaO	51.22	53.68	51.78	43.40	50.10	51.20	46.57	37.43	53.87	50.42
P_2O_5	None.	Trace.	.09	Trace.	Trace.	Trace.	Trace.	None.	Trace.	Trace.
Loss on ignition	42.80	42.93	43.21	45.95	41.71	41.00	39.20	30.71	42.45	41.53
	99.92	100.11	100.06	99.46	99.32	100.14	99.59	99.87	100.10	99.68

Revised analyses of fossil crinoids.

	1	2	3	4	5	6	7	8	9	10
SiO_2	1.00	2.85	1.57	0.24	3.11	6.94	10.48	29.30	2.55	4.10
R_2O_3	2.66	.28	2.64	.44	2.22	.64	.88	1.74	.30	1.97
$FeCO_3$	2.21	None.	....	None.	2.16	None.	1.94	.43	None.	1.42
$MnCO_3$	.21	None.	....	Trace.	.24	Trace.	.26	.06	Trace.	.06
$MgCO_3$	1.66	.80	1.79	20.23	1.66	.80	2.56	1.23	1.90	1.67
$CaCO_3$	92.26	96.07	93.80	79.09	90.61	91.62	83.88	67.24	95.25	90.78
$Ca_3P_2O_8$	None.	Trace.	.20	Trace.	Trace.	Trace.	Trace.	None.	Trace.	Trace.
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

In some respects these analyses are unsatisfactory, for they show no regularities of any kind. In only one of them, No. 4, is there exhibited a concentration of magnesium carbonate; in the others the percentage of this constituent is very low. The reason for this falling off of magnesia is by no means clear. It is conceivable that the ancient crinoids may have been deficient in magnesia, but it is more probable that the loss is due to alteration, perhaps to the infiltration of calcium carbonate. Such a change would obviously lower the apparent proportion of magnesium carbonate. Several of the crinoids contain noteworthy quantities of ferrous carbonate and manganese—constituents which did not appear in the analyses of the modern species. In No. 8 there is a very strong silicification, 29.11 per cent; but the matrix of the specimen contained only 7.55 per cent of silica. Here again the infiltration of the impurity seems to be very clear. Some of the deficiencies in magnesia may have been caused by solution and leaching, but calcium carbonate should then have been removed to a greater extent. In short, the fossil crinoids differ widely in composition from the still living species, and in a very irregular manner, and it is worth noting that in three analyses of fossil algæ reported by Högbom [1] a similar falling off of magnesia appears. It would be easy to speculate on the significance of these differences, but the conclusions so reached would not be entitled to much weight. That the recent crinoids are distinctly magnesian and that the proportion of magnesia is dependent in some way on temperature are the two positive results of this investigation.

[1] Loc. cit.

CONTRIBUTIONS TO THE STRATIGRAPHY OF SOUTHWESTERN COLORADO.

By Whitman Cross and Esper S. Larsen.[1]

INTRODUCTION.

In the course of field work of the United States Geological Survey in the San Juan region of Colorado observations have been made in the last three seasons that considerably extend our knowledge of the great stratigraphic break below the La Plata sandstone, which is currently assumed to be of Jurassic age. The new data pertain partly to the relations existing in the Gunnison Valley, north of the San Juan Mountains, where the unconformity marking this break was already known at certain places, and partly to the conditions in the Piedra Valley, on the south side of the mountains, where the unconformity had not before been noted. The Piedra Valley is of special interest, and it seems well to call attention to the relations observed even though they were examined only in a reconnaissance. The first part of this paper is devoted to the evidence of the overlap of the La Plata sandstone; the second to the stratigraphic relations in the Piedra Valley.

The section of sedimentary formations in Piedra Canyon is of much interest because none of the pre-La Plata formations are known east of this locality on the south side of the San Juan Mountains. Most of these formations exhibit a notably different facies where they reappear from beneath the overlying beds at their nearest exposures in New Mexico, southeast of the Piedra Valley. It is believed that the character of the formations in the Piedra section should be recorded for the benefit of geologists who may be studying the Paleozoic and Mesozoic rocks of New Mexico, and accordingly the second part of the paper presents details of the structure and the stratigraphic section of Piedra Valley.

THE STRATIGRAPHIC BREAK BELOW THE LA PLATA SANDSTONE.

GENERAL RESULTS OF THE HAYDEN SURVEY.

The Hayden Geological Survey established the existence of great stratigraphic breaks in the central and western mountain regions of Colorado below both Triassic and Jurassic formations, and a corresponding overlap is also represented on the Hayden map of western Colorado as occurring at the base of the Dakota Cretaceous. The map represents this break as being particularly prominent along the Gunnison Canyon, between the town of Gunnison and Vernal Mesa. The shales of Colorado age, belonging to the formation now distinguished in western Colorado as the Mancos shale, are also represented as overlying the pre-Cambrian rocks east of Gunnison, on both sides of Tomichi Creek, and as abutting against the gneisses and schists of Vernal Mesa in primary contact.

The overlap of the Cretaceous formations upon the pre-Cambrian in this region, as shown on the Hayden map, is in accord with the view expressed by A. C. Peale,[2] that "The Archean area along the northern edge of the San Juan Mountains and south of the Gunnison River probably formed a shore line in Cretaceous times."

F. M. Endlich was the geologist who visited the area within which the "Colorado" shales are represented by the Hayden map as lying on granite, in the valley of Tomichi Creek, for a distance of about 15 miles above Gunnison. As we shall explain more fully later on, he found other sediments beneath the shales of this area, which are not shown on the map.

[1] The authors wish to acknowledge the efficient assistance of J. Fred Hunter in the field work on which this paper is based.
[2] U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1875, p. 69, 1877.

The contact of Cretaceous shales and pre-Cambrian rocks on Vernal Mesa, thought by Peale[1] to be of primary origin, is now known to be a fault contact in a zone of complex folding and fracturing, the details of which have been shown by the tunnel of the Uncompahgre irrigation project.

THE OVERLAP IN THE GUNNISON VALLEY.

The assumed overlap of the Dakota sandstone in the Gunnison Valley is unquestionably explained by the fact that Peale and other Hayden Survey geologists included in the Dakota several hundred feet of beds that belong in the Gunnison formation (Jurassic?) of Eldridge, embracing equivalents of the McElmo and La Plata formations of the San Juan region, a fact clearly shown by Peale's section of the assumed Dakota occurring in Gunnison Canyon about a mile above Sapinero.[2] This section embraces 536 feet of strata, which are described as predominantly sandstone, with some shaly beds and thin limestones. The upper member of Peale's section, 100 feet thick and described as "massive yellow siliceous sandstone," is all that, in our opinion, belongs in the Dakota. In mapping the Uncompahgre quadrangle we have examined this and many other sections of the Gunnison Canyon, and we assign to the Dakota a thickness of about 100 feet. It has the character common to it over large areas of western Colorado, which have been examined by several parties of the Geological Survey in recent years. A thin remnant of Mancos shale in some places lies between the Dakota and overlying volcanic rocks.

The beds beneath the Dakota sandstone in the Gunnison Valley are largely sandy, as Peale has stated, but shaly beds of red, lilac, green, or yellowish colors are in many places well developed between the sandstones. At its base the sandstone is thicker and more massive, and this portion undoubtedly corresponds to the La Plata sandstone, as distinguished in the San Juan Mountains area and the adjacent portions of the plateau country to the west. The La Plata is also well developed in the Uncompahgre Plateau and the Uncompahgre Valley.

In the wild lower canyon of the Gunnison, between Cimarron Creek and Smiths Fork, the Hayden map represents a thin Jurassic formation as appearing between the Dakota sandstone and the gneisses and schists, but farther down the canyon a thin Triassic formation appears in similar manner between the Jurassic and the crystalline rocks. This makes the section of the lower Gunnison Canyon correspond with that of the eastern flanks of the Uncompahgre Plateau, 30 miles to the west. But though Peale[3] refers to his Jurassic formation as appearing beneath the Dakota at a certain point and thickening toward the north, he was unable to examine the section in detail, and it seems reasonable to assume that if these beds are Jurassic they belong in the Gunnison formation with the greater part of the section above them, included by Peale in the Dakota. They may illustrate the progressive overlap of succeeding beds of the Gunnison on an uneven floor of crystalline rocks.

The age of the supposed Triassic rocks of the lower Gunnison Canyon has not been determined by fossils or by close lithologic correlation with known Triassic rocks of similar position in the Uncompahgre Plateau, and it must be remembered that Eldridge found that the Gunnison formation in the southern Elk Mountains (=La Plata+McElmo) rests unconformably on red strata of the Maroon conglomerate (Carboniferous),[4] and in the Uncompahgre Valley below Ouray both Triassic and Permian (?) beds occur between the La Plata and the Carboniferous.[5]

Coming now to new data bearing on the character of the great overlap shown in the Gunnison Valley, we may say that our observations during the last few years have demonstrated the presence of the Gunnison formation between the Dakota and the pre-Cambrian all along the Gunnison Canyon and also in the valley of Cebolla Creek, the southern tributary of the Gunnison called "White Earth River" on the Hayden map. During the survey of the Uncompahgre quadrangle in 1911 it was found that the lower member of that formation, now

[1] U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1874, p. 132 and Pl. VII; fig. 2, facing p. 97, 1876.

[2] U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1874, p. 131, 1876. The section is referred to as "beneath station 73"; the location is shown on the map facing p. 170 and the profile in fig. 1, Pl. XIV, facing p. 169.

[3] U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1874, p. 126, 1876.

[4] U. S. Geol. Survey Geol. Atlas, Anthracite-Crested Butte folio (No. 9), 1894.

[5] Idem, Ouray folio (No. 153), 1907.

called the La Plata sandstone, extends for 16 miles up the ridge east of the Cebolla, overlying a variety of pre-Cambrian rocks. In some places the McElmo beds are preserved above it; in a few others there are also remnants of the Dakota sandstone. Tertiary volcanic rocks overlie all these sediments.

East of Cebolla Creek the Gunnison beds probably extend continuously underneath the volcanic rocks to the valley of Cochetopa Creek. They are exposed north of Agency Peak and on the ridge west of the Cochetopa, where the Hayden map represents the volcanic rocks. About 12 miles south of Tomichi Creek the Gunnison beds cross the Cochetopa and pass under the Dakota sandstone on its eastern bank, in the area where the Hayden map represents Colorado shales as resting on granite. The shales occur in this region but are restricted to the higher country several miles south of the Tomichi.

In Razor Creek valley, next east of the Cochetopa, nearly 1,000 feet of Mancos shale is locally preserved beneath the volcanic rocks. In an eastern branch of that stream not shown on the Hayden map a fault brings up the Dakota, the Gunnison, and the underlying granite in a small area nearly surrounded by volcanic rocks.

In the extreme eastern part of this sedimentary area, which is traversed by Tomichi Creek, the Dakota and Gunnison formations are everywhere present beneath the Mancos shale. Moreover, these formations occupy a somewhat larger area than is assigned to them on the Hayden map, especially on the north and east. The hills and smooth-sloped ridges near the Tomichi are in most places formed of the soft McElmo strata, though rhyolitic tuff occurs in certain hills. The Dakota maintains its usual character and thickness, and from its superior induration it is everywhere the most prominent of these formations. On the northwest slope of Tomichi Dome it has a measured thickness of 80 feet.

Near Tomichi Creek some low cliffs, which appear at about the horizon where the Dakota might be expected, are of rhyolite. The volcanic rocks rest on a very uneven surface and are not readily recognizable at a distance. Moreover, the sediments are gently folded, and this adds to the difficulty of tracing formation boundaries in reconnaissance work.

The Gunnison formation is rarely well exposed. The lower sandstones, which in the western part of the area are so prominent as to suggest a correlation with the La Plata sandstone, are thin or entirely absent in the eastern part. The formation here exceeds 200 feet in thickness in but few places. Northwest of Tomichi Dome its thickness was found to be 150 to 175 feet. It consists chiefly of reddish and greenish shales, sandstone being very subordinate.

The decided thinning of the Gunnison formation eastward suggests that it may not have been everywhere present beneath the Dakota in the central mountain region of Colorado. The change in lithologic character here noted indicates that this thinning was due to nondeposition of the normal section in the area under discussion and not to unconformity caused by erosion.

As to the structure exhibited by the Mesozoic formations in the basin of Tomichi Creek it is sufficient to say that for about 20 miles east of Gunnison the creek flows in a syncline, the strata dipping at high angles toward it from the north and south. But the limitation of the formations on the east is due to a steep upturning of the beds. The Dakota and Gunnison beds assume westerly dips of 80° or more and are in some places overturned. On the north side of Tomichi Creek the gradual change from a low southerly dip can be observed in the area northeast of Tomichi Dome, but on the south side of the creek the lower beds hold their steep dips until they disappear beneath the volcanic rocks.

In regard to the Paleozoic sediments, the representation on the Hayden map of Tomichi Dome as "Lower Carboniferous" is incorrect, for the dome is made up of a plug of rhyolite, about a mile across, intruding Mancos shale. Moreover, Paleozoic sediments, not shown on the Hayden map, form most of the basin of Indian Creek, the fork of Marshall Creek which enters from the north about 4 miles southeast of the town of Sargents. The Paleozoic beds are thus known within 5 miles of Marshall Pass. About 600 feet of these beds are exposed over the pre-Cambrian in this area, and the section is similar to that of Fossil Ridge, where the Carboniferous is represented on the Hayden map. The beds dip about 20° S. and on the east, west, and south are overlain by volcanic rocks, while on the north they overlie the pre-Cambrian rocks.

The error of the Hayden map in representing Colorado shales on pre-Cambrian east of Cochetopa Creek is perhaps entirely cartographic. It is certainly not entirely due to incorrect observation, for the map does not agree with Endlich's statements concerning the distribution of the Cretaceous formations in Cochetopa and Tomichi valleys, nor with his profile sections through this region.[1] He repeatedly refers to quartzites under the shales as probably "Lower Cretaceous," but they were omitted from the map prepared some years later. The name Dakota does not appear to have been applied to these sandstones at the time of Endlich's report.

SAN JUAN MOUNTAINS AREA.

The representation of the Hayden map by which Triassic, Jurassic, and Dakota Cretaceous beds are shown to overlap and in turn come in contact with the pre-Cambrian in canyon branches of Cimarron Creek, north of Uncompahgre Peak, is wholly hypothetical. There are no such exposures in these canyons, for the volcanic rocks descend to the streams. Yet an overlap of this general character for the La Plata sandstone must exist beneath the volcanic rocks between the Gunnison Canyon at the mouth of Blue Creek and the Uncompahgre Valley below Ouray. Endlich, who was responsible for this part of the Hayden map, understood the nature of the overlap existing beneath the volcanic rocks, but drew on his imagination for the exposures to express it. In the Ouray quadrangle the La Plata is found on the Dolores (Triassic) formation, and beneath the Dolores is the complete known sedimentary section of the San Juan region from the Cutler formation (Permian?) to the Ignacio quartzite (Cambrian). The beginning of the overlap is near the Uncompahgre, however, for on Cow Creek, one of its eastern tributaries, the La Plata rests with angular unconformity on Cutler beds, the Dolores and an unknown amount of the Cutler being missing.

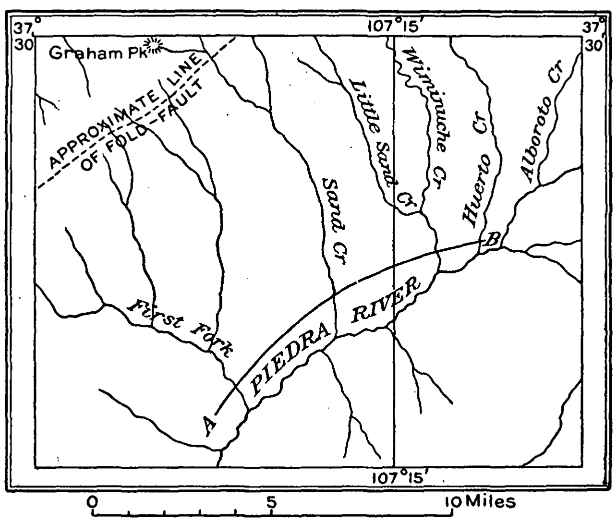


FIGURE 2.—Drainage map of a part of the Piedra Valley, Colo.

The sedimentary sections of the San Juan Mountains district from the Uncompahgre Valley, on the north, around the western slopes and eastward on the southern side as far as Pine River agree in showing the La Plata sandstone resting on the Triassic red beds (Dolores formation), the full Paleozoic sequence of the region occurring in most places. The details of these relations are described in the Ouray, Telluride, Rico, La Plata, and Engineer Mountain folios of the United States Geological Survey. At many localities, however, the sandstone of the Dolores formation beneath the La Plata has been much eroded, causing local unconformities.

As stated in the Engineer Mountain and Needle Mountains folios, the great overlaps shown on the Hayden map in the Animas Valley and east of it are not to be found as represented. Our recent work has shown, however, that about 25 miles east of the Animas, on the west side of Wiminuche Creek, both faulting and earlier overlap are plainly exhibited nearly on the northeast-southwest line where the Hayden map represents "Upper Dakota" beds in original contact with "Metamorphic granite." In the small portion of this area that lies in the San Cristobal quadrangle, north of 37° 30′, the fault mentioned brings Dolores (Triassic), La Plata (Jurassic), and McElmo (Jurassic?) beds successively into vertical or steeply inclined position against pre-Cambrian rocks on the northwest. A coarse granite is the chief of these older formations, but gneiss and Algonkian quartzite also appear in Wiminuche Valley near the point where the fault disappears under the later volcanics. The relations of Wiminuche Creek, Piedra Canyon, and other localities mentioned are shown in figure 2.

[1] U. S. Geol. and Geog. Survey Terr. Ann. Rept. for 1873, Pl. XIV, pp. 341-342, 1874.

Farther southwest this fault is lost under glacial drift and a thick forest cover, but on the east and southeast slopes of Graham Peak, a granite mountain near by, which is unnamed on the Hayden map but assigned an elevation of 12,836 feet, small remnants of quartzite and greenish shales rest on the granite northwest of the fault line. These beds dip gently to the southeast. Their character suggested to us that they belong to the La Plata and McElmo formations, and the exposures of the Piedra Canyon, to be described, practically prove this correlation to be correct. The fault probably passes into a fold within the area shown in figure 2, but time was not available for an examination of the district where this change presumably occurs, nor were we able to examine the country southwest of Graham Peak, where the overlap of the La Plata sandstone over the whole section of older sedimentary formations must apparently occur within a few miles.

The Hayden map is also incorrect in its representation of the geology of Piedra Canyon and lower Wiminuche Valley and of the slope between Piedra River and the granite divide to the northwest, which is colored as entirely occupied by the "Upper Dakota." Endlich, who mapped this district, usually applied this term to the strata still called the Dakota sandstone, and at most a few hundred feet of lower beds. In the area referred to, however, the valleys and canyons on the dip slope have a depth of more than 1,000 feet, and as the true Dakota is less than 200 feet thick in this region lower formations are naturally exposed. It is in the canyon sections that the overlap to be described is so clearly exhibited.

A traverse down Wiminuche Creek to Piedra River and down the canyon of the Piedra for 6 miles to the mouth of the second large tributary from the northwest, called "First Fork," revealed a most interesting structural and stratigraphic complexity, which is described in some detail on pages 44–46 of this paper. Within a few miles the river cuts across a monocline and two anticlinal uplifts, exposing three areas of pre-Cambrian rocks, which are overlain by somewhat different sections of the Paleozoic and Triassic formations, and these in turn are covered in marked unconformity by the La Plata sandstone. Above this come the McElmo and Dakota formations, the Dakota forming the rim rock of a warped and dissected plateau.

The northeastern of these eroded uplifts reveals the La Plata resting on granite or Algonkian schist; the middle one exposes the same pre-Cambrian formations but shows a varying Paleozoic section between them and the La Plata; the southwestern uplift was seen only from a distance, but it also appears to have a pre-Cambrian core in the rugged canyon below First Fork, and Paleozoic formations must be present, though perhaps in an incomplete section.

RÉSUMÉ.

From the evidence here presented it appears that the overlap of the Gunnison formation on the pre-Cambrian rocks extends at least 50 miles farther up the valleys of the Gunnison and Tomichi than was represented for the Jurassic beds on the Hayden map. It takes the place of the assumed transgressions of the Dakota sandstone and "Colorado" shale. Eldridge has shown that the Gunnison extends northward through the Elk Mountains in marked unconformity with the Paleozoic formations.[1] The relations in the Piedra Valley suggest that the La Plata sandstone overlapped earlier sediments and came into contact with the pre-Cambrian rocks along a general north and south line, crossing the San Juan Mountains area. Piedra Canyon is about 75 miles south of Gunnison River, and it seems not unlikely that the area of the La Plata overlap extended eastward through the present mountain district to the San Luis Valley. The suggestion has been entertained that the strata known as the Gunnison formation on the western slope and the Morrison formation on the eastern slope were once continuous deposits, having been connected across the area of the Sawatch Mountains and perhaps also across the areas of the Sangre de Cristo, the Arkansas Valley, and the district south of South Park. Although it is difficult to outline land areas in central and southern Colorado where the Morrison or Gunnison beds were not deposited, or to prove that there were any such areas, the thinning of the Gunnison formation eastward, as described on page 41, indicates that the two formations may never have been continuous.

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[1] Eldridge, G. H., U. S. Geol. Survey Geol. Atlas, Anthracite-Crested Butte folio (No. 9), 1894.

It is the current practice of the Geological Survey to refer the La Plata sandstone to the Jurassic because strata believed to be its equivalent occur in Utah beneath marine Jurassic beds. This reference does not require the assignment of the McElmo and Morrison formations to the Jurassic. It seems, however, to indicate that sedimentation may have continued in Colorado, with no considerable interruption, from Jurassic through Lower Cretaceous time.

STRATIGRAPHIC RELATIONS IN THE PIEDRA VALLEY.

STRUCTURE OF THE UPPER MESOZOIC FORMATIONS.

The Mesozoic formations exposed in the lowlands adjacent to the San Juan Mountains, in the area traversed by San Juan and Piedra rivers, exhibit many gentle folds and minor faults which can be grouped in no definite systems. These structural features are brought out by the Dakota sandstone in characteristic ledge outcrops on steep slopes and along the walls of small canyons, or by undulations where it serves as the sustaining floor of many nearly level stretches between streams near the mountains. Such rolls and small faults are especially well shown near Pagosa Springs, where several small streams have cut through a thin mantle of Mancos shale and revealed the underlying Dakota.

The McElmo and La Plata formations must take part in these minor structures, but erosion has not revealed them, so far as known, in the valleys east of the Piedra. The structure shown immediately adjacent to Piedra Canyon is rudely expressed in figure 3. It will be noted that the La Plata, and with it the overlying beds, has been warped by three low folds. The one best shown in the figure lies between Sand Creek and First Fork. The fold southwest of First Fork is probably still more striking, for it is plain that the La Plata, McElmo, and Dakota formations must all disappear beneath the Piedra, by southwesterly dips or faulting, within 4 or 5 miles of First Fork. These low folds of the La Plata are located, at least in a general way, above more pronounced folds of pre-Jurassic formations, to be described under the next heading.

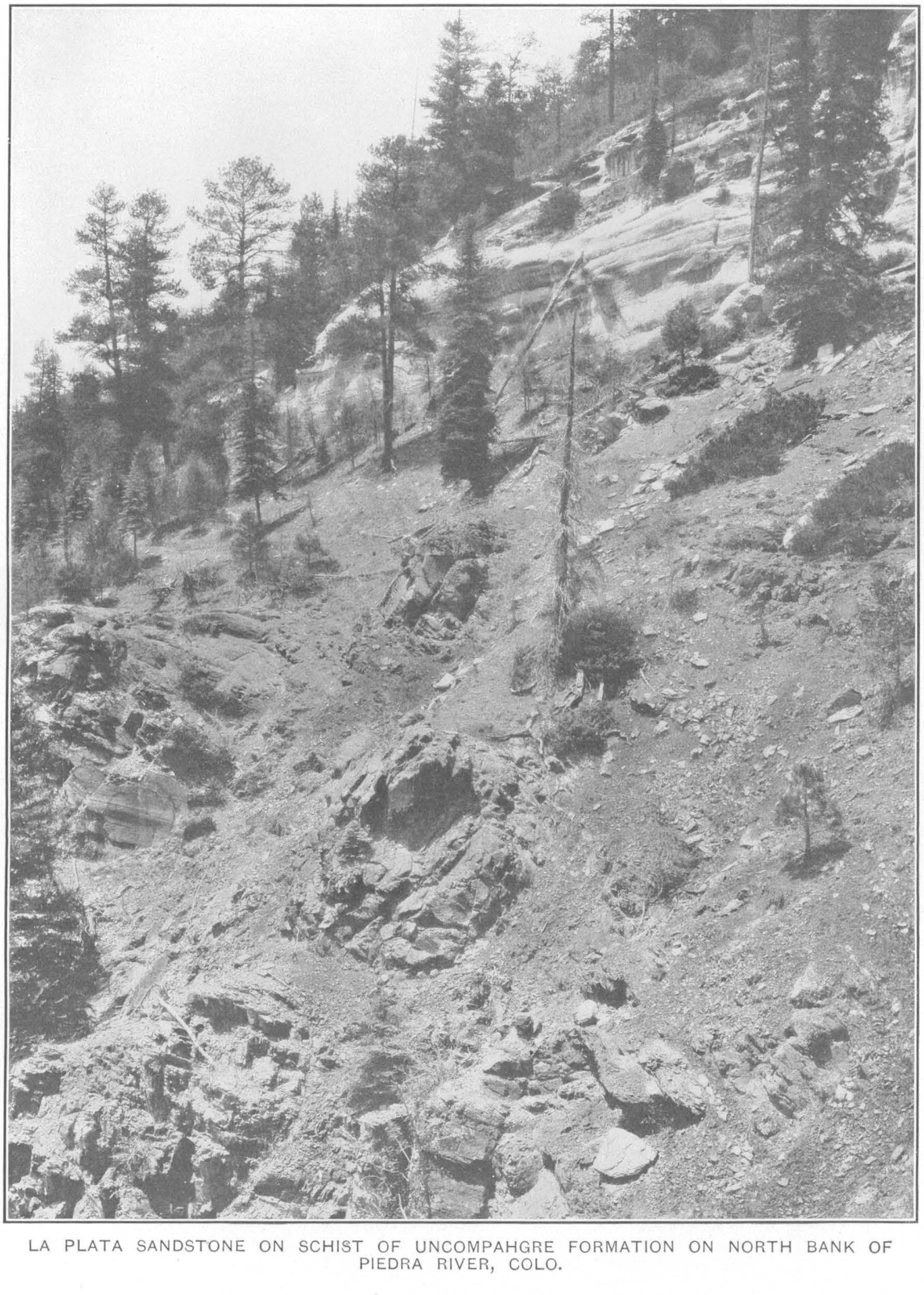
The structure of the underlying beds probably had much to do with the location of the later minor folds of the La Plata along the Piedra, for many small faults in younger formations in the San Juan region represent renewed movement on fault planes along which older formations have been more extensively dislocated at some much earlier period. It seems reasonable to suppose that the same is true of the folds, and the gentle flexures of the Piedra appear to be the results of such repeated movement, but further study is necessary to ascertain definitely the relations of the folds in this region.

Mention has been made (p. 42) of a major fold-fault of southwest-northeast trend that crosses the Wiminuche north of the area shown in figure 2. Whether this movement was synchronous with the minor flexures here referred to is not known.

THE UNCONFORMITY BELOW THE LA PLATA SANDSTONE.

The character of the unconformity may be more clearly brought out by describing in somewhat greater detail the relations so well exhibited in the Piedra Valley and its branches below the mouth of Wiminuche Creek. The Piedra itself first cuts through the La Plata sandstone about a mile above the mouth of that creek. The La Plata there dips very slightly to the southeast and rests on steeply upturned shales, schists, and thin quartzites of the Uncompahgre (Algonkian) formation. These relations are brought out by the view given in Plate VIII. The schists are much decomposed and their appearance indicates that they had long been subjected to weathering before the deposition of the La Plata.

In the angle between Piedra and Wiminuche Creek the base of the La Plata lies about 200 feet above the junction of the streams. It runs up the Wiminuche with nearly regular position, crossing it at about a quarter of a mile above Little Sand Creek, and in this distance it crosses an ill-exposed contact between the Uncompahgre strata and a great intrusive mass of coarsely porphyritic granite, regarded as a part of the Eolus granite, which occupies a large area in the Needle Mountains. There may be a fault contact at this point.



LA PLATA SANDSTONE ON SCHIST OF UNCOMPAHGRE FORMATION ON NORTH BANK OF PIEDRA RIVER, COLO.

Below Wiminuche Creek the base of the La Plata descends gradually, with very gentle undulations, keeping from 100 to 200 feet above the river, to the point of the ridge east of Sand Creek. The Uncompahgre beds underlie the La Plata in the Piedra Canyon with a general northwestern dip of 43°–45°, to a point about a mile below the mouth of Wiminuche Creek, where they disappear beneath the lower Paleozoic formations, which dip about 11° SW. These beds belong to the northeastern limb of a shallow syncline, the opposite side of which rises more steeply beyond Sand Creek.

Owing to this older structure the La Plata overlaps discordantly the formations from the Elbert? (Devonian?) to the Hermosa (Pennsylvanian), and at the point of the ridge east of Sand Creek it lies on Hermosa beds several hundred feet above the base of the formation, with an angular unconformity rudely illustrated by figure 3.

Sand Creek is nearly in the trough of the syncline just referred to, and it has cut below the La Plata for its entire length. The gradient of the stream is equal to the southeastern dip of the La Plata sandstone, about 4°, so that the base of the sandstone keeps its position, from 100 to 200 feet above the stream, for over 7 miles from the Piedra. The underlying Hermosa also persists until the great fold-fault alluded to on page 42 is approached. Where the lower beds turn up adjacent to that fold the creek cuts through them into granite.

Somewhere in the region near Graham Peak the La Plata again overlaps the lower Paleozoic formations, but a heavy cover of forest and old glacial gravels obscure these relations and no

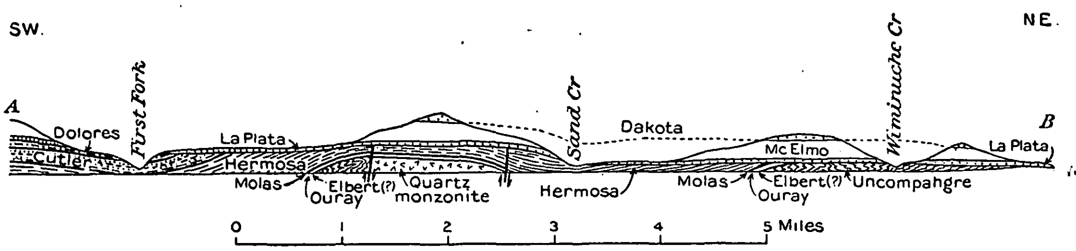


FIGURE 3.—Diagrammatic section along the northwest side of Piedra Canyon, Colo.

exposures of the unconformity were found. Erosion may have removed the La Plata from the rather narrow zone in which it might otherwise be present.

The divide at the head of Sand Creek and farther north is in the Eolus granite, and the base of the La Plata turns up sharply on the higher slopes and swings around to the northeast where the fold merges into the Wiminuche fault. On some of the ridges of these upper slopes northwest of the fault remnants of the La Plata sandstone overlie the granite.

Below the mouth of Sand Creek the La Plata sandstone assumes a northeastern dip and in a distance of less than a mile its base rises 1,000 feet above the bed of Piedra River. It then turns gently to the southwest and east of the mouth of First Fork, which is the next main stream, it is again only a few hundred feet above the Piedra. As shown in figure 3, there is an older and more pronounced fold in the pre-Jurassic strata between Sand Creek and First Fork and the La Plata truncates these older formations, the overlap being very plainly demonstrated by the section displayed in Piedra Canyon and the valley of First Fork.

As the Piedra cuts across this anticline it first reveals the Eolus granite beneath the sediments, but on the southwest side a fault brings schists of the Uncompahgre formation once more to view. The river flows through these pre-Cambrian formations in a rugged canyon. The Hermosa and earlier Paleozoic formations are well exposed on the northwest side of the canyon.

First Fork also flows in a synclinal trough and for at least several miles above its mouth cuts below the La Plata. In the lower part of the valley bright-red sandstones are prominent in the southwest bank and also appear on the southeast side of the Piedra. These beds and 300 to 400 feet of variously colored grits, sandstones, shales, and nodular limestones which overlie them, clearly belong to the Permian (?) Cutler formation, for they are in turn overlain by the Triassic Dolores formation. The characteristic fine-grained "saurian conglomerate" of the Dolores, carrying fragments of bones and teeth and made up mainly of small pebbles of gray limestone, is exposed on the northeast side of First Fork, halfway to the principal forks of the stream shown in figure 2, and also in the ridge between the forks.

The white La Plata sandstone occurs 300 to 350 feet above the forks, being clearly shown in the main ridge to the northeast. It thus appears in First Fork in about the same position relative to the underlying section of Triassic and Paleozoic formations that it holds throughout the San Juan region, to the west, as described in the published folios. Except for a part of the Dolores formation the overlap from Triassic to pre-Cambrian rocks is complete between First Fork and Wiminuche Creek.

Below the mouth of First Fork the canyon of the Piedra has been seen only from a distance. The canyon closes in and the walls are high and rugged. The Paleozoic beds form a sharp anticline, with very steep dips on the southwest limb, and the pre-Cambrian rocks are probably again exposed in the canyon. The La Plata and overlying beds are also folded, but less sharply than are the underlying rocks, the conditions resembling those above First Fork. Within a few miles down the river all pre-Dakota formations disappear beneath the surface by southerly dips.

The overlap of the La Plata has been described with special reference to the exposures examined on the northwest side of the Piedra, but the same general relations are shown on the opposite side, as could be seen from many good points of view. But the structure exhibited by the older formation southeast of the Piedra is more complex than has been described. Pre-Cambrian rocks rise about 1,000 feet above the river in an amphitheater nearly opposite Sand Creek, and are there immediately overlain by the La Plata sandstone. A more detailed study than we could make is necessary in order to determine fully the structural relations of the formations in this area.

PRE-DAKOTA SECTION OF PIEDRA VALLEY.

JURASSIC (?) SYSTEM.

McELMO FORMATION.

The McElmo strata, occurring between the Dakota and La Plata sandstones, are widely distributed in the Piedra and adjacent valleys, but owing to their soft, friable nature are well exposed at few places. The only good section observed is in the little canyon of Wiminuche Creek, about 5½ miles north of the area shown in figure 2, where the stream cuts across the strata adjacent to the fault mentioned on page 42. In this canyon 470 feet of McElmo strata are exposed in vertical position.

At the base of this McElmo section is a dark-red marly shale, such as occurs at many places in this position. It is succeeded by wavy friable sandstones, sandy shales, and clay shales, in beds that are rarely more than a few feet thick, without marked change in character. On slopes the harder sandstones form ribs separating shale depressions. The colors, especially those of the shaly layers, exhibit the variegation characteristic of the formation, from red, through pink, green, lilac, and yellow, to gray.

It seems probable that this section does not show the true thickness of the formation, owing to squeezing and shearing near the fault, and that the softer beds in particular are thinner than is normal. No fossils have been observed in the McElmo formation.

JURASSIC SYSTEM.

LA PLATA SANDSTONE.

General character.—The La Plata of the Piedra Valley exhibits variations which are natural in a region of overlap upon an uneven topography. In other parts of the San Juan region the La Plata consists of two thick members of white massive cross-bedded quartzose sandstone, separated by a subordinate and variable calcareous member in places carrying some limestone but more generally consisting of calcareous sandstones and shales. In Piedra Canyon and its branches the lower La Plata sandstone in many places has nearly its normal character and above it come dark bituminous limestones, locally thin-bedded and brecciated. The upper La Plata sandstone is presumably present in less than the normal thickness, but owing to its soft and friable character it affords no good exposures. This character renders it possible, however, that these soft beds belong in fact to the McElmo formation and that the La Plata here lacks its upper member.

At the base of the La Plata a basal conglomerate, variably developed, is composed mainly of dense quartzite pebbles from the Algonkian Uncompahgre formation, a great thickness of which is shown in the adjacent Needle Mountains area. Such conglomerate was observed at several places near the mouth of Wiminuche Creek, where the La Plata rests on an irregular surface of Algonkian strata.

The lower La Plata sandstone is variable in thickness and is very thin or wanting in some places, as on the east side of the Wiminuche about a mile above its mouth. A short distance below this point conglomerate and some sandstone occur between the underlying granite and dark limestone breccia. These variations are no doubt due to the uneven surface on which the sandstone was deposited.

The limestone member of the La Plata in the Piedra Valley presents very nearly the same features that it does north of Ouray. Its total thickness is locally more than 30 feet, and usually a gray massive cavernous limestone lies in thin beds above and below it, but in some localities almost the entire member is black breccia of thin limestone cemented by white calcite. In the thin shaly limestone layers below the more massive part scanty fish remains were found. Dr. C. R. Eastman has examined these remains carefully but is unable to make any satisfactory determinations of the forms represented.

Section of La Plata sandstone.—On the northwest side of the Piedra, about midway between Sand and Wiminuche creeks, the section given below was found.

Section of La Plata sandstone on Piedra River between Sand and Wiminuche creeks.

Top.	Feet.
1. Sandstone of the McElmo formation, red, thin-bedded, argillaceous; poor exposures.	
2. No exposures; unexposed interval probably occupied by upper La Plata sandstone with some McElmo beds	70
3. Limestone breccia, dark, made up of fragments like underlying limestone; contains open spaces, as the cementing material does not fill all the interstices; makes good ledge outcrops	15
4. Limestone, dark, in places nearly black; shaly; has a decided bituminous odor; carries fragments of small fish	10
5. Quartzose sandstone, light yellowish gray, fine, even-textured; weathers with rounded, pitted forms	20
6. Quartzose sandstone, white, even-grained, cross-bedded; makes rounded cliffs	55

This is the normal section of the La Plata of this area, but the two limestone members are rather variable and the upper limestone breccia alone reaches a thickness of 30 feet just north of the mouth of Sand Creek, though at some other places it is much thinner. The heavy sandstone bed at the base is also somewhat variable in thickness.

TRIASSIC SYSTEM.

DOLORES FORMATION.

The only known exposures of the Dolores formation are adjacent to the fault in Wiminuche Canyon and in the valley of First Fork. In neither locality were good sections seen, but it is clear that the formation here exhibits no marked change in character from that shown in the Animas Valley, as described in the Engineer Mountain folio. There is the usual alternation of fine limestone conglomerate and thin-bedded sandstones and shales near the base, followed above by intensely red shales and more or less massive sandstones. The original thickness of this sandstone in this region is presumably nowhere preserved, owing to pre-La Plata erosion, and it may have been much greater than at present. Probably 350 to 400 feet is a maximum measure of the Dolores formation now occurring in the Piedra Valley.

Unless small isolated exposures of the Dolores occur in the San Juan, Navajo, or other valleys east of the Piedra, near the volcanic rocks of the mountains, these outcrops of Dolores beds of the Piedra are probably nearer than any others of Colorado to the long-known fossiliferous beds of Rio Chama in New Mexico. No conglomerate like that of the Dolores has been reported from New Mexico, but it is evident that if the worn particles of limestone were a little smaller than they are in the conglomerate of First Fork and were mingled with sand grains the peculiar character of the "saurian conglomerate" would be lost.

CARBONIFEROUS SYSTEM.

PERMIAN (?) SERIES.

CUTLER FORMATION.

The most complete section of the Cutler formation is in Dolores Valley below Rico, Colo.[1]

The only observed outcrops of the Cutler formation in the areas here considered are those in First Fork, already mentioned, where, as noted, some of the sandstones and shales are very bright red, but the strata near the Dolores formation have the character of the partial section given below, which occurs on the northeast side of First Fork about half a mile above the Piedra, where it is crossed by the Forest Service trail leading up First Fork. The top of the section is not more than 200 feet below the Dolores, but the intervening beds are poorly exposed.

Section of Cutler formation about one-half mile above the Piedra.

Top.	Feet.
1. Arkose grit with subordinate red sandy shale; upper bed of arkose, 6 to 12 feet thick, varies locally inversely with red sandstone	20
2. Arkose, cross-bedded, massive, pink; forms rounded outcrops	12–15
3. Shale, calcareous, and nodular pink limestone	8
4. Sandstone, light gray, somewhat calcareous, weathering into rounded forms; tough fracture	6–7
5. Limestone and shale; red nodular limestone with shaly matrix; crumbling	3
6. Sandstone, gray, fine and even-grained	3
7. Shale, sandy; dark red in upper part, grading below into dark-green sandstone at base	12
8. Sandstone; thin-bedded, greenish gray, dark at top and lighter below; strike N. 12°–18° E., dip 7°–8° W	30
	98

This section is in general characteristic of the Cutler of the southern San Juan region as to the variety of beds and their alternation, though no two sections agree in thickness or similar beds or in details of gradation. No exposures were found in the zone between the Cutler beds and the typical Hermosa, so that it is uncertain whether the Rico formation (Permian ?) is present in the Piedra Valley or not.

PENNSYLVANIAN SERIES.

HERMOSA FORMATION.

The lower part of the Hermosa is exposed south of Sand Creek and near the Piedra, in a diagonal section which is continuous for about 500 feet, the beds dipping 18° to 25° NE. Owing to a fault the actual base of the formation is not shown in relation to this section, but probably there is a gap of less than 200 feet. The section is on the northeast limb of the anticline shown in figure 3.

Partial section of Hermosa formation near Piedra Canyon, south of Sand Creek.

Top.	Feet.
1. Sandstone, yellowish green, argillaceous	4
2. Sandstone, pinkish, with a few thin variegated bands; slightly cross bedded, medium to coarse-grained	16
3. Shale, purplish	3
4. Limestone, dark gray	2
5. Sandy shale, dark red to purplish	20

[1] Cross, Whitman, and Howe, Ernest, Red beds of southwestern Colorado and their correlation: Geol. Soc. America Bull., vol. 16, p. 464, 1905.

	Feet.
6. Grit, light gray	6
7. Limestone, nodular, with very fossiliferous shale layers	6
8. Limestone, nodular and fossiliferous, and shale; strike N. 65° W., dip 27° NE.	
9. Shale, reddish to purplish at base, drab at top	20
10. Limestone, nodular and fossiliferous, with thin shale	3
11. Shale, purplish	17
12. Shaly limestone; fossils	2
13. Shale, sandy and reddish near base, calcareous and black near top	6
14. Sandstone, coarse, somewhat variegated, brown or red	8
15. Sandy shale	2
16. Sandstone, soft, shaly, greenish, and somewhat variegated	5
17. Grit and coarse sandstone	19
18. Limestone, very fossiliferous	1
19. Grit, light colored	22
20. Shale, reddish and calcareous at top	23
21. Grit, light colored	17
22. Limestone, dark gray; few shells	3
23. Sandstone, thin-bedded, shaly, gray, and cross-bedded	9
24. Shale, forming flaky sandy clay, upper part dark gray, lower part reddish	20
25. Limestone, sparingly fossiliferous; strike N. 35° W., dip 18° NE	4
26. Shale, very fine-grained, green and gray, or red; soft and poorly exposed (estimated thickness)	40
27. Sandstone, arkosic, green with prominent red feldspar grains	5
28. Limestone; upper 5 feet nodular, gray, dense, rich in Productus, Spirifer, Terebratula, and Triticites; lower 7 feet earthy limestone grading downward; alternation of shales and limestone in layer 3 to 4 inches thick; fossiliferous	12
29. Shale, dark, calcareous	3
30. Limestone, nodular; rich in *Triticites secalicus*	2½
31. Shale, soft, gray; poorly exposed	20
32. Sandstone, yellowish gray	2
33. Limestone, nodular in upper part, thinner bedded and sandy below; very fossiliferous	23
34. Shale and shaly sandstone	10
35. Grit, arkosic, pink, gray, and mottled; cross-bedded, massive; much quartz	14
36. Shale, red and gray	8
37. Limestone, part laminated, part nodular; fossiliferous	22
38. Shale, red, with irregular nodules of limestone	12
39. Limestone, massive, gray	5
40. Shale, red	4
41. Limestone and red shale of irregular development; rich Triticites-bearing limestone layer	20
42. Grit, gray, massive	25
43. Sandstone, dense, with dark-red shale partings to beds; pink and gray spots in sandstone	18
	490

Below this section is a zone, about 200 feet wide, in which the rocks are not exposed, and below that the Ouray limestone appears. On the south side of the fault which interrupts the continuity of the section the two lowest beds of the Hermosa are exposed. At the base is a gritty sandstone about 20 feet thick, and overlying it is a more or less sandy fossiliferous limestone of wavy bedding, exhibiting an irregular alternation of pure dark-gray material with streaks of yellowish earthy limestone. This constitution is characteristic of the lowest limestone of the Hermosa in the Animas Valley.

MOLAS FORMATION.

The descriptions of the Molas formation in the Silverton, Needle Mountains, and Ouray folios show the persistent character of this thin and peculiar formation throughout the San Juan region.

The Ouray limestone south of and adjacent to the fault that interrupts the Hermosa section lies below reddish clay, shale, and calcareous beds that are typical of the Molas formation. The full thickness of the Molas formation was not seen, but near the fault there are unusually good though not continuous exposures, making it clear that the formation is at least 100 feet thick. It has the usual character, consisting mainly of red calcareous shale. Much of it is almost a red clay, but where the calcareous element is prominent the mass becomes irregularly nodular or lumpy. Layers or lenses of mottled limestone are rare. The largest extend several yards laterally. Some layers of calcareous mud are twisted and are held by ordinary shale or clay. Near the top is a calcareous sandstone, apparently quartz-free, 1 to 2 feet thick. The upper 20 feet is not well enough exposed to show the character of the rock.

CARBONIFEROUS AND DEVONIAN SYSTEMS.

OURAY LIMESTONE.

A massive light-gray crystalline limestone about 30 feet thick occurs below the Molas formation in the section on the northeast limb of the anticline below Sand Creek. The upper surface of the limestone contains deep solution crevices filled by the reddish mud of the Molas, a condition common throughout the San Juan region. In the limestone were found cup coral and fragments of crinoid stems such as are common in the Carboniferous part of the Ouray limestones elsewhere. Chert nodules occur in the upper part of the limestone. No Devonian fossils were found, and it may be that no part of the limestone here should be referred to that period.

DEVONIAN SYSTEM (?).

ELBERT FORMATION(?).[1]

Below the Ouray limestone there are several quartzite beds, 4 to 5 feet thick in all, and some reddish or mottled crumbling sandstone. Green or reddish shale occurs below these sandstones but is poorly exposed. No place for a section was found. It is estimated that there are 40 to 50 feet of sandy and shaly beds between the Ouray limestone and pre-Cambrian formations, and the reference of these to the Elbert rather than to the Upper Cambrian (Ignacio quartzite) is based simply on probabilities. The Ignacio is absent on Pine River about 12 to 15 miles west of the Piedra Canyon.

ALGONKIAN SYSTEM.

UNCOMPAHGRE FORMATION.

As shown in the profile section, there are in the Piedra Canyon two distinct exposures of quartzite and schist or shale belonging to the Uncompahgre formation. In the one at and near the mouth of Wiminuche Creek the strata have nearly the same character that they exhibit in the Needle Mountains. The quartzites are dense and hard and are bluish-gray in color. They are in part coarse and in part fine grained. The shales have been somewhat metamorphosed and some beds are schistose through abundant mica, but in many places they are soft and crumbling. Much of the decomposed appearance of these strata is probably due to weathering in a long period of exposure before the decomposition of the earliest Paleozoic sediments.

In the area of these Uncompahgre beds in the Piedra Canyon between Sand Creek and First Fork quartzite, accompanied by pronounced schists, is the principal rock, occurring in a band about 100 feet wide, adjoining the granite body. Brown tourmaline and rudely developed chiastolite or andalusite characterize the schists near the granite and indicate that the granite is intrusive. The Piedra Canyon, cut for a depth of 200 to 300 feet in these beds, is very rugged and has somber gray walls.

The Uncompahgre strata beneath the La Plata sandstone of Plate VIII are locally contorted and crushed. Those of the canyon below Sand Creek strike nearly east and dip 60° or more to the north.

[1] The Elbert formation was first described in 1904 (Cross, Whitman, A new Devonian formation in Colorado: Am. Jour. Sci., 4th ser., vol. 18, p. 245). For further descriptions and map of type locality see U. S. Geol. Survey Geol. Atlas, Engineer Mountain folio (No. 171), p. 5, 1910.

A RECONNAISSANCE IN THE CANYON RANGE, WEST-CENTRAL UTAH.

By G. F. Loughlin.

INTRODUCTION.

PREVIOUS STUDIES IN THE REGION.

The Canyon Range, in west-central Utah, which derives its name from the deep valley cut through its northern part by Sevier River, has hitherto received no general geologic study, not even of a reconnaissance nature. The atlas of the Wheeler Survey,[1] though showing the geology of the surrounding ranges, leaves the Canyon Range blank. Gilbert, in his study of Lake Bonneville,[2] examined the lake deposits in the valleys on the east and west sides of the range and in Sevier Canyon which connects them, but paid no special attention to the hard rocks of the range. Tower and Smith,[3] in their report on the Tintic district, north of the Canyon Range, mention the presence of folded Paleozoic strata, including Carboniferous limestone, along Sevier Canyon, and of Eocene conglomerate resting unconformably upon the Paleozoic rocks. Their statement was based on observations made during a day's drive from Juab to Leamington by Smith, who noted the absence of volcanic material in the Eocene conglomerate and the abundance of it in the Pleistocene and recent alluvial deposits, and therefore concluded that the Tertiary volcanic rocks, which form the southern part of the Tintic Mountains, were post-Eocene. The latest geologic map of North America [4] represents the Canyon Range as composed entirely of Cambrian and Lower Ordovician strata.

FIELD WORK.

The writer in 1912 [5] made a trip through Sevier Canyon, noting the unconformity between the Eocene conglomerate and the Paleozoic strata and also the presence of a bed of dark-colored volcanic rock, presumably andesite or latite, resting upon Eocene conglomerate, thus verifying Smith's conclusions. The close resemblance of the Paleozoic quartzite in general lithologic character to the Cambrian quartzite of the Tintic district, together with the age assigned to it on the geologic map of North America (just cited), led the writer to describe the Tertiary conglomerate as here resting on Cambrian quartzite. In June, 1913, however, while visiting the Leamington mining district, he took the opportunity to make a hasty reconnaissance of the range, spending half a day in the mountains north of Sevier Canyon and three days in trips up Wood, Yellowstone, Fool Creek, and Oak Creek canyons and along the west base of the range. It was found that the quartzite, instead of being Cambrian, rested in apparent conformity upon lower Mississippian limestone. No careful measurements of the thicknesses of these formations were attempted, but interesting structural data were gathered, which, though far from complete, are believed to be worthy of presentation.

[1] U. S. Geog. Surveys W. 100th Mer., atlas sheet 50.

[2] Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, pp. 104, 166, 192, and 193, 1890.

[3] Tower, G. W., and Smith, G. O., Geology and mining industry of the Tintic district, Utah: U. S. Geol. Survey Nineteenth Ann. Rept., pt. 3, pp. 617, 671, and 673, 1899.

[4] Willis, Bailey, Index to the stratigraphy of North America: U. S. Geol. Survey Prof. Paper 71, Pl. I, 1912.

[5] Loughlin, G. F., Reconnaissance in the southern Wasatch Mountains, Utah: Jour. Geology, vol. 21, p. 448, 1913.

TOPOGRAPHY.

The Canyon Range, as shown on the accompanying map (fig. 4), has the general features of the maturely dissected basin ranges, but the transverse canyons on its west side are surprisingly broad in proportion to their lengths. Those on the east side were not seen at close range. Most of the lateral branches of the canyons on the west side are strike valleys separated by "hogback" ridges. (See fig. 5.) Some of these canyons are occupied by small creeks, the largest of which is Oak Creek, in the southern part of the range.

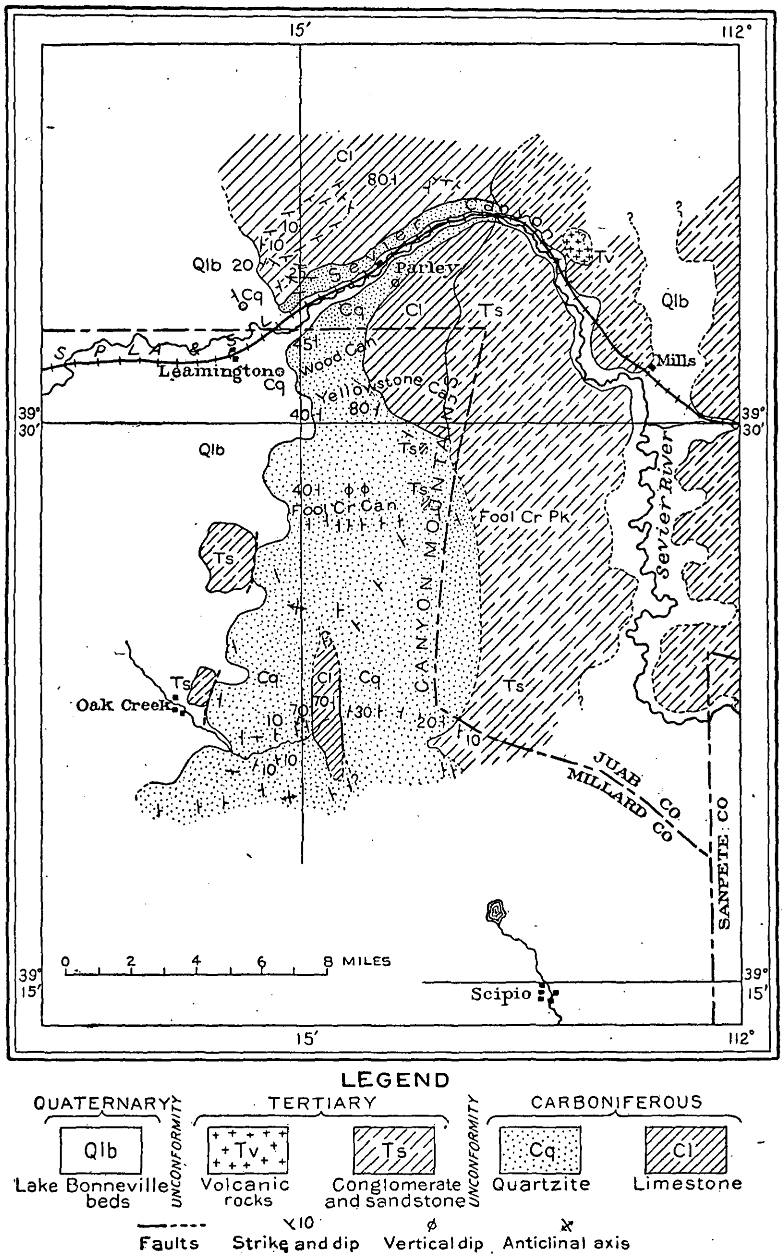


FIGURE 4.—Reconnaissance map of the Canyon Range, Utah, showing geologic formations.

The most striking topographic feature is Sevier Canyon, in reality a rather wide valley with a flat bottom and gently sloping sides, which cuts completely across the range in a curved course at a very gentle gradient. Sevier River has terraced the unconsolidated lake deposits which constitute the canyon floor and follows a meandering course, interrupted at one or two places by gentle rapids, where it has uncovered buried ridges of quartzite.

SETTLEMENTS.

Two small agricultural towns are situated at the west base of the range at places where water for irrigation is available—Leamington, at the mouth of the canyon of Sevier River, and Oak Creek, or Oak City, at the mouth of Oak Creek canyon. A few ranches are located between these two towns, especially near the mouth of the canyon of Fool Creek, which supplies water for irrigation. The San Pedro, Los Angeles & Salt Lake Railroad passes through Leamington and Sevier Canyon. Oak Creek is reached by stage from Leamington.

GEOLOGY.

STRATIGRAPHY.

GENERAL FEATURES.

The Canyon Range is composed almost entirely of sedimentary rocks—Carboniferous limestone and quartzite overlain unconformably by Eocene conglomerate. Volcanic rocks have been reported from the extreme northern and southwestern parts of the range, beyond the limits of the area visited. The valleys on either side of the range are floored with beds of Pleistocene age that were deposited in Lake Bonneville and are known as Lake Bonneville beds, and locally with later alluvial deposits.

SEDIMENTARY ROCKS.

CARBONIFEROUS LIMESTONE.

The limestone, as shown on the map (fig. 4), is the prevailing rock northwest of Sevier Canyon and forms the middle western slope of the range south of Sevier Canyon as far as the south boundary of Yellowstone Canyon. North of Sevier Canyon it has generally low dips, associated with gentle anticlinal and synclinal flexures, but locally its beds stand nearly vertical. South of Sevier Canyon the dip varies from steep westerly to vertical. The limestone on both sides of Sevier Canyon dips beneath quartzite. A smaller limestone area extends north and south across Oak Creek. Its beds show a monoclinal structure, dipping 70° W. beneath the quartzite and are separated on the east from quartzite by a strike fault. Limestone is also said to be exposed in the narrow southern part of the range, near Scipio. A lens of limestone in quartzite was noted on the north side of Fool Creek. This lies well above the main limestone formation.

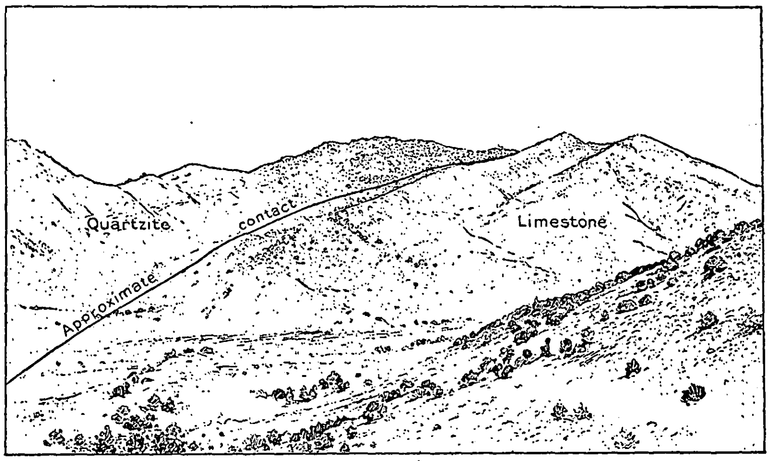


FIGURE 5.—View across North Fork of Yellowstone River, Canyon Range, Utah, looking northwest from Arbroath shaft.

The lithologic character of the limestone varies somewhat in different places. The lowest strata seen, about 3 miles northwest of Sevier Canyon, are thick to rather thin bedded, of medium to dark gray color, and fine to rather coarse grained in texture. Fossils are fairly abundant in certain beds. At a higher horizon, due north of Parley station, which is 5 miles northeast of Leamington, intercalated beds of shale are conspicuous. About a mile north of Parley station, on the east wall of a southward-sloping canyon, there is a prominent bluff of vertical strata which consists largely of conglomerate composed of limestone and chert pebbles and which lie within the zone of intercalated shale beds. The stratigraphic significance of this conglomerate can not be determined without detailed study, but from the paleontologic evidence (see p. 54) it appears to be only a local variation within a single limestone formation.

The uppermost limestone beds vary in character at different places. On the west slope of the range, northwest of Sevier Canyon, they are very cherty, nodules and continuous bands of chert comprising as much as 50 per cent of some beds. Perfect pseudomorphs of brachiopod shells are conspicuous in much of the chert. Shale beds at this place are not conspicuous, and the gradation from limestone upward into quartzite appears to be marked by increase in chert. The exact relations of the chert to the quartzite were not ascertained.

In Wood Canyon the uppermost beds are of light to medium gray color and are dolomitic. Many of them are characterized by a concretionary or pisolitic structure, the concretions ranging up to an inch or more in diameter and offering greater resistance to weathering than the matrix. Above and intercalated with these strata are beds of striped shaly limestone, alternating with shale, and these in turn are overlain by a bed of brown ferruginous quartzite, which is followed by typical quartzite.

At no place is the entire thickness of the limestone exposed. A rough estimate of the exposed thickness northwest of Sevier Canyon gives 1,700 to 2,000 feet, but there are so many local variations in strike and dip that there are many chances for error in this estimate. The thickness of the limestone in Yellowstone Canyon is certainly much greater, but the entire exposed width was not studied, and the lower part of the limestone is concealed beneath thick bodies of Eocene conglomerate. In Oak Creek Canyon the exposed thickness is at least 3,500 and may be over 4,000 feet.

Fossils collected from the upper cherty limestone beds on the west slope of the range, 2½ to 3 miles northeast of Leamington station, were determined by G. H. Girty, of the United States Geological Survey, as follows:

Crinoid stems, large and numerous.
Zaphrentis sp.
Schuchertella chemungensis?
Schizophoria swallowi?
Spirifer centronatus.
Spirifer incertus?
Syringothyris carteri.
Cliothyridina aff. sublamellosa.

Another lot, collected at a horizon much lower stratigraphically, in the saddle between the two main ridges of the range, about 2½ miles north of Parley station, contains *Spirifer centronatus* and *Composita humilis*. Mr. Girty states that the first lot "is clearly of lower Mississippian or Madison facies," and that the second lot "is less diagnostic, since there are two Pennsylvanian species very similar to the only two comprised in the collection, but since the latter occurs below the first it must needs be Madison also." Fragments of fossils similar to those listed above were noted in Yellowstone Canyon in the upper part of the limestone.

The fossils prove the upper 1,700 to 2,000 feet of the limestone to be of lower Mississippian or Madison age. Lower portions may prove, on close study, to be older than Mississippian. In the Tintic district, 12 miles north of the Canyon Range, limestone of Mississippian age is 2,000 to 2,250 feet thick and is underlain by 4,400 to 4,600 feet of Cambrian and Ordovician limestone. In the southern Wasatch Mountains similar conditions are found, but only 2,400 or 2,500 feet of the older limestones are present. These two sections are the basis for the suggestion that the lower part of the limestone in the Canyon Range may be of pre-Mississippian age.

QUARTZITE.

The quartzite of the Canyon Range is exposed along the western half of Sevier Canyon and extends continuously southward well beyond Oak Creek. South of the divide between the Yellowstone and Fool Creek canyons the quartzite constitutes the summit and entire western slope of the range, with the exception of the faulted band of limestone (p. 53) across Oak Creek.

The quartzite as a rule is of fine, even grain and varies in color from nearly white to light and dark brown or reddish brown. Some of its beds are greenish. Its general appearance is very similar to that of the thick Cambrian quartzite exposed in the Tintic district and at several places along the Wasatch Range, thus accounting for the fact that the quartzite has heretofore been regarded as of Cambrian age.

The quartzite contains a conspicuous and persistent dark-reddish finely banded member, 400 or 500 feet thick, which is a convenient horizon marker and indicator of the geologic structure. (See figs. 6 and 7.) The northernmost exposure of this member is on the south side of Sevier Canyon, near its mouth, where it stands vertical in a pinched synclinal trough of southwesterly pitch. It was not traced southward across Wood and Yellowstone canyons.

but is undoubtedly present in that part of the range. South of Yellowstone Canyon the red member follows the west edge of the range almost as far south as Fool Creek. It then swings southeast, crossing the lower part of Fool Creek canyon, and following an undulating course, probably passing north and east of Fool Creek Peak, the highest peak of the range. South of Fool Creek canyon the red member is probably present in the western part of the range, but was seen only in the vicinity of Oak Creek. North of Oak Creek canyon it is again prominent along the west edge of the range and is exposed in a very gentle anticline for a considerable distance along both walls of the canyon, from a point near its mouth to the first north branch. Here a sudden steepening of the easterly dip carries it below the surface, but it reappears about a mile farther up the canyon a short distance west of the limestone band. It again appears in the trough of a gentle syncline on the north slope of the canyon near its head. It was not followed south of Oak Creek canyon.

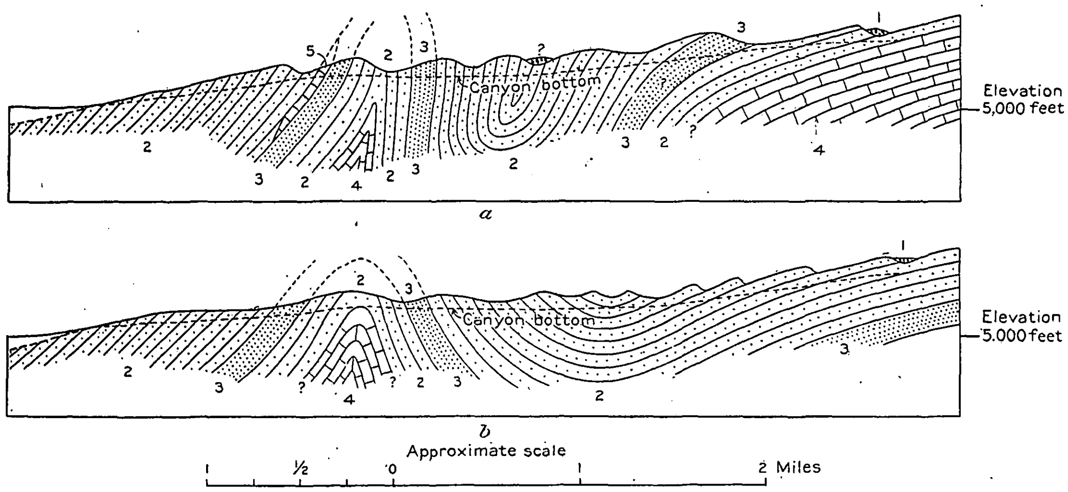


FIGURE 6.—Generalized section along north (*a*) and south (*b*) sides of Fool Creek canyon, Utah. 1, Tertiary conglomerate and sandstone; 2, Carboniferous quartzite; 3, red member of the quartzite; 4, Carboniferous limestone; 5, limestone lentil in quartzite.

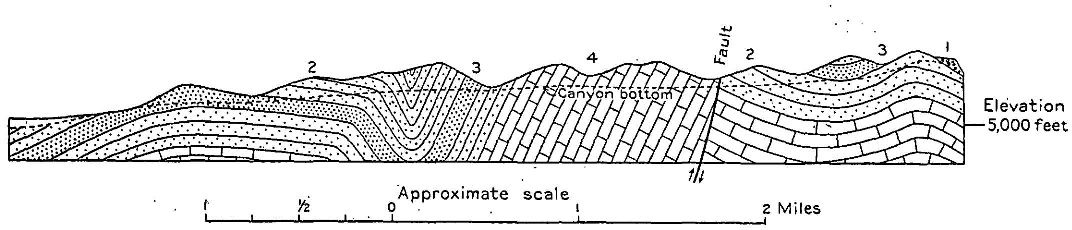


FIGURE 7.—Generalized section along north side of Oak Creek canyon, Utah. 1, Tertiary conglomerate and sandstone; 2, Carboniferous quartzite; 3, red member of the quartzite; 4, Carboniferous limestone.

One lens of gray limestone, mentioned on page 53, was noted on the north side of Fool Creek canyon. Detailed study may prove the presence of several such lenses.

The entire thickness of the quartzite was at no place exposed, owing to erosion of its upper portion. On the north side of Fool Creek canyon (fig. 6) the thickness of the exposed vertical strata on the east limb of the close anticline appears to be at least 5,000 feet. Elsewhere the variations in dip prevented a closer estimate.

No fossils were found in the quartzite, but its apparent conformable position above limestone of Madison age suggests that its lower part at least is Mississippian. Its upper part may be Pennsylvanian. A similar quartzite of great thickness, containing some limestone beds, forms the greater part of the West Tintic Mountains, the southern end of which is almost connected with the northwest end of the Canyon Range, and the writer has found upper Mississippian fossils in the limestone beds. Correlation, therefore, with this quartzite fixes the age of the quartzite of the Canyon Range as upper Mississippian.

The upper Mississippian studied by the writer in the Tintic Mountains north of the Canyon Range and east of the West Tintic Range consists of a thick series of alternating limestone, shale, and sandstone or quartzite beds. The same series, 5,000 to 6,000 feet thick, is present in the southern part of the Oquirrh Range,[1] and is overlain by the thick Bingham quartzite, which has been referred by Girty to the Pennsylvanian series.[2] In the Wasatch Mountains the same intercalated series of limestones, shale, and sandstone is overlain by the Weber quartzite of Pennsylvanian age. These data indicate a transition northward and eastward from quartzite into strata composed largely of limestone and shale, and suggest that in late Mississippian and Pennsylvanian time the deposition of siliceous sediment was extended northward and eastward, overlapping the intercalated beds of limestone, shale, and sandstone.

EOCENE CONGLOMERATE.

The Eocene conglomerate is almost wholly confined to the east half of the range. A few small outliers were noted on the higher spurs north of Fool Creek, and their approximate positions are shown in figures 4 and 6. A considerable area, in which the rocks are very poorly exposed, was traversed along the low foothills north of the town of Oak Creek.

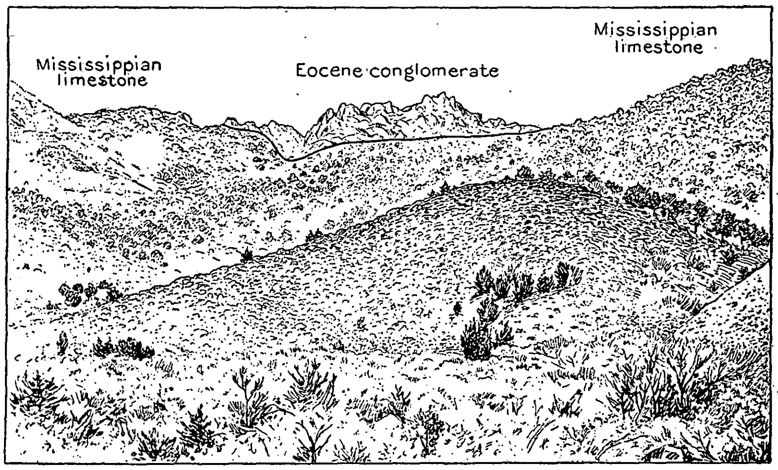


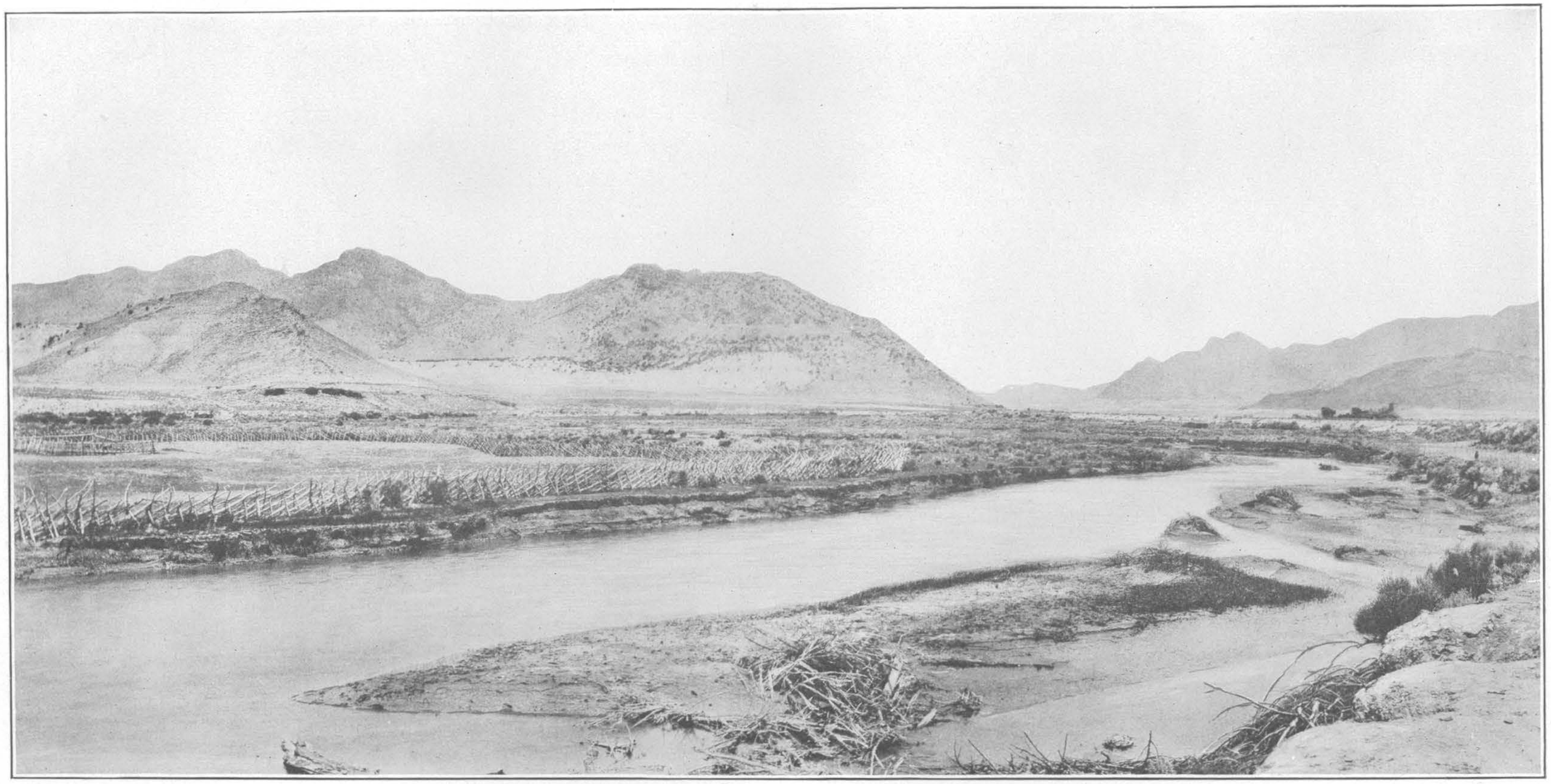
FIGURE 8.—Eocene conglomerate resting on upturned Mississippian (or older) limestone, at head of Yellowstone Canyon, Utah.

In the principal area the Eocene consists of light-gray and red beds of conglomerate and sandstone, the conglomerate pebbles including limestone, quartzite, and chert. The western boundary of the principal area is exposed in Sevier Canyon near its northernmost point, where a coarse conglomerate rests unconformably on quartzite. On both sides of the canyon the boundary can easily be seen from a distance, owing to the marked contrast in color between the younger and older formations. South of the canyon the Eocene beds rest on the upturned lower Mississippian limestone and form the crest and upper west slope of the range along the heads of Wood and Yellowstone canyons. (See fig. 8.) North of Fool Creek Peak the west boundary crosses the summit and extends along the eastern slope as far as the saddle at the head of Oak Creek canyon, where the contact is well exposed, the Eocene beds, with a dip of about 10° E., abutting against a steep erosion surface of quartzite. This relation of dip to contact indicates a very uneven pre-Eocene topography.

The Eocene beds at the top of the saddle have disintegrated into loose cobbles and pebbles, with only scattered remnants of solid conglomerate. This disintegrated area lies between quartzite summits and is further indication of the unevenness of the Eocene topography.

The small outliers north and south of Fool Creek were recognized from a distance by their characteristic red color and by their rounded weathered surfaces, which sharply contrasted with the angular surfaces of the surrounding quartzite. The outliers occupied depressions between quartzite summits, suggesting that the basal portion of the Eocene conglomerate was deposited in strike valleys. (See fig. 6.) The existence of these pre-Eocene strike valleys at the heads of present strike valleys suggests that the present drainage is essentially the same as in pre-Eocene time, and may thus account for the shapes of the canyons, which, as already remarked (p. 52), are unusually broad in comparison to their lengths.

[1] Spurr, J. E., Economic geology of the Mercur mining district, Utah: U. S. Geol. Survey, Sixteenth Ann. Rept., pt. 2, p. 377, 1896.
[2] Boutwell, J. M., Economic geology of the Bingham mining district, Utah: U. S. Geol. Survey Prof. Paper 38, appendix, p. 387, 1905.



LAKE BONNEVILLE BEDS AT THE MOUTH OF SEVIER CANYON, NEAR LEAMINGTON, UTAH.

The rocks which form the low foothills north of Oak Creek are almost completely reduced to a loose mass of limestone, quartzite, and chert cobbles, with a few remnants of consolidated conglomerate. These remnants furnish the clue to the origin of the foothills, which without them could not be explained, as the foothills are bounded on all sides by steep slopes and bear no direct relation whatever to the Quaternary alluvial deposits. The presence of the Eocene material in these deposits is presumably due to the sinking of a block during the faulting period when the Basin Ranges were developed. This occurrence extends the western boundary of Eocene deposition somewhat farther westward than has heretofore been indicated.

As only the eroded western edge of the Eocene beds was studied no idea of its thickness was gained. The beds are assigned to the Eocene by correlation with similar strata in the southern Wasatch Mountains[1] and in the ranges immediately east of the Canyon Range.[2]

QUATERNARY DEPOSITS.

The Quaternary deposits include the Lake Bonneville beds of clay and marl deposited in Pleistocene time and the overlying alluvial deposits at the mouths of the canyons. The Lake Bonneville beds are terraced by Sevier River and are well exposed at Leamington and along the sides of Sevier Canyon, as shown in Plate IX. No special attention was given to these deposits by the writer, and the reader is referred for further information to Gilbert's monograph.[3]

VOLCANIC ROCKS.

No volcanic rocks were seen at close range. From a distance a bed of dark columnar volcanic rock was seen overlying Eocene beds northeast of the canyon, and its approximate location is shown in figure 6. Volcanic rocks are said to be abundant in the extreme northern part of the range, and porphyry dikes are reported along Dry Canyon, south of Oak Creek.[4]

STRUCTURE.

The Carboniferous rocks are characterized by a few major folds with steep dips, by several intervening minor folds with gentle dips, and by a prominent strike fault which appears to be coincident with a broken anticline. The northernmost major fold is the unsymmetrical syncline of southwesterly pitch, whose axial plane is nearly parallel with the western half of Sevier Canyon. Its northwestern limb has a moderate dip, 25° to 40°, which becomes lower away from the axis, passing into an area of prevailingly monoclinal structure, though the general low and regular inclination of the beds is interrupted by several inconspicuous anticlines and synclines. The southeast limb is nearly or quite vertical along Sevier Canyon, but along Wood and Yellowstone canyons its prevailing dip is near 45°.

In Fool Creek canyon an anticline and syncline with north-south axes are exposed. (See fig. 6.) On the north side the details of the structure are not very clear. The moderate westerly dip of the quartzite changes eastward to vertical, the latter persisting for about 1½ miles and then gradually changing to a moderate westerly dip, which continues eastward probably to the crest of the range. The only clue to the structure is given by the red quartzite member, aided by comparison with the simpler structure on the south side of the canyon, which shows the strata to be folded into a close anticline of vertical dip and an unsymmetrical syncline with vertical west limb and moderately dipping east limb. Detailed study, however, may show the vertical strata to be more complexly folded than figure 6 indicates. The structure on the south side of the canyon (fig. 6) needs no special comment. The lengths of these folds are not definitely known, but the anticline may extend as far north as the rim of the south fork of Yellowstone Canyon, where the uppermost limestone beds stand nearly vertical. That the limestone is probably not far below the surface where the anticline crosses Fool Creek may be inferred

[1] Loughlin, G. F., Jour. Geology, vol. 21, p. 448, 1913.
[2] U. S. Geog. Surveys W. 100th Mer., atlas sheet 50.
[3] Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, pp. 104, 166, 192, and 193, 1890.
[4] Oral information by James Overson, of Leamington, Utah.

by the proximity of the red member of the quartzite to the top of the limestone in Sevier and Oak Creek canyons.

Between Fool Creek and Oak Creek canyons several minor folds can be seen from the western foothills. In the lower part of Oak Creek canyon a gentle anticline with limbs dipping about 10° is well exposed. About 2 miles above the mouth this passes into a syncline, both of whose limbs dip 60° to 70°. The syncline, however, is not symmetrical. (See fig. 7.) The west limb is relatively small, but the east limb is at least 1½ miles in horizontal width and brings the limestone to the surface. The limestone is bounded on the east by the strike fault already mentioned, which separates it from quartzite of gentle easterly dip. The actual fault plane or zone is concealed, but the dips of the strata to either side of it north of the creek suggest a compression fault. (See fig. 7.) The fault appears to die out both southward and northward. Northward it appears to pass into an anticline whose axis is in the limestone; southward its relation to folding is not so clear, as the axes of the folds there swing southeastward and the trend of the fault is obscure. East of the fault the quartzite is folded into a rather gentle syncline and anticline, the anticlinal axis lying just east of the crest of the range.

The character of the folds show that in the central and southern parts of the range the dominant compressive force was eastward, whereas in the northern part the prevailing force was northwestward. No explanation of this difference in direction is warranted from so brief a study of this limited area.

GEOLOGIC HISTORY.

The geologic history of the Canyon Range may be summarized as follows: Deposition of limestone in early Mississippian and perhaps in still earlier time were followed by deposition of quartzite which continued during later Mississippian and possibly Pennsylvanian time. The next recorded event was the folding of these sediments, which presumably took place during the post-Jurassic upheaval that affected a great part of the Cordilleran region. The period of folding was followed by one of erosion, during which the rocks were dissected into ridges and valleys generally similar to those of to-day. The steep east slope along the southern part of the range, against which the Eocene strata are banked, was evidently formed at this time, and it is probable that a pronounced valley was developed in the Sevier Canyon syncline. Deposition during this erosion interval is represented by Cretaceous strata in the country to the south and east of the Canyon Range, and it is possible that the lowest beds called Eocene in the Canyon Range are Cretaceous. This deposition continued in the Eocene, during which the crest of the range was probably entirely covered by conglomerate and sandstone. The volcanic rocks were erupted in late Eocene or post-Eocene time.

The volcanic epoch was followed by the period of profound faulting in late Tertiary time which developed the Basin Ranges. One of these faults extends along the west base of the range, separating it from another block which moved downward and has left only its cap of disintegrated Eocene conglomerate above the present surface. A period of rapid erosion followed, during which all the Eocene strata were removed from the west side of the range save a few remnants which occupied the heads of old north-south valleys. During this combined period of uplift and erosion, Sevier River eroded its channel through the soft Eocene rocks fast enough to maintain its course. After it had worn through the Eocene strata which formerly existed on the west side of the present range its course was guided by the pronounced southwest-pitching syncline, along which, as was just suggested, a valley may have existed in pre-Eocene time.

During a late stage in the erosion period, after the outline of the range was developed into virtually its present form, the surrounding lowlands were covered by the waters of Lake Bonneville, which at their highest (Bonneville) stage occupied Sevier Canyon and formed a land-locked bay on the east side of the range. It was in this stage that the fine material of the lake beds was deposited. Later, during the Provo stage of the lake, the waters lowered until they receded from the canyon, and Sevier River resumed its course, cutting its channel into the lake beds and building a low delta from Leamington southwestward to Deseret. Final recession of the lake waters left the topography essentially as it is to-day. The only noteworthy work of subsequent erosion was the further cutting of the Sevier channel through the newly formed delta.

ORE DEPOSITS.

Ore deposits thus far worked or prospected in the Canyon Range comprise only a few small bodies of lead or lead-zinc ore in Wood and Yellowstone canyons and some quartz veins stained with copper carbonates near Fool Creek and Dry canyons. Only two properties, so far as the writer has learned, have shipped ore.

LEAD AND ZINC.

Yellowstone mine.—The Yellowstone mine is located in the south fork of Yellowstone Canyon, about 4 miles southeast of Leamington. The workings include an inclined shaft 200 feet deep, following the dip of the limestone, about 60° W., and drifts at the 50, 100, and 170 foot levels. The country rock includes the uppermost beds of limestone. The ore forms small replacement bodies along the intersection of one of the limestone beds by fissures. On the 50-foot level small bodies were stoped along the intersection of the bed with a north-south strike fissure and one body where the bed was somewhat shattered at the intersection of the strike fissure and an east-west cross fissure. The 100-foot level was inaccessible. The 170-foot level follows the contact between a shale and limestone bed, along which there is a zone of veinlets, consisting chiefly of spar (dolomite and calcite), which are said to assay 3 to 4 per cent lead.

The ore stoped consisted principally of galena and cerusite (lead carbonate) in a gangue of ferruginous dolomite and calcite spar. A little secondary aragonite was noted on a crust of fibrous calcite that lined a pocket along the strike fissure on the 50-foot level. Assays of the ore have run from 30 to 65 per cent lead, the higher grade carrying 5 to 6 ounces of silver. A little gold has also been reported. The mine has been worked intermittently and has shipped only about 15 carloads of ore in over 20 years. No zinc has been found.

Arbroath mine.—The Arbroath shaft is situated about an eighth of a mile north of the Yellowstone, in a low spur which separates the south fork from the north fork of Yellowstone Canyon. The writer did not gain access to the mine, which was idle, but the material on the dump showed the mineralization to be of the same type as that of the Yellowstone mine. The ore thus far found during assessment work is reported to be of two grades, the higher carrying 76 per cent lead and 9 ounces silver, and the lower 10 to 11 per cent lead and 1 ounce silver. Only a small quantity of ore has been found thus far.

Wood Canyon group.—The Wood Canyon group of claims is situated on the north side of Wood Canyon and includes the uppermost beds of the limestone formation. The mineralized outcrop is a brown, rust-stained dolomitic bed, containing a large amount of ferruginous dolomite spar, white where fresh and brown where weathered, through which are scattered grains of galena and yellowish-brown zinc blende. The stained rock is closely associated with two fissures, one tending north-south and the other of S. 55° E., both of whose outcrops are marked by shallow gulches. Plans for dry concentration of the ore were being considered in the summer of 1913. No assays, either of crude ore or concentrates, had been made.

COPPER PROSPECTS.

A small copper prospect in quartzite is situated on the low ridge just north of the mouth of Fool Creek canyon. The mineralized material thus far found is white vein quartz with numerous minute fractures stained by films of green and blue copper carbonates, with small spots and patches of dark brown iron oxide evidently derived through oxidation of pyrite and chalcopyrite.

Other copper and lead prospects have been reported along Dry Canyon, south of Oak Creek, but the writer's attempts to get in touch with the owners were not successful, and he could learn nothing further in regard to the deposits.

COMPARISON WITH ORES OF OTHER DISTRICTS.

The lead and lead-zinc ores above described are similar in mineralogy and mode of occurrence to certain ores in the North Tintic, East Tintic, Santaquin, and Mount Nebo districts. These ores, which as a rule occur rather remote from important bodies of intrusive igneous rock, consist essentially of galena, zinc blende, and more or less pyrite, or oxidation products of these sulphides, with gangues of dolomite and calcite, and only minor amounts of quartz. Their silver content is low, averaging as a rule 3 to 5 ounces, but in some deposits rising as high as 8 to 10 ounces per ton. The sizes and shapes of ore bodies vary according to conditions; strong fissures may contain continuous veins; permeable beds of pure limestone may be rather extensively replaced; but argillaceous and dolomitic beds have yielded only small bodies of high-grade sre and a few more extensive bodies of milling ore. The ore bodies of the Canyon Range are no exception to this rule. Those mined up to the present have replaced dolomitic limestone beds along their intersections with narrow fissures and are small or of low grade. The higher-grade ore bodies when found may be mined at no great expense, but the cost of prospecting for new bodies after old ones have become exhausted is likely to equal or exceed the net receipts from ore sales.

In some of the districts above named there are small copper prospects near the lead and zinc mines. These, according to the writer's experience, are quartz veins containing chalcopyrite and pyrite or their oxidation products and are confined to the siliceous rocks—quartzite, schist, or granite. The copper prospects of the Canyon Range may, from the meager knowledge available, be classed with this type. Veins intermediate in composition between these and the lead and zinc deposits have occasionally been found, and suggest that the two types were derived from a common source. None of these copper-bearing veins, to the writer's knowledge, have yielded steady shipments of ore.

THE MONTANA GROUP OF NORTHWESTERN MONTANA.

By Eugene Stebinger.

INTRODUCTION.

Recent field work has shown that the formations of the Montana group in and near the Blackfeet Indian Reservation of northwestern Montana are very different from those of the type area of the Judith River and associated formations on Missouri and Musselshell rivers, in the central part of the State, but similar to the formations in southern Alberta as described by Dawson. They seem to deserve special description not only because they present new evidence regarding the relations of the Belly River formation of Canada to the Judith River formation, but also because they indicate the varying geographic conditions that prevailed during Cretaceous time in this region. Furthermore, the stratigraphy as interpreted affords an excellent example of variation in sedimentation from the seaward to the landward side of a zone of deposition.

The Montana group, as here described, was first studied by the writer in the summer of 1911, along Cut Bank Creek and Two Medicine River on the Blackfeet Indian Reservation, in company with Mr. T. W. Stanton, who has already briefly described some of the features of this region [1] and to whom the writer is much indebted for paleontologic determinations which, especially those for the marine formations encountered, were of great assistance in interpreting the stratigraphy. During the next two seasons these formations were traced northward into the type area of the Belly River beds, described by G. M. Dawson [2] in 1885, and eastward into an area of the Judith River formation, as definitely determined by Stanton and Hatcher [3] in 1903. The interpretation of the field relations presented is therefore based primarily on the areal tracing of the formations, although every conclusion was substantiated by paleontologic evidence.

FORMATIONS CONSTITUTING THE MONTANA GROUP.

SECTION ON TWO MEDICINE RIVER.

A section showing the complete sequence of the formations of the Montana group in northwestern Montana is exposed along the valley of Two Medicine River in the southern part of the Blackfeet Indian Reservation, and because of its completeness and of the excellence of the exposures is offered as a standard for the region. The section extends westward upstream from the mouth of the river, in T. 31 N., R. 5 W., to a point about 3 miles above the Holy Family Mission (Family post office), in T. 31 N., R. 9 W. Throughout this distance, about 35 miles, the formations either lie nearly flat or dip slightly westward at an angle rarely exceeding 3°. As the river runs nearly at a right angle to the strike, it crosses the formations in succession from younger to older. On the whole the locality is almost ideal for a study of the formations, the structure being simple and easily determined and the rocks perfectly exposed throughout most of the distance in the minutely carved badlands along the sides of the valley.

[1] Stanton, T. W., Some variations in Upper Cretaceous stratigraphy; presidential address before the Geological Society of Washington, 1912: Washington Acad. Sci. Jour., vol. 3, pp. 66-69, 1913.

[2] Report on the region in the vicinity of the Bow and Belly rivers, Northwest Territory: Canada Geol. Survey Rept. Progress for 1882-1884, pp. 1-169c.

[3] Stanton, T. W., and Hatcher, J. B., Geology and paleontology of the Judith River beds, with a chapter on the fossil plants by F. H. Knowlton: U. S. Geol. Survey Bull. 257, pp. 51-53, 1905.

From the top of the Colorado shale, which is readily recognized by its characteristic marine fauna and general appearance, the rocks naturally group themselves in ascending order into four lithologic units—(1) a massive gray sandstone, chiefly marine; (2) a rudely bedded mass of clay and sandstone, chiefly a fresh-water deposit; (3) a dark marine clay shale; and (4) a massive gray sandstone, brackish and marine. Nos. 1 and 3 correspond to the Virgelle sandstone, as the lower sandstone member of the Eagle sandstone has recently been designated,[1] and to the Bearpaw shale of the Missouri and Musselshell river section in central Montana, whereas Nos. 2 and 4, formations hitherto not recognized, whose stratigraphic equivalents elsewhere are represented by formations having different limits and lithology, are here named the Two Medicine formation and Horsethief sandstone. The important details of the section are shown below.

Formations of the Montana group of northwest Montana exposed on Two Medicine River between its mouth and Family post office.

Formation.	Lithology.	Fossils.	Topographic features.	Thickness in feet.
Horsethief sandstone.	Gray to buff coarse-grained, much cross-bedded, massive sandstone in upper half. In lower half slabby gray sandstone, becoming shaly toward the base. In places beds of heavy magnetite-bearing sandstone.	Mainly a brackish-water fauna containing Ostrea, Corbicula, Corbula, and Anomia. In places a marine littoral fauna yielding *Tancredia americana*, *Cardium speciosum*, and Mactra.	Where the formation lies nearly horizontal it may form a bold escarpment; where it is steeply tilted it forms prominent hogback ridges.	360
Bearpaw shale.	Dark-gray clay shale with a few limestone concretions.	An abundant marine fauna (Pierre) containing Baculites, Placenticeras, Inoceramus, Avicula, and Scaphites.	Subdued and rounded topography, gumbo soil, and few exposures.	490
Two Medicine formation.	Gray to greenish-gray clay and soft irregular sandstone which is most abundant in the lower 250 feet. In places thin beds of red clay and nodular limestone.	An abundant reptilian fauna of Judith River types. At many horizons a fresh-water fauna containing Unio, Viviparus, and Campeloma; at others brackish-water forms, Ostrea, Corbula, etc. One marine horizon yielding *Tancredia americana*, *Cardium speciosum*, Mactra, land plants, and much fossil wood.	Eroded into extensive badlands along principal streams; elsewhere a smooth rounded topography.	1,950
Virgelle sandstone.	Gray to buff coarse-grained, much cross-bedded, massive sandstone with many ferruginous concretions in upper half. In lower half slabby gray sandstone, becoming shaly toward the base.	Contains a poorly developed littoral marine fauna.	Where the formation lies nearly horizontal it forms a bold escarpment in many places; where it is steeply tilted it forms prominent hogback ridges.	220

VIRGELLE SANDSTONE AND HORSETHIEF SANDSTONE.

Both these formations are composed of massive gray to buff sandstone, and although they are 2,500 feet apart stratigraphically they are so nearly identical that they can best be described together. Each seems to be a sandy beach or near-shore deposit laid down in a retreating sea, the Virgelle representing a great recession of the Colorado sea at the close of Colorado time and the Horsethief representing an even greater recession at the close of Pierre time. The two are therefore genetically identical, each being a sandstone laid down on a marine shale in a retreating sea. Similar rocks are associated with both of these formations, each being overlain

[1] Unpublished report by C. F. Bowen entitled "The stratigraphy of the Montana group" (U. S. Geol. Survey Prof. Paper 90-I), from which the following definition is quoted: "The name Eagle sandstone was given by Weed (U. S. Geol. Survey Geol. Atlas, Fort Benton folio, No. 55) to the formation overlying the Colorado shale in north-central Montana and typically exposed on Missouri River at the mouth of Eagle Creek, 40 miles below Fort Benton. In the type locality the formation as defined by Weed consists of three more or less distinct units, comprising an upper member of thin-bedded sandstone, a middle member of shale, and a lower member of massive ledge-making sandstone. This lower member is so persistent and characteristic over a large area in north-central Montana, even where the other divisions of the formation are not recognizable, that it seems desirable for purposes of description and correlation to give it a name. It is well exposed along Missouri River from the town of Virgelle, a few miles below Fort Benton, eastward, and the name Virgelle sandstone member of the Eagle sandstone has therefore been adopted by the United States Geological Survey for this division of the formation. The Virgelle sandstone member is the lower massive ledge-making sandstone of the Eagle sandstone as defined by Weed." In northwestern Montana the Virgelle sandstone is recognized as a distinct formation, and the overlying Two Medicine formation includes the equivalent of the remainder of the Eagle sandstone.

by a thick mass of continental deposits, apparently conformable and very similar in composition and appearance.

In the section along Two Medicine River the Virgelle sandstone rises in bold cliffs above the few feet of sandy shale that form the uppermost beds of the Colorado group exposed at the mouth of the river. From this point the sandstone, dipping very slightly westward, is continuously exposed upstream for a distance of 8 miles, forming a narrow, steep-walled canyon several hundred feet deep, which is a little-known but picturesque feature of this part of Montana. Similarly the Horsethief sandstone, where it is cut through by Two Medicine River just above Family post office, also stands out in bold cliffs over 300 feet high.

The principal fossils found in these sandstones are invertebrates, although in many places both the formations, especially the Virgelle, seem barren. The Horsethief sandstone (named for Horsethief Ridge, in the Blackfoot quadrangle) has yielded both marine and brackish water forms. The brackish water forms are mainly oysters, which are locally very abundant; the marine forms belong to the Fox Hills near-shore fauna, the dominant species being *Tancredia americana* and *Cardium speciosum*. On Two Medicine River the Virgelle sandstone is apparently unfossiliferous, but elsewhere it is known to contain a marine near-shore fauna.

TWO MEDICINE FORMATION.

The Two Medicine formation, which lies immediately above the Virgelle sandstone, is a great mass of light-colored rocks about 2,000 feet thick, consisting mainly of typical continental deposits. From the upper end of the canyon in the Virgelle sandstone, in T. 31 N., R. 5 W., nearly all the formation is excellently exposed in badlands that extend for 20 miles upstream to the mouth of Badger Creek, in T. 31 N., R. 8 W. It is composed principally of light-gray to greenish-gray clay and clay shale, so rudely bedded that it is impossible to follow a given stratum for any great distance. In places the beds of clay are variegated, red and yellow strata appearing. Thin nodular and nonpersistent limestone, apparently of fresh-water origin, also occurs at irregular intervals. Probably 20 per cent of the total mass of the formation is made up of soft coarse-grained sandstone in lenticular beds which, even where 20 to 30 feet thick, can not be traced more than 1 or 2 miles. At many localities these sandstones show the very irregular cross-bedding that is characteristic of eolian deposits. The lower 200 feet of the formation is more sandy than the remainder, probably half of this part consisting of massive sandstone in irregular beds, the thickest measuring 50 feet.

A well-developed vertebrate fauna, chiefly dinosaurs of Judith River types, occurs in this formation. The abundance of fossil bones, especially in the upper 200 feet, is unusual. C. W. Gilmore,[1] of the United States National Museum, who spent the season of 1913 in collecting from these beds, noted parts of 13 different individuals of dinosaurs in the course of a single day's field work. Much of the material collected by him is new and will add greatly to our knowledge of the Cretaceous reptiles. Fragments of fossil wood and many complete sections of tree trunks are also very common throughout the formation. All the plant remains collected were identified by F. H. Knowlton as "Belly River or Judith River."

The fossil shells found in the Two Medicine formation also indicate that it is essentially of continental origin, Unio, Viviparus, and other fresh-water genera being found at many horizons. In the lower, sandy part of the formation, as well as at the top, there are local thin brackish-water beds with Ostrea, Corbula, and Corbicula. A fauna indicating a temporary incursion of purely marine waters while the formation was being deposited occurs in a sandstone about 200 feet above its base and has already been characterized by Mr. Stanton[2] as a Claggett-Fox Hills fauna. It is almost identical with the fauna found at the top of the Horsethief sandstone, a fact that shows that it existed in the shallow-water portions of the Pierre sea throughout nearly all Montana time.

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[1] Personal communication.

[2] Stanton, T. W., Some variations in Upper Cretaceous stratigraphy: Washington Acad. Sci. Jour., vol. 3, p. 66, 1913.

BEARPAW SHALE.

The Bearpaw shale is a typical dark marine clay shale averaging 500 feet in thickness in this part of the State. The change in the character of the rocks from the Two Medicine formation to this one is very abrupt, there being practically no transition beds near the contact, and although shallow water must have existed for some time at this horizon while the Bearpaw sea was advancing, no trace of the marine fauna of Fox Hills facies, noted in the Two Medicine formation and above in the Horsethief sandstone, has yet been found here. Invertebrate fossils are abundant in concretions throughout the shale and are of characteristic Pierre types, allowing fairly close and certain correlation with the Bearpaw shale of central Montana.

RELATIONS OF THE MONTANA GROUP TO THE BELLY RIVER AND JUDITH RIVER FORMATIONS.

The age of the Judith River formation and its correlation with the Belly River formation of Canada have been under discussion, mainly by paleontologists, ever since the Judith River beds were first studied. Nearly every worker who during the last 40 years has been interested in the Cretaceous formations of the Rocky Mountain and Great Plains regions has taken part in this discussion, the extensive literature of which has been thoroughly reviewed by Stanton and Hatcher.[1] In 1902, on the publication of Lambe and Osborn's report [2] on the vertebrate fauna of the Belly River formation, the controversy [3] was revived with renewed vigor. So great a difference of opinion was developed during the following winter that Stanton and Hatcher decided on a joint field investigation, which they made in the summer of 1903. The results of their work were published first in a preliminary note [4] and later in a detail report. They determined the succession of formations in the Montana group for the central Montana region, which has since been found to extend over a large area, and proved the Cretaceous age of the Judith River formation. Then, by means of practically continuous exposures, they traced the Judith River formation into the extreme southeastern part of the large area of Belly River beds, as originally mapped by G. M. Dawson.[5] This led to their second important conclusion, namely, that the Belly River formation and the Judith River formation are of identical age. Their conclusions were generally accepted as having satisfactorily answered this much-discussed question in Cretaceous stratigraphy. There was no reason to suspect that the type section of the Belly River beds as described by Dawson, occurring on Belly River, was different from that in the locality into which they had traced the Judith River formation. That these sections are different appeared only when the section here described was examined and compared both with Dawson's section and with the section of Stanton and Hatcher on Missouri River.

In a recent paper [6] A. C. Peale again raises the question of the age of the Judith River formation. He does not deny the existence of the formations of the Montana group in central Montana in the succession as originally described by Stanton and Hatcher, nor that they extend over a large area in central Montana, as proved by C. F. Bowen, R. W. Stone, and other workers, but contends that beds originally called Judith River in the type area on the Missouri near the mouth of Judith River are of Lance age and are not equivalent to the formations mapped as Judith River over a large part of Montana. Peale's contention thus raises the question of the exact interpretation of the structure and stratigraphy in the small disturbed type area at the mouth of Judith River, and if his view is substantiated the name Judith River, as applied to the formation which has been so extensively mapped under that name, will be

1 Stanton, T. W., and Hatcher, J. B., Geology and paleontology of the Judith River beds: U. S. Geol. Survey Bull. 257, pp. 14–31, 1905.

2 On vertebrate of the mid-Cretaceous of the Northwest Territory: Lambe, L. M., New genera and species from the Belly River series (mid-Cretaceous); Osborn, H. F., Distinctive characters of the mid-Cretaceous fauna: Canada Geol. Survey. Contr. Canadian Paleontology, vol. 3, pl. 2, 1902.

3 Science, new ser., vols. 16, 17, 18.

4 Hatcher, J. B., and Stanton, T. W., The stratigraphic position of the Judith River beds and their correlation with the Belly River beds: Science, new ser., vol. 18, pp. 211–212, 1903.

5 Canada Geol. Survey Rept. Progress for 1882–1884, pp. 1–169c.

6 Jour. Geology, vol. 20, pp. 530–549.

invalidated. Therefore, without entering into the question raised by Peale, it is important to insist that the correlations made later in this paper refer to the formation mapped as Judith River over nearly all of central Montana.

In the course of their stratigraphic study in central Montana, Stanton and Hatcher established the succession shown in the following table:

Section of Cretaceous rocks in central Montana.

Formation.	Character of rocks and fossils.	Thickness in feet.
Bearpaw shale	Dark clay shale with marine fauna	750?
Judith River formation	Variable shale and soft sandstone with dinosaurs and other reptiles and fresh and brackish water shells	500
Claggett formation	Dark clay shale with several beds of sandstone, especially in the upper part; marine fossils throughout, those of the sandstone including many Fox Hills species.	400±
Eagle sandstone	White, gray, and yellowish massive sandstone in lower and shale, coal, and thin sandstone in upper part. Contains marine shells, land plants, and dinosaurs.	200-300
Colorado shale	Dark marine shale	800+

On comparing this section with that on Two Medicine River, the Colorado shale, which can be traced continuously from its outcrops on Missouri River to those at the mouth of the Two Medicine and is also easily recognized because of its characteristic marine fauna and appearance, affords a safe stratigraphic datum plane on which to base comparative sections. First of all, the identification of the sandstone lying above the Colorado shale in the Two Medicine section as the lower or Virgelle sandstone member of the Eagle is made fairly certain by both its position and the fact that it also can be traced on the outcrop over the greater part of the distance from the exposures on Two Medicine River to those on the Missouri at the type locality, though its limits may vary slightly from point to point. The outcrop of this sandstone can be traced without interruption in bold cliff exposures from the mouth of Two Medicine River to the Sweetgrass Hills. From this locality to the outcrops of the Eagle, near Virgelle, on the Missouri, the bedrock formations are completely covered with drift, but the continuity of the sandstone over all of this distance is suggested by its presence in a well boring in T. 34 N., R. 8 E. The formation recognized as Bearpaw on Two Medicine River can not be traced to Missouri River in the same manner because it has been eroded away between these localities, but fortunately a characteristic marine fauna is found in the shale, which, together with the lithologic appearance, thickness, and relative position of the formation above the Colorado shale, makes its correlation with the Bearpaw shale of the Missouri River section about as certain as a correlation of this sort can be. This leaves the Two Medicine formation occupying the entire interval between the Virgelle sandstone and the Bearpaw, and it is therefore equivalent to all the strata on Missouri River that make up the Judith River formation, the Claggett formation, and the coal-bearing shale and sandstone forming the upper member of the Eagle sandstone.

In his report on the region in the vicinity of the Bow and Belly rivers Dawson[1] established the following section for the Cretaceous rocks occurring there:

Section of Cretaceous rocks near Bow and Belly rivers, Canada.

Formation.	Character of rocks.	Thickness in feet.
Fox Hills sandstone	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 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, in places including arenaceous shales	800

This section was compared with the section on Two Medicine River and it was fortunately found possible to trace all the members of the Two Medicine section due north to the equivalent parts of the section in Alberta without interruption in the outcrops. The Colorado shale

[1] Canada Geol. Survey Rept. Progress for 1882-1884, p. 112-c.

exposed at the mouth of Two Medicine River can be traced directly into an area near the international boundary mapped by Dawson as Lower dark shales. The Bearpaw shale can be traced with equal facility into the shale mapped by Dawson as Pierre, and the Horsethief sandstone into Dawson's Fox Hills sandstone. The strata designated by Dawson the Belly River series comprise all the rocks between his Lower dark shales and Pierre shales, so that if his Lower dark shales are Colorado shale, and his Pierre shale is Bearpaw, it becomes evident that his Belly River series, lying between these two marine shales, is equivalent to the Virgelle sandstone and Two Medicine formation taken together, for they lie between the same two marine shales and the formations are entirely conformable; or, carrying the correlations to Stanton and Hatcher's section on Missouri River, it is apparent, from the correlation between the section on Two Medicine River and that on the Missouri, already made, that the Belly River formation of Canada is equivalent to the Eagle, Claggett, and Judith River formations combined.

The correlations made by Stanton and Hatcher in 1903, by tracing the Judith River formation up Milk River into Canada to beds mapped as Belly River by Dawson, leading them to the conclusion that the Belly River and Judith River formations were identical, are correct as far as they had gone, as can be understood by reference to the diagram (fig 9). Starting from the section in central Montana, they traveled northwestward, following the wedge of the Judith River formation to a point on Milk River near Pakowki Lake in Alberta, where the section is as at A in the accompanying diagram and there found Claggett shale beneath the Judith River formation. But Dawson had already mapped the beds found in this locality as Belly River, so that Stanton and Hatcher were justified in assuming the identity of the Belly River and Judith River formations. Dawson had also seen and described the dark marine shale of the Claggett near Pakowki Lake, but had erroneously correlated it with his Lower dark shales (Colorado shale) of the area he mapped farther west, so that the formation he had mapped as Belly River in the vicinity of Pakowki Lake included only a part of the Belly River formation as he had defined it in his type area along Belly River.

Dawson's error in correlating beds in different parts of the area originally mapped as Belly River, although suspected by Stanton and Hatcher,[1] has apparently never been recognized by Canadian geologists, for since the publication of Stanton and Hatcher's report they have assumed that the section of the Montana group occurring on the Missouri in central Montana was applicable to all the area of southern Alberta up to the base of the Rockies. This seems evident from a report by D. D. Cairnes, of the Canadian Geological Survey, on the Moose Mountain district,[2] a tract lying adjacent to the mountain front in the "disturbed belt" on the west edge of the large area originally mapped by Dawson. Cairnes has described Claggett shale from this district, but, reasoning from our present understanding of the relations between the Judith River and Claggett formations to the beds mapped by Dawson as Belly River, it seems highly improbable that a lithologic unit equivalent to the Claggett shale exists at any point in the western part of the area originally mapped by Dawson. Cairnes, because of the intricate structure of the foothill belt near the mountains, has probably mistaken areas of Bearpaw shale for the Claggett, to which it is very similar both lithologically and in fossil content.

RELATIONS OF THE CONTINENTAL TO THE MARINE SEDIMENTS IN THE MONTANA GROUP.

The formations at the locality on Two Medicine River described in this paper lie near the western edge of the Cretaceous interior basin. (See index map on fig. 9, showing the Cretaceous deposits of the interior basin of North America.) No areas west of this locality afford exposures of the Montana group belonging to this basin, so that by comparing sections of the Montana from the Black Hills region, the central Montana region, and the section on Two Medicine River, all of which lie approximately on a straight line, we are able to present correlations of this part of the Cretaceous from a point near the center of the Cretaceous basin to a point on the western

[1] Stanton, T. W., and Hatcher, J. B., Geology and paleontology of the Judith River beds: U. S. Geol. Survey Bull. 257, pp. 24-25, 1905.

[2] Moose Mountain district of southern Alberta: Canada Geol. Survey Bull. 968, pp. 26-29, 1907.

edge of the strata as they now remain. In other words, we can show the relations, definitely in some areas and with probability in others, of the sediments that must have been deposited near the center of this Montana sea to those along its western margin.

These relations are illustrated in the diagram forming figure 9. The section at each of the localities given is built up on the top of the Colorado group as a datum plane, the rock units being all conformable and the thicknesses drawn to scale, so that the relative thickening or thinning of these units is properly indicated. The sediments that are mainly continental are indicated by open lining, those that are mainly marine are shown in closer lining, and the three important sandstone units of the group are shown in a stippled pattern. The general thickening of the strata on the landward side of the basin, due to the increase in the supply of material, is evident at a glance. The record from the top of the Colorado shale, a horizon that probably marks the period of maximum extent of the Upper Cretaceous sea in this region, shows a series of advances and retreats of the sea on the westward or landward side of this basin, while marine conditions to the east or seaward side remained undisturbed. These were, as indicated by arrows on the diagram, first, a marked recession of the sea during which the Virgelle sandstone was laid down, followed immediately by the piling up of continental sediments which in the section on the Two Medicine are represented by the strata at the base of the Two Medicine formation; next an advance of the sea which did not reach so far as Two Medicine River except in probably only one brief epoch, during which the wedge of the marine Claggett shale was deposited; next a second recession, during which again a shore sand—

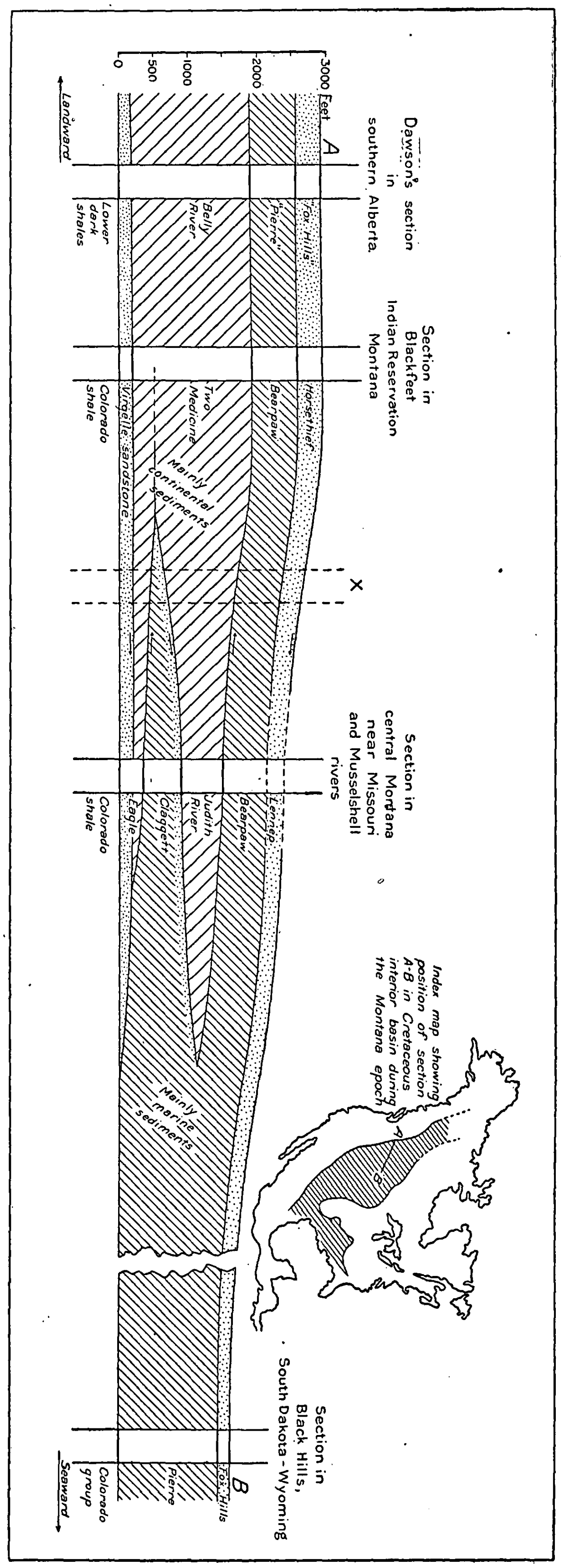


FIGURE 9.—Diagram showing probable relations of the marine and continental sediments of the Montana group in the northern Great Plains region, the top of the Colorado group being taken as a datum plane. X, Section on extreme eastern edge of area mapped by Dawson in 1881-1883 and assumed by him to be the same as that found farther west. It is recognized that lines of synchronous deposition on this diagram may run diagonally to the formation boundaries at varying angles and in different directions.

the upper part of the Claggett—was laid down. This recession was immediately followed by a period of continental deposition, in which was formed the wedge of the Judith River formation; then a second advance—the Bearpaw—much more extensive than the Claggett, which, like the former advance, did not result in the deposition of any great amount of sand; and, lastly, a third and very extensive recession, probably the final one for the western part of the region considered, during which again a persistent and easily identifiable sandstone was laid down, this deposition being followed immediately by the piling up of continental sediments. The deposition of a sand upon each retreat of the sea in contrast to the practical absence of such a sand on each advance is a notable phenomenon in this sedimentary record, and seems to indicate that each retreat of the sea was accompanied by land uplift with an increase in stream gradients and consequent coarsening of sediments and each advance by the opposite conditions. The close similarity between these three sandy formations is further brought out by the fact that they contain littoral marine faunas, those of the Fox Hills and Horsethief sandstones and the sandstone at the top of the Claggett being practically identical and that of the Virgelle being a direct forerunner of later faunas.

Above the Horsethief sandstone in the section on Two Medicine River there are light-colored soft clayey and sandy strata, already referred to as of continental origin, that are identical in appearance with the Belly River and Judith River strata. Although these rocks are younger than Montana in age, they deserve mention here because they seem to complete for a third time a cycle of sedimentation proceeding from purely marine to fresh-water or continental conditions. The first of these cycles is from the marine Colorado shale, through Virgelle sandstone, to the strata of continental origin in the lower part of the Two Medicine formation; the second is from the marine shale of the Claggett, through the sandstone in its upper part to strata, also of continental origin, comprising the Judith River formation; and the third is from the marine Bearpaw, through the Horsethief sandstone, to the continental deposits above that sandstone. The relations in each cycle between the continental deposits and the underlying sandstone seem to be identical. The strata are apparently perfectly conformable and the impression is very strong that the same conditions ruled in each transition from marine to land conditions, or, in other words, the strata above the Horsethief sandstone are physically as closely related to the Bearpaw shale as the Judith River formation is to the Claggett or the Two Medicine formation to the Colorado shale. Now, these strata of continental origin above the Horsethief sandstone constitute the St. Mary River beds of Dawson, which occupy the same position in the geologic column as the Edmonton formation of central Alberta and approximately that of the Lance formation of Wyoming. The age of this formation is therefore involved in the Lance-Laramie problem of North American geology, and in the opinion of the writer the fact that in this part of the interior basin this formation, which seems to be equivalent to the Lance, appears to be as intimately related stratigraphically to Cretaceous marine shale below it as are similar continental deposits well down in the Cretaceous section to a corresponding marine shale should receive considerable weight in the consideration of that problem.

Lastly, the sedimentary record that has been described seems noteworthy because it shows three successive marked recessions of a sea which are not known to have produced unconformity or other hiatus in the stratigraphy—conditions commonly attendant on such recessions—but, on the contrary, seem to have been followed immediately by sedimentation at an increased rate, the strata deposited bearing conformable relations to the underlying rocks. The proper concept seems to be that each recession of the Upper Cretaceous sea in the northern interior region of North America was accompanied in extensive areas of lowlands on its margins not by uplift and erosion but by uplift and an increased rate of sedimentation.

A DEEP WELL AT CHARLESTON, SOUTH CAROLINA.

By Lloyd William Stephenson.

INTRODUCTION.

A deep well at Charleston, S. C., completed in May, 1911, has furnished valuable information in regard to the stratigraphy of the Cretaceous and younger deposits underlying that city. The well is owned by the Charleston Consolidated Railway & Lighting Co. and is at the company's gas works at the foot of Charlotte Street, near the shore of Cooper River. The well samples and the well log from which the geologic data contained in this report were obtained were sent to T. Wayland Vaughan, of the United States Geological Survey, by I. N. Knapp, engineer in charge. The driller was H. O. Hendricks. Drilling was begun January 31, 1911, and the well was completed May 15, 1911. The total depth of the well is 2,001 feet (2,007 feet below the top of the casing).

METHOD EMPLOYED IN DRILLING.

The well was drilled by the hydraulic rotary method,[1] by which a drill pipe with a drill or bit belonging to one of several types attached at the lower end is rotated by machinery and at the same time water is forced down on the inside of the drill pipe to the bottom of the well and up again to the surface between the outside of this pipe and the wall of the hole. The materials loosened by the rotating bit are carried in suspension to the surface by the forced current of circulating water. When the bit is penetrating loose, caving sands, the water, before it is introduced into the drill pipe, is mixed with clay until it forms a rather thick slush. The pressure of the column of muddy water as it is being raised to the surface on the outside of the drill pipe forces the slush into the interstices of the sands that form the wall of the boring, thus plastering the wall and producing a sort of mud casing, which usually prevents serious caving. It is expected that the material loosened by the bit and carried to the surface by the ascending current will be mixed with the material used to form the slush and also with such material as, in spite of the mud casing, may chance to cave from the walls of the boring. Samples of the mixture thus formed are obtained by passing the emerging stream through a series of screens, or by catching the slush in a vessel and washing out the suspended materials. In this manner fossils and fragments of the harder strata penetrated may be obtained. The softer sands, clays, and marls invariably have their character changed and more or less obscured by the mixing process. As the bit is rotated clay or limy mud frequently adheres to it; and in this material fragments of rock or fossil remains are sometimes caught and when the drill pipe is drawn from the well for the purpose of sharpening or renewing the bit samples of the adhering mud and its contents may be procured.

Fossils obtained from a well drilled by this process, even if the material containing them is a mixture derived from several geologic horizons, may still have definite value in correlation, for a fossil must have come either from the depth at which it was taken or from some higher level; it could not have come from a lower level. Therefore, if fossils characteristic of a certain zone are taken at a given depth the zone must have been penetrated at that depth or at a higher level.

In the samples from the Charleston well there is evidence of considerable mixing due to caving, but many of the samples contain fragments of rock which appear to reveal accurately the character of the harder strata penetrated at the depths indicated, and many of them contain fossils which appear to have come from approximately the depths indicated by their labels

[1] A more detailed description of this method is given by Isaiah Bowman in U. S. Geol. Survey Water-Supply Paper 257, pp. 70-75, 1911.

and which are sufficiently well preserved to permit their identification. Many of the samples contain a mixture of shells of Pliocene or Pleistocene age, originally derived from strata penetrated in the first 85 feet of the boring, the mixing having been effected in part through the slush used to form the mud casing and in part by the caving of the walls of the well. The nature of the fossils and their condition of preservation are such that most of them are easily distinguishable from the older fossils, obtained at greater depths, and for this reason they do not interfere seriously with the interpretation of the remainder of the section.

The diameter of the hole to various depths and the size and length of casings inserted are indicated diagrammatically in figure 10. The well was completed in 90 working days of 10 hours each, the time including that required for inserting casing, fishing for lost tools, and making all necessary repairs.

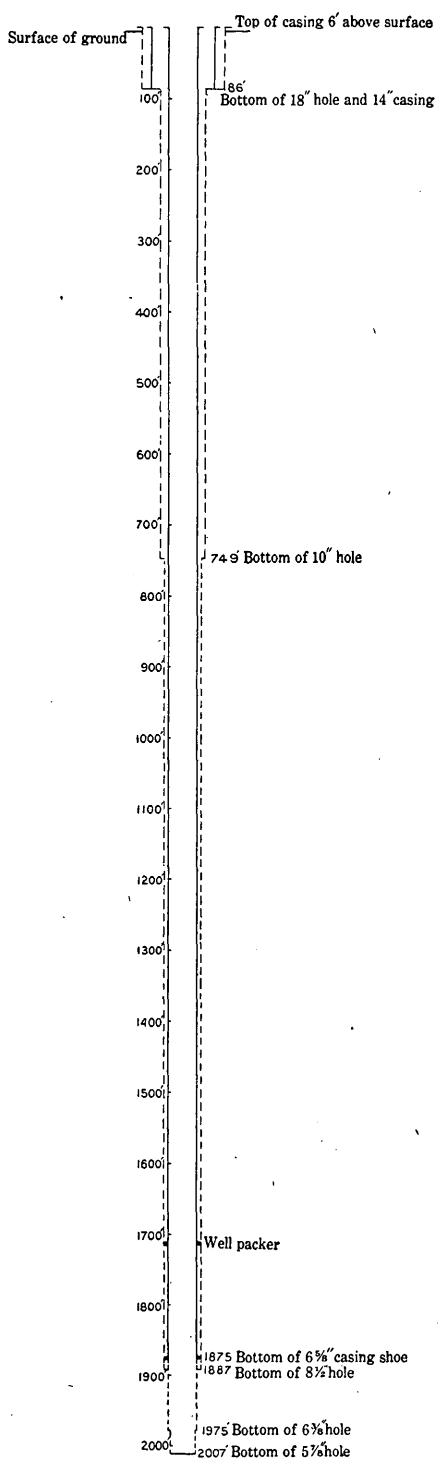


FIGURE 10.—Diagram of well at Charleston, S. C., showing size of hole and length of casings inserted. All the measurements of depths were made from the top of the rotary jaws, which stood 6 feet above the surface of the ground.

PRACTICAL RESULTS.

QUANTITY AND TEMPERATURE OF THE WATER.

The results of the undertaking are given in the following statement, which is quoted in substance from the original log furnished by I. N. Knapp, engineer in charge:

On May 16, the day after drilling was discontinued, clear water was pumped into the well in the same manner that the slush was pumped during the process of drilling. The temperature of the water emerging as a result of the forced overflow thus procured was 66° F. A natural flow soon started, and by evening the temperature of the water had increased to 85° F. and it was flowing at the rate of 100 to 150 gallons a minute.

On May 17 the flow increased, as did also the temperature, and fragments of shale and micaceous sand were brought up in suspension.

On May 18 the flow was irregular, varying with the amount of shale and sand brought up in suspension.

On May 19 the water was flowing from the well at a rate sufficient to fill a 50-gallon barrel in 15 seconds. The water was muddy and at times carried much sand and shale in suspension.

On June 3 the temperature of the water as it emerged from the well was 99.75° F. The flow of the water, which rose to a height of 11 feet above mean low-water level, was sufficient to fill a 50-gallon barrel in 7 seconds, or at the rate of 617,143 gallons a day. The water would rise in a pipe and flow a small stream at a height of 75 feet above mean low-water level. The water was still somewhat muddy.

ECONOMIC VALUE OF THE WATER.

According to R. B. Dole, of the United States Geological Survey, the analysis indicates an extremely soft water, softer than the waters from the Chisholm mill well (depth, 425 feet) and the old Wentworth Street well (depth, 1,260 feet). (See analyses in table on p. 93.) The water would deposit no scale in boilers and under ordinary conditions would cause no corrosion; if too strongly concentrated by continuous evaporation it might cause foaming, but this could be obviated by regular blowing off. Nothing in the analysis indicates that the water would be harmful for drinking, though it doubtless has a slight mineral taste.

The object in drilling the well was to obtain water for a boiler supply at the gas works and, according to Mr. Knapp, a practical test has shown that the water is satisfactory for this purpose.

SCIENTIFIC RESULTS.

THE WELL RECORD.

A record of the well, compiled from a set of well samples and a well log furnished by Mr. Knapp, the engineer in charge, is given below. The fourth column gives the source of the samples as recorded by the engineer and additional information furnished by him concerning the character of the strata from which some of the samples were taken; the fifth column contains the writer's description of the samples; the sixth, seventh, and eighth columns constitute the well log, which was prepared by Mr. Knapp as the drilling progressed and which records his impression of the character of the materials penetrated.

The materials penetrated in the well are of marine origin and consist of sands, clays, marls, and limestones. The sands are either soft, incoherent beds or layers in various stages of induration, the hardest being a quartzite-like rock. They are in greater or less degree calcareous. Many of the samples are glauconitic and some are micaceous. The clays are likewise either soft unconsolidated beds or layers in various stages of compactness, the hardest being almost shaly. They are more or less calcareous and usually contain some mica. The limestones occur chiefly in the Eocene portion of the section. Some of the layers appear to be fairly pure, but the rock in most of the samples contains more or less sand. The drill penetrated many beds of shell marl.

Record of Charleston Consolidated Railway & Lighting Co.'s well, drilled in 1911 at the gas works of the company, foot of Charlotte Street, near Cooper River, Charleston, S. C.

[Engineer in charge, I. N. Knapp; driller, H. O. Hendricks. Drilling begun Jan. 31, 1911; well completed May 15, 1911.]

Age and formation.		Sample No.	Depth (in feet) at which sample was obtained.	Method of obtaining samples and other information furnished by engineer in charge.	Author's description of samples.	Log of well furnished by engineer in charge.[a]		
						Material.	Thickness in feet.	Depth to base in feet.
Quaternary.	Pleistocene.	1	40	From overflow.[b]	Dark-gray, finely arenaceous and micaceous clay, with a few shells and fragments of lignite.	Length of casing protruding above surface of ground. Cinders, bricks, and tar ..... Layers of spongy material, blue clay, and shells, with roots and bits of wood.	6 10 44	6 16 60
Quaternary.	Pleistocene.	2	62	From overflow.	Very coarse quartz sand with numerous fragments of shells and a few well-preserved shells.	An abundance of broken shells with sand.	2	62
Quaternary.	Pleistocene.	3	73-75	From overflow.	Chiefly fragments of shells but contains numerous well-preserved shells. Includes a small percentage of coarse quartz sand.			
Tertiary.	Pliocene.	4	82-83	Concentrated from overflow.	Same as sample No. 3 but contains small chunks of greenish-yellow sand and small black phosphatic pebbles.			
Tertiary.	Uppermost Eocene or Oligocene. Cooper marl.	5	86	Mud from bit.	Chunks of greenish-gray soft, slightly sandy and argillaceous limestone or marl with Foraminifera and nodules of dark-gray calcareous phosphatic sandstone. (See list of Foraminifera in table on pp. 79-80.)			
Tertiary.	Uppermost Eocene or Oligocene. Cooper marl.	6	102	Mud from bit.	Same as sample No. 5. (See list of Foraminifera in table on pp. 79-80.)	Layers of marl and some shells with nodules of phosphate rock.	88	150
Tertiary.	Uppermost Eocene or Oligocene. Cooper marl.	7	200	Mud or cuttings from overflow.	Greenish-gray calcareous sand resembling Nos. 5 and 6 in color, with some Foraminifera and some shells. (See list of Foraminifera in table on pp. 79-80.)			

[a] All the measurements given in this record were made from the top of the rotary jaws as a datum plane. As the top of the rotary jaws was 6 feet above the surface of the ground the exact depth of the well below the surface is 2,001 feet instead of 2,007 feet. The top of the rotary jaws was 14½ feet above mean low water level.

[b] The term overflow, as used in this well record, means the flow of water emerging from the mouth of the well during the process of drilling, after its passage under pressure from the pumps, down the interior of the drill pipe, and up again to the surface between the outside of the drill pipe and the wall of the hole.

Record of Charleston Consolidated Railway & Lighting Co.'s well, drilled in 1911 at the gas works of the company, foot of Charlotte Street, near Cooper River, Charleston, S. C.—Continued.

Age and formation.		Sample No.	Depth (in feet) at which sample was obtained.	Method of obtaining samples and other information furnished by engineer in charge.	Author's description of samples.	Log of well furnished by engineer in charge.		
						Material.	Thickness in feet.	Depth to base in feet.
Tertiary—Continued.	Uppermost Eocene or Oligocene—Continued. Cooper marl—Continued.	8	220	Mud from bit.	Same as samples Nos. 5 and 6; contains Foraminifera and a few pelecypods. (See list of Foraminifera in table on pp. 79–80.) (From this depth to the bottom of the well nearly all the samples contain a few Recent, Pleistocene, or Pliocene shells, which doubtless represent mixtures resulting from the caving of the walls in the upper 85 feet of the well.)	Layers of marl with streaks of shells. Very hard whitish limestone.	109 1	259 260
	Eocene. Mount Hope marl of Sloan (?).	9	262–263	Concentrated from overflow; hard limestone rock.	Fragments of gray, rather soft limestone or marl; contains Nodosaria cf. *raphinistrum;* Cristellaria 1, 2, 6, 7, and 9.			
		10	270	Mud from bit; hard drilling, about 6 inches per hour.	Chunks of gray limy mud, derived from limestone.			
		11	290	Concentrated from overflow.	Fragments of rather soft limestone or marl with a few echinoid spines; contains also Nodosaria 3 and Cristellaria 10.			
		12	299	Mud from bit; hard lime rock.	Chunks of gray limy mud derived from limestone.	Alternate layers of limestone and marl; hard to medium drilling. Hard rock Very soft material	68 5 4	328 333 337
		13	348–350	Concentrated from overflow.	Fragments of gray sandy, rather soft limestone or marl with a few echinoid spines.	Marl Hard rock	11 6	348 354
		14	361	Mud from bit; very hard.	Chunks of bluish-gray calcareous, argillaceous, and sandy mud, with chunks of dark calcareous sandstone, probably derived from sandy limestone.	Medium hard rock	7	361
		15		Sample missing.				
		16	362	Mud from bit; hard drilling, about 1 inch per hour.	Apparently a sandy limestone ground to a fine white mud by the bit.	Excessively hard rock; drilled 1 inch per hour with fishtail bit.	1	362
		17	365	Concentrated from overflow.	Fragments of light-gray sandy limestone with a few echinoid spines and fragments of shells; contains also Nodosaria 11 ?.	Hard rock and flint Excessively hard rock	9 1	371 372
		18	375	Mud from bit.	Apparently a sandy limestone ground to a fine gray mud by the bit.			
		19	395	Mud from overflow.	Chunks of gray porous calcareous sandy mud, apparently a sandy limestone ground and mixed by the bit.	Hard white limestone	20	392
		20	395	Concentrated from overflow.	Fragments of light-gray sandy limestone with fragments of shells.	Layers of marl; easy drilling.	19	411
		21	427–433	Fragments of selected clay or shale from overflow.	Fragments of gray calcareous, micaceous shaly clay.	Very soft material Hard dark-gray rock Marl Very hard material Soft material with sand and shells. Very hard material Soft dark clay	2 3 5 1 3 1 7	413 416 421 422 425 426 433
		22	435	Concentrated from overflow.	Fragments of light-gray sandy limestone with numerous fragments of shells.			
		23	439–444	Concentrated from overflow; bed of shells.	Fragments of light-gray sandy limestone with numerous fragments of echinoid spines, bryozoans, and shells; contains Nodosaria 5.	Coarse-cutting rock, with shells. Shells and rock	6 5	439 444

Record of Charleston Consolidated Railway & Lighting Co.'s well, drilled in 1911 at the gas works of the company, foot of Charlotte Street, near Cooper River, Charleston, S. C.—Continued.

Age and formation.		Sample No.	Depth (in feet) at which sample was obtained.	Method of obtaining samples and other information furnished by engineer in charge.	Author's description of samples.	Log of well furnished by engineer in charge.		
						Material.	Thickness in feet.	Depth to base in feet.
Tertiary—Continued.	Eocene—Continued. Mount Hope marl of Sloan (?)—Continued.	24	447	Concentrated from overflow.	Mixture of fragments of light-gray sandy limestone and darker-gray, finely arenaceous, calcareous shaly clay, with numerous shell fragments and some fragments of Bryozoa; contains Nodosaria 2 cf. *raphinistrum?* Nodosaria 5.			
		25	454	Mud and fragments of rock from bit.	Chunks of dark-gray, finely arenaceous and micaceous, calcareous clay; contains Textularia *b* cf. *sagittula*, Verneuilina *a* cf. *propinqua*, Uvigerina *a* cf. *canariensis*, Globigerina *b* cf. *æquilateralis*, Truncatulina *f* cf. *lobatula*, Polystomella, Massilina.	Dark clay or shale Hard rock; required 2 hours to drill with fishtail bit.	24 1	468 469
Upper Cretaceous or Tertiary.	(?)	26	478	Mud from bit.	Chunks of lighter-gray, finely arenaceous and micaceous, calcareous clay; contains Textularia *b* cf. *sagittula*, Cassidulina cf. *subglobosa*, Lagena *b* cf. *sulcata*, *Uvigerina pygmæa*, Truncatulina *f* cf. *lobatula*, Polystomella.	Soft material with shells Black shale or clay; no shells.	4 21	473 494
		27	500	Mud from overflow.	Chunks of greenish-gray porous sandy calcareous clay.			
		28	500	Concentrated from overflow.	Fragments of gray calcareous shaly clay with some admixture of quartz sand.			
		29	504	Sand from overflow.	Loose dark-green, highly glauconitic sand; the grains of quartz are clear and angular; contains Textularia *b* cf. *sagittula*, Polymorphina *d*, Sphæroidina cf. *bulloides*, Truncatulina *f* cf. *lobatula* Truncatulina *h*, Polystomella.	Variable streaks of yellow sand and marl. Layers of black sand with streaks of marl.	7 9	501 510
		30	515	Concentrated from overflow.	Fragments of gray shaly calcareous clay mixed with greenish-gray calcareous mud.			
		31	525-540	Concentrated from overflow; parts of several samples taken from between 525 and 540 feet; all much the same, clay and marls.	Fragments of gray shaly, finely arenaceous, micaceous, calcareous clay and chunks of soft greenish-gray limestone or marl which probably fell down from the Cooper marl; also loose sand; contains Foraminifera. (See list in table, pp. 79-80.)	Alternating streaks of marl and clay, some yellow, some dark gray. Very hard rock	26.5 .5	536.5 537
		32	544	Mud from bit, medium hard, black when wet.	Chunks of dark-gray argillaceous, glauconitic, calcareous sand.	Not described	8	545
		33	550-570	Concentrated from overflow; average of several samples.	Fragments of gray shaly, finely arenaceous, micaceous, calcareous clay and chunks of soft greenish-gray limestone or marl which probably fell down from the Cooper marl; also loose sand; contains Cristellaria 11 cf. *clypeiformis*.	Hard rock	1	546
		34	585	Concentrated from overflow.	Fragments of gray shaly, finely arenaceous micaceous, calcareous clay and chunks of soft greenish-gray limestone or marl which probably fell down from the Cooper marl; also loose sand; contains Nodosaria 2 cf. *raphinistrum*.	Alternating layers of black and dark-gray shale, medium to hard; no shells.	41	587
		35	600	Concentrated from overflow.	Fragments of gray shaly calcareous clay and chunks of soft greenish-gray limestone or marl which probably fell down from the Cooper marl, with some sand.	Soft material	2	589

Record of Charleston Consolidated Railway & Lighting Co.'s well, drilled in 1911 at the gas works of the company, foot of Charlotte Street, near Cooper River, Charleston, S. C.—Continued.

Age and formation.		Sample No.	Depth (in feet) at which sample was obtained.	Method of obtaining samples and other information furnished by engineer in charge.	Author's description of samples.	Log of well furnished by engineer in charge.		
						Material.	Thickness in feet.	Depth to base in feet.
Upper Cretaceous or Tertiary—Continued.	(?)	36	608	Mud from bit.	Chunks of gray, finely arenaceous and micaceous, calcareous clay, with fragments of greenish-gray marl which probably fell down from the Cooper marl.	Alternatinglayers of medium hard dark-colored marls and shales. Bit pulled from 608 feet showed mica in mud. Very hard material..........	36 1	625 626
		37	630–660	Concentrated from overflow. Average of several samples; formation variable, thin strata, hard to soft, in color yellowish, light gray, dark gray, black.	Fragments of gray shaly, finely arenaceous, micaceous, calcareous clay and chunks of soft greenish-gray limestone or marl which probably fell down from the Cooper marl; also loose sand; contains Foraminifera. (See list in table, pp. 79–80.)			
		38	661	Mud from bit.	Chunks of gray, finely arenaceous and micaceous, calcareous clay.			
		39	680–685	Concentrated from overflow.	Fragments of gray shaly, finely arenaceous, micaceous, calcareous clay and chunks of soft greenish-gray limestone or marl which probably fell down from the Cooper marl; also loose sand; contains Nodosaria 15.	Thin layers of light-colored marl and limestone, medium hard to hard.	75	701
		40	702	Mud from bit; very hard dark-blue limestone.	Chunks of gray calcareous clay with white streaks of lime; contains Nodosaria 15 and Cristellaria 11 cf. *clypeiformis*.	Very hard blue limestone....	1.5	702.5
		41	725	Concentrated from overflow.	Fragments of gray shaly, finely arenaceous, micaceous, calcareous clay and chunks of soft greenish-gray limestone or marl which probably fell down from the Cooper marl, also loose sand; contains Cristellaria 11 cf. *clypeiformis*.	Variable layers of light-colored clay or marl......... Soft grayish-white clay in overflow. Not described...............	31.5 2 5	734 736 741
		42	742	Mud from bit; dark gray, almost black when wet; very hard.	Chunks of gray calcareous clay with white streaks of lime; contains Nodosaria 15 and Cristellaria 11 cf. *clypeiformis*.	Very hard material; required 10 hours continuous drilling with fishtail bit.	3	744
Upper Cretaceous.	Peedee sand (?).	43	750	Mud from overflow.	Gray calcareous, slightly argillaceous, glauconitic sand; contains Clavulina cf. *angularis*, Nodosaria 2 cf. *raphinistrum* ?, Nodosaria 14, Nodosaria 15, Cristellaria 11 cf. *clypeiformis*, Vaginulina.	Hard material; medium to hard drilling. Hard rock................. Alternating thin layers of medium to hard rock. Soft material, possibly sand.	18 5 24 2	762 767 791 793
		44	805–808	Sandrock cuttings, concentrated from overflow.	Very coarse quartz sand with fragments of gray glauconitic sandstone and numerous small black phosphatic pebbles.	Marl....................... White sandy material.......	12 3	805 808
		45	810	Mud from overflow; in hard rock.	Gray porous calcareous clay with some sand; contains Clavulina cf. *angularis*, Nodosaria 14, Cristellaria 11 cf. *clypeiformis*, Vaginulina.			
		46	840–850	Cuttings concentrated from overflow.	Gray shaly, finely arenaceous clay with numerous small black phosphatic pebbles and some sand; contains Clavulina cf. *angularis*, Cristellaria 11 cf. *clypeiformis*.			
		47	855–860	Cuttings concentrated from overflow.	Same as sample No. 46, except that black pebbles are not numerous; contains Clavulina cf. *angularis*, Nodosaria 14, Cristellaria 11 cf. *clypeiformis*.			
		48	870–890	Selected from overflow; average.	Same as sample No. 47; contains Clavulina cf. *angularis*, Nodosaria 14, Nodosaria 15, Cristellaria 11 cf. *clypeiformis*.	Layers of light-gray to black marl; easy drilling; variable materials.	110	918

Record of Charleston Consolidated Railway & Lighting Co.'s well, drilled in 1911 at the gas works of the company, foot of Charlotte Street, near Cooper River, Charleston, S. C.—Continued.

Age and formation.		Sample No.	Depth (in feet) at which sample was obtained.	Method of obtaining samples and other information furnished by engineer in charge.	Author's description of samples.	Log of well furnished by engineer in charge.		
						Material.	Thickness in feet.	Depth to base in feet.
Upper Cretaceous—Continued.	Peedee sand.	49	920	Mud from overflow.	Gray calcareous, slightly argillaceous sand; contains Clavulina cf. *angularis*, Nodosaria 15, Cristellaria 11 cf. *clypeiformis*.			
		50	920	Same as sample No. 49 with mud washed out.	Gray shaly calcareous, finely arenaceous clay with some sand; contains Clavulina cf. *angularis*, Ostrea sp. (young individual), fragments of *Anomia argentaria* Morton, and tooth of *Corax falcatus* Agassiz.	Greenish shale	4	922
		51	950	Mud from overflow.	Gray calcareous, argillaceous sand.			
		52	950	Same as sample No. 51 with mud washed out.	Gray shaly, finely arenaceous clay with a few small black phosphatic pebbles and some sand; contains Nodosaria 16 cf. *inflexa*, Ostrea sp. (young individual), and *Anomia argentaria* Morton.	Uniformly hard material, probably sandy limestone. Marl; easy drilling Hard limestone	38 14 4	960 974 978
		53	1,000	Mud from overflow.	Gray calcareous, slightly argillaceous sand.	Marl Probably cemented shells; rough drilling.	14 2	992 994
		54	1,000	Concentrated from mud; same as sample No. 53.	Coarse sand with numerous fragments of gray shaly calcareous clay; contains Ostrea sp. (young individual), and tooth of *Corax falcatus* Agassiz?	Marl	6	1,000
		55	1,015–1,030	Concentrated from overflow.	Gray shaly calcareous, finely arenaceous clay with sand and sandstone fragments; contains *Ostrea falcata* Morton, *Ostrea plumosa* Morton, *Anomia argentaria* Morton, and tooth of *Corax falcatus* Agassiz?	Sandrock	15	1,015
		56	1,035–1,045	Concentrated from overflow.	Loose light-gray calcareous sand with scattered grains of glauconite; contains *Ostrea falcata* Morton.	Thin layers of shale, sandrock, and marl. Hard material, probably sandrock.	20 4	1,035 1,039
		57	1,055–1,058	Mud from overflow.	Chunks of gray calcareous, argillaceous, slightly glauconitic sand.			
		58	1,055–1,058	Concentrated from overflow.	Fragments of gray shaly calcareous, finely arenaceous clay, with considerable fine, slightly glauconitic gray sand and a few small black phosphatic pebbles; contains *Anomia argentaria* Morton (fragment).			
		59	1,090–1,100	Concentrated from overflow; uniformly hard, sandy clay.	Fine light-gray, slightly glauconitic sand with small fragments of gray calcareous shaly clay.	Layers of light to dark gray clay with thin layers of sandrock.	61	1,100
		60	1,130–1,140	Concentrated from overflow; easy drilling; uniform material, consisting of sandy clay, with some shells.	Same as sample No. 59; contains *Lima reticulata* Forbes (fragment).			
		61	1,150–1,200	Selected from concentrates.	Gray shaly, finely arenaceous and micaceous, calcareous clay, with a few chunks of greenish-gray calcareous clay and some sand; contains *Belemnitella americana* (Morton)? (fragment).	Dark-gray and blue sandy shale; good drilling.	83	1,183

Record of Charleston Consolidated Railway & Lighting Co.'s well, drilled in 1911 at the gas works of the Company, foot of Charlotte Street, near Cooper River, Charleston, S. C.—Continued.

Age and formation.	Sample No.	Depth (in feet) at which sample was obtained.	Method of obtaining samples and other information furnished by engineer in charge.	Author's description of samples.	Log of well furnished by engineer in charge.		
					Material.	Thickness in feet.	Depth to base in feet.
Upper Cretaceous—Continued. Peedee sand—Continued.	62	1,230–1,250	Concentrated and selected; fossils, pyrites, and marls.	Same as sample No. 61, with chunks of greenish-gray marl which probably fell down from the Cooper marl; contains the coral Trochocyathus sp. (aff. *T. woolmani* Vaughan), identified by T. Wayland Vaughan.	Sandy marl with reddish fossil shells. Hard rock	57 1	1,240 1,241
	63	1,259	Mud from bit; black and grayish when wet.	Chunks of dark-gray, finely arenaceous and micaceous clay with some sand.	Not described	19	1,260
	64	1,262–1,275	Mud from overflow.	Gray sandy, slightly argillaceous, calcareous sand.			
	65	1,262–1,275	Same as sample No. 64 but washed and concentrated.	Gray coarse, slightly glauconitic sand and gray shaly, finely arenaceous and micaceous clay.	Medium-hard rock Soft sandrock	2 14	1,262 1,276
	66	1,306	Mud from bit.	Chunks of gray, finely arenaceous and micaceous clay.			
	67	1,300–1,306	Washed from overflow and selected.	Fragments of gray calcareous shaly clay and gray calcareous sandstone with a few small black phosphatic pebbles.	Soft to medium-hard layers of marl and sandstone.	30	1,306
	68	1,310–1,320	Concentrated from overflow.	Gray calcareous sand and fragments of sandstone with fragments of gray shaly calcareous clay.	Hard rock Variable layers of shale and sandy shale, with some shells and fish teeth.	2 28	1,308 1,336
	68a	1,340–1,360	Mud from overflow; medium-hard sandy rock; good drilling.	Loose gray calcareous, slightly glauconitic and micaceous sand, with chunks of slightly indurated sand.			
	69	1,340–1,360	Washed and selected from overflow; same as sample No. 68.	Chunks of gray calcareous, slightly glauconitic sandstone, and fragments of gray shaly calcareous clay; contains Ostrea sp. (young individual) and Exogyra sp. (fragments of the small valve).			
	70	1,375–1,400	Concentrated and selected; shells 1,375 to 1,381 feet.	Coarse gray sand and fragments of calcareous sandstone with a few fragments of gray shaly calcareous clay; fragments of shells numerous; contains *Ostrea plumosa* Morton, Ostrea sp. (young individuals), Exogyra sp. (fragments), and tooth of Lamna?; shells from 1,375 to 1,381 feet.	Medium-hard sandy rock; uniform drilling. Hard rock Soft material with broken shells. Probably sandy marl; good drilling. Hard rock	36 3 6 35 2	1,372 1,375 1,381 1,416 1,418
	71	1,420–1,430	Concentrated and selected from overflow.	Same as sample No. 70.	Not described Very hard rock	12 1	1,430 1,431
	72	1,440–1,450	Concentrated and selected from overflow; shells.	Same as samples Nos. 70 and 71; contains *Ostrea plumosa* Morton, Exogyra sp. (fragments), *Anomia argentaria* Morton, and a small shark tooth.			
	73	1,460–1,470	Concentrated and selected from overflow.	Similar to samples Nos. 70–72 but contains more loose sand.			
	74	1,480–1,490	Concentrated and selected from overflow.	Fragments of gray, finely arenaceous and micaceous, calcareous clay and gray argillaceous sandstone.			
	75	1,500–1,510	Concentrated and selected from overflow.	Same as sample No. 74.			
	76	1,514	Mud from bit; very hard material.	Chunks of dark-gray, finely arenaceous and micaceous clay with some sand.	Layers of soft black sticky clay with medium to hard shales and sandstones in thin layers.	88	1,519

Record of Charleston Consolidated Railway & Lighting Co.'s well, drilled in 1911 at the gas works of the company, foot of Charlotte Street, near Cooper River, Charleston, S. C.—Continued.

Age and formation.		Sample No.	Depth (in feet) at which sample was obtained.	Method of obtaining samples and other information furnished by engineer in charge.	Author's description of samples.	Log of well furnished by engineer in charge.		
						Material.	Thickness in feet.	Depth to base in feet.
Upper Cretaceous—Continued.	Peedee sand—Continued.	77	1,540–1,550	Cuttings selected from overflow.	Gray shaly, finely arenaceous and micaceous clay and fragments of soft gray calcareous, argillaceous, slightly glauconitic sandstone; contains *Pecten venustus* Morton.	Uniformly hard shale....... Very sticky shale........... Rock..........................	12 16 5	1,531 1,547 1,552
	Black Creek formation (?).	78	1,550–1,560	Shale and bits of pyrites selected from overflow.	Same as sample No. 77.			
		79	1,560–1,570	Selected from overflow.	Same as samples Nos. 77 and 78.	Layers of medium to hard shales with iron pyrites and layers of black shales; required frequent spudding.	63	1,615
		80	1,590–1,600	Cuttings from overflow.	Same as samples Nos. 77–79 but contains some sand.	Very hard rock..............	2	1,617
		81	1,620–1,630	Cuttings from overflow.	Similar to samples Nos. 77–80 but contains much sand.	Variably thin strata of dark shale.	23	1,640
		82	1,640–1,642	Mud from overflow.	Same as samples Nos. 77–79; contains some fragments of shells.	Broken shells............... Marl......................... Very hard rock..............	2 3 3	1,642 1,645 1,648
		83	1,660–1,670	Selected from overflow.	Same as samples Nos. 77–79; contains Ostrea sp. (young individual) and two teeth of fish.			
		84	1,660–1,670	Mud from overflow; soft; easy drilling.	Loose gray calcareous sand with numerous fragments of gray shaly calcareous clay.			
		85	1,700–1,705	Selected from overflow.	Same as samples Nos. 77–79.	Shales in layers; easy drilling. Hard rock, probably limestone. Probably limestone and flint; very hard and rough drilling.	46 13 4	1,694 1,707 1,711
		86	1,720–1,723	Concentrated from overflow; very hard.	Gray shaly, finely arenaceous and micaceous clay, with fragments of gray calcareous sandstone; contains a shark tooth.			
		87	1,720–1,723	Mud from overflow; same as sample No. 86.	Loose light-gray glauconitic, calcareous sand, with fragments of gray shaly clay.	Layers of hard rock; rough drilling.	13	1,724
	Black Creek formation.	88	1,725–1,730	Mud from overflow; hard to very hard, with one soft streak.	Same as sample No. 87; contains Nodosaria 6 and 17, *Ostrea cretacea* Morton? (young individual), and fragments of *Pecten quinquecostatus* (Sowerby).	Soft, sticky whitish clay....	5	1,729
		89	1,736	Mud from bit.	Chunks of gray argillaceous, micaceous, calcareous sand; contains Crassatellites sp. (cast).			
		90	1,763–1,767	Concentrated from overflow; very hard, with one soft streak.	Loose gray calcareous, slightly glauconitic sand, with fragments of gray calcareous shaly clay.	Thin layers of hard rock (rough drilling) with thin streaks of soft material. The layers are a few inches to 2 feet thick. Whitish clays and shales, with hard lumps and layers. Soft white shales...........	30 15 2	1,759 1,774 1,776
		91	1,790–1,800	From overflow; hard rock.	Same as sample No. 90.			
		92	1,800–1,812	Selected from overflow (from 1,802 to 1,804 feet lost water; probably water sand, sandrock, and thin streaks of marl).	Loose coarse quartz sand, with fragments of gray calcareous shaly clay; contains Bryozoa?, *Ostrea cretacea* Morton, and a coprolite.	Hard black marl, with nodules and lumps; rough drilling. Sands and shales; lost water in drilling.	25 2	1,801 1,803

Record of Charleston Consolidated Railway & Lighting Co.'s well, drilled in 1911 at the gas works of the company, foot of Charlotte Street, near Cooper River, Charleston, S. C.—Continued.

Age and formation.		Sample No.	Depth (in feet) at which sample was obtained.	Method of obtaining samples and other information furnished by engineer in charge.	Author's description of samples.	Log of well furnished by engineer in charge.		
						Material.	Thickness in feet.	Depth to base in feet.
Upper Cretaceous—Continued.	Black Creek formation—Continued.	93	1,813	Mud from bit.	Chunks of gray calcareous, finely arenaceous and micaceous clay.			
		94	1,815–1,818	Selected from overflow.	Chunks of soft greenish-gray limestone or marl which probably fell down from the Cooper marl, and chunks of hard gray glauconitic sandstone.	Layers of excessively hard limestone with thin layers of sand, black shale, pyrites, shells, and fossil wood. Soft yellow sandrock	12 3	1,815 1,818
		94a	1,830?	Questionably from this depth.	Chunk of hard gray, slightly calcareous sandstone or quartzite.	Not described	12	1,830
		95	1,832	Mud from bit.	Chunks of finely arenaceous and micaceous calcareous clay, with white streaks of lime; contains fragment of *Exogyra ponderosa* Roemer?	Hard white limestone	2	1,832
		96	1,835	Mud from bit; very hard conglomeratic rock.	Same as sample No. 95.			
		97	1,835	Taken from mud on bit.	Chunk of hard gray calcareous sandstone or quartzite, with poorly preserved shell remains.			
		98	1,839	Concentrated from mud on bit; very hard; slow drilling; knots or lumps in material.	Loose, coarse sand with chunks of hard gray sandstone, a few small water-worn pebbles and chunks of gray sandstone; contains Ostrea sp. (fragment), and tooth of *Corax falcatus* Agassiz.			
		99	1,839	From mud on bit; same as sample No. 98.	Chunk of hard gray calcareous, micaceous sandstone or quartzite.			
		100	1,841	Concentrated from mud on bit.	Coarse sand with chunks of gray calcareous sandstone, gray calcareous shaly clay, a few quartz pebbles up to $\frac{1}{16}$ inch in length, and fragments of shells; contains *Hamulus onyx* Morton, *Ostrea cretacea* Morton, and undetermined pelecypod cast.	Layer of shale, conglomerate, limestone, sandstone; excessively hard, thin layers of pyrites; some layers of pyrites drilled at rate of 1 inch per hour with Sharp & Hughes bit in good order. Very hard sandy limestone; good drilling.	15 14	1,847 1,861
		101	1,862	Mud from bit.	Gray calcareous, finely arenaceous and micaceous clay.			
		102	1,862	Concentrated from mud on bit; same as sample No. 101.	Very coarse sand with chunks of gray calcareous sandstone, chunks of gray calcareous shaly clay, a few quartz pebbles up to ½ inch in length, and shell fragments; contains *Ostrea cretacea* Morton, Gryphæa sp. (small), and *Exogyra ponderosa* Roemer?	Very hard rock	6	1,867
		103	1,887	Concentrated from mud on bit.	Same as sample No. 102; contains Ostrea sp.			
		104	1,887	Mud from bit; same as sample No. 103.	Chunks of dark-gray, finely arenaceous and micaceous clay.			
		105	1,940–1,960	Sand from overflow.	Loose gray, slightly glauconitic, calcareous sand; contains Cristellaria 12.	Hard shales which produce a sticky mud. Very soft material Medium-hard shales with thin, soft layers, probably sand; easy drilling with fishtail bit.	39 3 38	1,906 1,909 1,947
		106	1,950–1,960	Concentrated from overflow.	Loose, coarse sand with numerous small fragments of shells.	Medium-hard rock Soft to medium-hard layers of shale and sand; some sand and shell breccia in overflow.	4 23	1,951 1,974
		107	1,975	Mud from bit.	Chunks of gray calcareous, finely arenaceous and micaceous clay.	Very hard sandrock; fishtail bit would not make 1 inch per hour.	3	1,977

Record of Charleston Consolidated Railway & Lighting Co.'s well, drilled in 1911 at the gas works of the company, foot of Charlotte Street, near Cooper River, Charleston, S. C.—Continued.

Age and formation.		Sample No.	Depth (in feet) at which sample was obtained.	Method of obtaining samples and other information furnished by engineer in charge.	Author's description of samples.	Log of well furnished by engineer in charge.		
						Material.	Thickness in feet.	Depth to base in feet.
Upper Cretaceous—Continued.	Black Creek formation—Continued.	108	2,000–2,005	Concentrated from overflow.	Loose, coarse light-gray sand with numerous small shell fragments.	Sandrock with much muck; fair drilling.	28	2,005
		109	1,974–2,007	Average of material brought to surface by natural flow.	Loose, medium-grained micaceous, calcareous sand with bits of lignite.			
		110	1,974–2,007	Fossil wood brought to surface by natural flow.	Lignite.			
		111	1,974–2,007	Brought to surface by natural flow.	Chunks of gray laminated micaceous, slightly calcareous clay with fine sand partings, contains comminuted vegetable fragments.			
		112	1,974–2,007	Brought to surface by natural flow.	Chunks of light-gray micaceous, calcareous sandstone or quartzite; chunks of gray calcareous shaly clay; one concretion of sandy limestone; concretions of iron pyrites; small waterworn pebble, lignite, and numerous shells and fragments of shells. Recognized fragment of small coral, Bryozoa (incrusting), Ostrea sp. nov. *a*, Ostrea sp. nov. *b*, *Ostrea cretacea* Morton, *Exogyra upatoiensis* Stephenson, Anomia sp. nov. (same as new species from Snow Hill, N. C.), and undetermined fragments of Ostreidæ.	Blue clay or shale	2	2,007

FOSSILS OBTAINED FROM THE WELL SAMPLES.

PROTOZOA.

The subkingdom Protozoa is represented in the well section by numerous specimens of Foraminifera, which were referred to Joseph A. Cushman for identification. The species recognized by him and their distribution in the well are indicated in the accompanying table. All measurements of depth indicated in this table and on the following pages were made from the top of the rotary jaws, which stood 6 feet above the surface of the ground:

Foraminifera from well of Charleston Consolidated Railway & Lighting Co., Charleston, S. C.

	Uppermost Eocene or Oligocene.				Eocene.						Eocene or Upper Cretaceous.									Upper Cretaceous.										
	Cooper marl.				Mount Hope marl of Sloan (?).															Peedee sand (?).					Peedee sand.			Black Creek formation.	
No. of sample	5	6	7	8	9	11	17	23	24	25	26	29	31	33	34	39	40	41	42	40	45	46	47	48	49	50	52	88	105
Depth in feet	86	102	200	220	262–263	290	365	439–444	447	454	478	504	525–540	550–570	585	680–685	702	725	742	753	810	840–850	855–860	870–890	920	920	950	1725–1730	1940–1960
Textulariidæ.																													
Textularia *a*	×																												
b cf. sagittula	×	×	×	×						×	×	×																	
c cf. gramen				×																									
d cf. sagittula var. atrata		×																											
e cf. millettii				×																									
Bolivina *a*	×												×																
b	×	×		×																									
d		×																											
e		×																											
f cf. reticulata	×	×	×	×									×																
g				×																									
Bulimina inflata	×																												
b		×											×																
buchiana			×										×																

Foraminifera from well of Charleston Consolidated Railway & Lighting Co., Charleston, S. C.—Continued.

	Uppermost Eocene or Oligocene.				Eocene.						Eocene or Upper Cretaceous.									Upper Cretaceous.									
	Cooper marl.				Mount Hope marl of Sloan (?).															Peedee sand (?).					Peedee sand.			Black Creek formation.	
No. of sample	5	6	7	8	9	11	17	23	24	25	26	29	31	33	34	39	40	41	42	43	45	46	47	48	49	50	52	88	105
Depth in feet	86	102	200	220	262–263	290	365	439–444	447	454	478	504	525–540	550–570	585	680–685	702	725	742	750	810	840–850	855–860	870–890	920	920	950	1725–1730	1940–1960
Gaudryina *a*		X																											
b		X																											
c	X	X																											
Verneuilina *a* cf. propinqua		X								X																			
Cassidulina cf. subglobosa				X							X																		
Clavulina *a* cf. parisiensis	X		X																										
cf. angularis																				X	X	X	X	X	X	X			
Chilostomellidæ.																													
Chilostomella ovoidea				X																									
Lagenidæ.																													
Lagena *a*	X			X																									
b cf. sulcata	X	X	X								X																		
c			X																										
d cf. staphyllearia				X																									
Nodosaria 1 cf. sagrinensis	X												X																
2 cf. raphinistrum	X	X	X		X				?				X			?					?								
3		X		X		X																							
4		X		X									X																
5		X						X	X																				
6		X																										X	
7		X																											
8 cf. lævigata		X																											
9 cf. communis		X											X																
10				X																									
11				X			?																						
12				X																									
13 cf. hirsuta		X																											
14																				X	X		X	X	X				
15																X	X		X	X				X					
16 cf. inflexa																											X		
17																												X	
Cristellaria 1	X				X																								
2		X			X								X																
3 cf. latifrons		X																											
4 cf. italica		X																											
5 cf. convergens		X																											
6		X		X	X																								
7		X		X	X																								
8		X		X																									
9					X																								
10						X							X																
11 cf. clypeiformis														X			X	X	X	X	X	X	X	X	X				
12																													X
Frondicularia *a*		X	X	X																									
b				X									X																
Marginulina	X	X	X																										
Polymorphina *a*	X	X																											
b cf. oblonga		X	X	X																									
c cf. elegantissima		X																											
d		X										X	X																
Uvigerina *a* cf. canariensis	X	X	X	X						X			X																
pygmæa *b*	X	X	X	X							X		X																
Vaginulina																				X	X								
Globigerinidæ.																													
Globigerina *a* cf. dubia	X	X	X	X																									
b cf. æquilateralis	X	X	X	X						X																			
Sphæroidina cf. bulloides	X	X	X	X								X	X																
Rotalidæ.																													
Pulvinulina cf. oblonga	X	X																											
Rotalia	X	X	X	X																									
Truncatulina *a*	X	X	X										X																
b	X	X																											
c cf. reticulata	X	X	X	X																									
d	X	X																											
e cf. akneriana	X	X	X	X																									
f cf. lobatula	X	X	X	X						X	X	X	X																
g			X	X																									
h			X	X								X																	
Nummulitidæ.																													
Polystomella	X	X	X	X						X	X	X	X																
Nonionina cf. umbilicatula	X	X	X																										
Miliolidæ.																													
Massilina	X	X	X	X						X			X																

In regard to the Foraminifera listed in the table, Dr. Cushman says:

The Foraminifera of the deep well at Charleston have been examined carefully down to station 50 (depth 920 feet), where the known Cretaceous begins, in order to determine, if possible, the limits of the Cretaceous in the questionable sections above. The samples of the Cooper marl, Nos. 5, 6, 7, and 8, were first carefully studied. These samples contain a very rich foraminiferal fauna, as will be seen by the accompanying chart of distribution. Of the 81 species recorded from the well 71 occur in these four samples. Sample 6 was much the richest in species, containing 50 of the 71 Cooper marl species. In general it is such an assemblage as may have occurred in water ranging in depth from 100 to 200 fathoms. It is most marked by the practical absence of the Miliolidæ, only one species being present and that allied to the forms found in the deeper water of present oceans.

A study of the washed material from stations 25 to 50, the questionable section, soon showed that material from several horizons had been mixed. As noted by those who had previously examined the lithology of this material, the Cooper marl had dropped down in the boring and had been mixed nearly throughout the samples taken below, so that it became necessary to eliminate the Cooper marl species from each sample. The occurrence of these species was noted and is charted for samples 25, 26, 29, and 31, but it was soon seen that these species represented merely the material which had accidentally dropped from above, so that the charting was not continued. These species occur similarly in the samples down to 50, where the known Cretaceous begins.

It became apparent that the upper part of the section was of slight interest as far as the Foraminifera were concerned, but in sample 39 other species were found. These, however, are too few and poor to afford very definite information, but when sample 43 was reached a marked change was shown in both the physical character of the test and in the species. At this level there were specimens of the genus Vitrewebbina attached to specimens of Cristellaria and Nodosaria. This genus is recorded from the Cretaceous of New Jersey by Bagg. These and certain other forms occurring at this level seem to show that the Cretaceous strata here lie as high as the 750-foot level. The same species characterize the samples taken immediately below.

Many of the forms, especially those of the Cooper marl, have been referred to known species, but the whole series shows marked differences from allied known faunas and the material must be carefully studied in conjunction with that from other localities for final determination. Meanwhile the data showing the distribution of the fossils in the well samples are available for use.

CŒLENTERATA.

A coral identified by Vaughan as Trochocyathus sp. aff. *T. woolmani* Vaughan was found in sample 62, depth 1,230–1,250 feet, and a fragment of an unidentified coral was found in sample 112, depth 1,974–2,007 feet.

ECHINODERMATA.

The spines of unidentified echinoderms were found in four of the samples as follows: Sample 11, depth 290 feet; sample 13, depth 348–350 feet; sample 17, depth 365 feet; sample 23, depth 439–444 feet.

VERMES.

Hamulus onyx Morton, a species regarded as belonging to the subkingdom Vermes, was found in sample 100, depth 1,841 feet.

MOLLUSCOIDEA.

The subkingdom Molluscoidea is represented in the well by Bryozoa, fragments of which were contained in samples 22, 23, and 24. In these samples R. S. Bassler has recognized the following species:

Sample 22, depth 435 feet, contains Entalophora cf. *macrostoma.*

Sample 23, depth 439 to 444 feet, contains Heteropora sp. nov., Escharinella (cf. *altimuralis* U. and B. of the Rancocas formation, but has smaller pores), Amphiblestrum (cf. *heteropora* G. and H. of the Rancocas formation), Lichenopora (cf. *grignonensis* Milne-Edwards).

Sample 24, depth 447 feet, contains Heteropora sp. nov., Escharinella (cf. *altimuralis* U. and B. of the Rancocas formation, but has smaller pores).

MOLLUSCA.

MOLLUSKS FROM THE PLEISTOCENE AND PLIOCENE.

Fossil mollusks were found in samples 1 to 4, as follows:

Sample 1, depth 40 feet, contained a few shells.

Sample 2, depth 62 feet, contained numerous fragments of shells and a few well-preserved shells.

Sample 3, depth 73–75 feet, consisted chiefly of fragments of shells with numerous well-preserved shells.

Sample 4, depth 82–83 feet, consisted chiefly of fragments of shells, with numerous well-preserved shells.

The fossils from samples 1 to 3 are of Pleistocene age and those from sample 4 are of Pliocene age. (See pp. 71, 85.)

Many of the samples taken between the depth of 86 feet and the bottom of the well contained a few Pleistocene or Pliocene shells, which doubtless represented mixtures resulting from the caving of the walls in the upper 86 feet of the well. Most of these fossils were easily distinguishable from the older Eocene and Cretaceous fossils, and since their mention would serve only to confuse the reader they have been disregarded in all that follows.

MOLLUSKS FROM THE EOCENE.

The samples from the strata of uppermost Eocene or Oligocene age between the depths of 86 and 220 feet (samples 5 to 8, inclusive) and the samples from strata of undoubted Eocene age penetrated in the well between the depths of 262 and 447 feet (samples 9 to 24, inclusive) contained a few fragments of unidentified mollusks in addition to numerous shells which were obviously present as a mechanical mixture from the upper 86 feet of the boring.

MOLLUSKS FROM THE CRETACEOUS.

Exclusive of the shells which were obviously present as a mechanical mixture from the upper 86 feet of the section, samples 50 to 112, representing depths from 920 to 2,007 feet, contained the species of fossil mollusks listed in the following table:

Cretaceous mollusks from the deep well of the Charleston Consolidated Railway & Lighting Co., Charleston, S. C.

No. of sample Depth in feet	50 920	52 950	54 1,000	55 1,015–1,030	56 1,035–1,045	58 1,055–1,058	60 1,130–1,140	61 1,150–1,200	69 1,340–1,360	70 1,375–1,400	72 1,440–1,450
Ostrea falcata Morton				×	×						
plumosa Morton				×						×	×
cretacea Morton											
sp. nov. *a*											
b (probably undescribed)											
(young individuals)	×	×	×						×	×	
(fragments)											
Gryphæa sp.											
Exogyra ponderosa Roemer											
upatoiensis Stephenson											
(fragments)									×	×	×
Pecten venustus Morton											
quinquecostatus Sowerby											
Lima reticulata Forbes							×				
Anomia argentaria Morton	×	×		×		×					×
sp. nov. (same as sp. nov. from Snow Hill, N. C.)											
Crassatellites sp. (cast)											
Undetermined casts of pelecypods											
Belemnitella americana (Morton)?								×			

No. of sample Depth in feet	77 1,540–1,550	83 1,660–1,670	88 1,725–1,730	89 1,736	92 1,800–1,812	95 1,832	98 1,839	100 1,841	102 1,862	103 1,887	112 1,974–2,007
Ostrea falcata Morton											
plumosa Morton											
cretacea Morton			?		×			×	×		×
sp. nov. *a*											×
b (probably undescribed)											×
(young individuals)		×									
(fragments)							×			×	×
Gryphæa sp.									×		
Exogyra ponderosa Roemer						?			?		
upatoiensis Stephenson											×
(fragments)											
Pecten venustus Morton	×										
quinquecostatus Sowerby			×								
Lima reticulata Forbes											
Anomia argentaria Morton											
sp. nov. (same as sp. nov. from Snow Hill, N. C.)											×
Crassatellites sp. (cast)				×							
Undetermined casts of pelecypods								×			
Belemnitella americana (Morton) ?											

ARTHROPODA.

The subkingdom Arthropoda is represented among the fossils from the well by specimens of Ostracoda. A species of Cytheridea, closely related to *C. perarcuata* Ulrich, was obtained from sample 25, depth 454 feet; a few Ostracoda were found in samples 26–48, depths 478 to 890 feet; and a few specimens of unidentified Ostracoda were also found in some of the samples taken between depths of 920 and 2,007 feet.

VERTEBRATA.

A few remains of fossil vertebrates were obtained from samples representing the Cretaceous portion of the section, as follows:

Samples 50, 54, 55, taken at depths of 920, 1,000, and 1,015–1,030 feet, respectively, *Corax falcatus* Agassiz (a shark); sample 70, 1,375–1,400 feet, Lamna?; samples 72, 83, 86, from depths of 1,440–1,450, 1,660–1,670, and 1,720–1,723 feet, respectively, shark teeth; sample 92, 1,800–1,812 feet, coprolite; sample 98, 1,839 feet, *Corax falcatus* Agassiz; sample 100, 1,841 feet, Ptychodus? (fragment of tooth).

PLANTS.

The only plant remains found in the samples were a few fragments of lignite in sample 1, depth 40 feet; numerous fragments of lignite from samples 109, 110, and 112, depth 1,974–2,007 feet; and numerous comminuted vegetable fragments in sample 111, depth 1,974–2,007 feet.

RECORD OF ANOTHER WELL AT CHARLESTON.

The record of a well 1,980 feet deep, drilled under the auspices of the city council of Charleston between the years 1876 and 1879 by Mr. F. Spangler, is inserted here for purposes of comparison. The well is known as the Citadel Green well and is at the southwest corner of the South Carolina Military Academy grounds, near the corner of King and Calhoun streets. A scientific committee was appointed by the city council to cooperate with the city civil engineer "in devising and employing the best means of preserving, recording, and classifying the stratifications of the new well and publishing a statement of the work when done."[1]

This committee sent a set of borings from the well to Prof. James Hall, whose report to the chairman of the committee is here quoted in full.[2]

New York State Museum of Natural History,
Albany, June 21, 1880.

Right Rev. P. N. Lynch, *Bishop of Charleston:*

I very much regret that it was not in my power to give prompt attention to the collection of specimens from the artesian well at Charleston which you placed in my hands, but you already know why I was not able to do so.

I herewith hand you some memoranda regarding the collection as it came into my hands and as indicated by marks showing the number of feet in depth. These depths are sometimes specifically marked, and in other cases the specimens in the box or parcel are marked as extending over many feet. Some of the specimens of fossils can be readily identified, but most of them are too fragmentary to give the means of satisfactory specific determination, and I have indicated only their generic relations.

The species described by Capt. Vogdes,[3] with a single exception, do not appear in the collection in a condition to be satisfactorily determined.

The higher beds are clearly of the modus Tertiary. There is nothing in the collection that indicates the presence of Cretaceous strata at any point above 600 feet. The parcel marked 600 to 1,300 feet contains Cretaceous forms, and the specimens marked respectively 654–767 and 700–720 feet have all the aspect of Cretaceous marl or green sand but are without fossils. At 900 feet there occur teeth of *Ptychodus mortoni* Leidy, a characteristic Cretaceous fossil.

[1] Artesian wells: The report of the scientific committee appointed by the city council on July 5, 1876, consisting of the Rev. P. N. Lynch, D. D., Prof. C. U. Shepard, jr., and J. F. M. Geddings, M. D., embracing a historical sketch of the several attempts, from 1823 to the present time, to bore artesian wells in this city; also an elaborate analytical investigation of the waters and the strata penetrated in the artesian wells and other analyses of cistern waters and of waters from many of the large fire wells of this city: Municipal report of the city of Charleston, S. C., 1881, 61 pp. Charleston, 1882.

[2] Idem, pp. 21-24.

[3] Am. Jour. Sci., 3d ser., vol. 16, pp. 69, 70, 1878.

The lowest depth of any marked specimens of fossils is 1,955 feet, and the parcel contains characteristic Cretaceous forms. The specimens indicated as 1,940–1,980 are of greenish clay, without fossils.

Regarding the Tertiary as terminating at the depth of about 600 feet this will give nearly 1,400 feet (1,980−600=1,380) of the Cretaceous formation in vertical thickness.

The lowest marked specimens of fossils are of characteristic Cretaceous forms and present no remarkable change from those several hundred feet higher in the series. From the character of these fossils we should be warranted in the inference that there may be a considerable thickness of Cretaceous beds below that horizon.

The clay indicated by the numbers 1,940–1,980 feet has the character of the lower clays of the Cretaceous formation in some localities, but it would be imprudent to draw any positive inference without further knowledge.

Truly yours,

JAMES HALL,
State Geologist and Director State Museum Natural History.

Notes on samples of borings from different depths of the artesian well at Charleston, S. C.

Depths.
65–100. Pliocene, Tertiary, Tellina, Arca, etc.
80–100. Tertiary, Venus, Tellina, shark's tooth, phosphatic nodules.
350–430. Tertiary, phosphatic nodules, oyster-shell breccia. [600 feet noted by Capt. Vogdes as containing Chama. No specimens.]
680. Shell marl, concretions. Nothing indicating geological position.
600–1,300. Cretaceous, *Exogyra foliacea*, iron pyrites nodules, soft limestone of calcareous rock with phosphate. Specimens marked as above; no indication of specific depth.
654. Cretaceous, marl with fragments of shells.
767. Cretaceous, marl with green sand, Anomia? sp. (fragmentary).
778. Cretaceous, phosphatic concretions, green sand, iron pyrites.
700–720. Cretaceous, compact marl, oolitic and micaceous shells which are indeterminable.
900. Cretaceous, *Ptychodus mortoni* Leidy (a characteristic Cretaceous fossil).
1,090. Cretaceous, calcareous marl with fragments of shells.
1,345. Cretaceous, Ostrea sp.?, *Gryphæa vomer*.
1,345–1,350. Cretaceous, *Exogyra costata*, *Gryphæa vomer*, charred wood.
1,349. Cretaceous, marl with sand, green sand, siliceous concretions.
1,369. Cretaceous, marl with sand, *Exogyra foliacea*.
1,400–1,403. Cretaceous, concretions of sand in a greenish marl.
1,472. Cretaceous, concretions of sand in a greenish marl with shell breccia.
1,520. Cretaceous, argillaceous marl.
1,533–1,538. Cretaceous, sand with shells, casts of shells, and shells of Ostrea, Exogyra, Anomia? sp., *Neithea mortoni* D'Orb.
1,553. Cretaceous, breccia of shells and bryozoans, Ostrea, fragments of bones, Serpula, lignite.
1,570. Cretaceous, green sand, *Exogyra costata*.
1,575. Cretaceous, green sand, siliceous concretions, Ostrea.
1,580. Cretaceous, green sand, argillaceous.
1,588. Cretaceous, green sand and marl, without shells.
1,558–1,560. Cretaceous, sand, concretions, micaceous, *Exogyra foliacea*, Inoceramus (fibrous portion of shell), Exogyra, fragments, Ostrea, casts of indeterminable fossils in green sand.
1,558. Cretaceous, valve of *Exogyra foliacea*.
1,600. Cretaceous, Inoceramus (fibrous portion of shell), *Exogyra costata*, Dentalium.
1,600–1,610. Cretaceous, green sand with Exogyra, Teredo.
1,610–1,620. Cretaceous, green sand with Exogyra.
1,625–1,650. Cretaceous, green sand with Exogyra, Ostrea.
1,650–1,675. Cretaceous, green sand with Exogyra, *Gryphæa vomer*, *Exogyra costata*.
1,690. Cretaceous, green sand with Exogyra.
1,690–1,705. Cretaceous, green sand with casts of fossils and fragments of Exogyra.
1,692–1,700. Cretaceous, green sand and marl.
1,700–1,725. Cretaceous, green sand and marl, Ostrea, Gryphæa.
1,710. Cretaceous, green sand, siliceous.
1,728. Cretaceous, green sand, siliceous.
1,730–1,750. Cretaceous, green sand, Exogyra.
1,745. Cretaceous, green sand, siliceous.
1,765. Cretaceous, green sand, siliceous, fragments of Exogyra, Ostrea, upper valve of *Exogyra costata*.
1,790. Cretaceous, green sand.
1,831. Cretaceous, *Exogyra costata*.
1,835. Cretaceous, fragments of bones and Exogyra, two forms of Bryozoa, undetermined siliceous aggregations.

Depths.

1,845. Cretaceous, Exogyra, shell, breccia.
1,840. Cretaceous, Exogyra, Ostrea, young of *Gryphæa convexa*.
1,840. Cretaceous, echinoderm (Bucleolites?).
1,850. Cretaceous, fragments of bone, siliceous pebble.
1,835–1,840. Cretaceous, Exogyra, Gryphæa, sand, pyrite, Dentalium, bones, shark's teeth of the genera Ptychodus and Lamna, echinoderms, *Nucleoletes* (*Catophygus*) *lynchii* Vogdes.
1,844–1,845. Cretaceous, shells of *Gryphæa vomer?*, *Exogyra costata*.
1,840–1,845. Cretaceous, sandstone with fragments of shells, shell breccia, *Exogyra costata* (young), *Gryphæa pitcheri*.
1,845. Sand pump, Cretaceous, *Gryphæa pitcheri*, *Gryphæa vomer*, sand concretions.
1,835–1,840. Cretaceous, concretions of coarse sand, shells, Ostrea, *Gryphæa shephardi*, Exogyra.
1,840. Cretaceous, shark's teeth.
1,840–1,940. Cretaceous, fish bone, Inoceramus sp.?
1,900(?). Cretaceous, sand, Ostrea.
1,900(?). Cretaceous, shark's tooth, pebble, sand.
1,932. Cretaceous, green sand, casts of fossils, pebbles, lignite, iron pyrite, Gryphæa.
1,930. Cretaceous, clay.
1,930. Cretaceous, micaceous sandstone.
1,900. Cretaceous, sandstone, iron pyrite, green sand, fine laminated clay.
1,900. Cretaceous, Inoceramus, wood.
1,900. Cretaceous, exterior shell of Inoceramus.
1,900. Cretaceous, Teredo.
1,923. Cretaceous, green sand, casts of Gastropoda, Inoceramus, Ostrea.
1,940. Cretaceous, phosphatic nodule with iron pyrite, sand aggregation with mica.
1,943. Cretaceous, lignite, red hematite.
1,950. Cretaceous, wood opal, iron pyrite.
1,949–1,980. Cretaceous, clay.
1,955. Cretaceous, lignite, iron pyrite.
1,955. Cretaceous, shell breccia, Nucula, Turritella.
1,955. Cretaceous, shell breccia, siliceous, Ostrea.
1,955. Cretaceous, oyster perforated by sponge, green sand, iron pyrites, Inoceramus.

According to Prof. Hall's interpretation the Cretaceous was reached in this well at a depth of 600 feet, although no characteristic Cretaceous fossils are recorded from a definitely determined depth less than 900 feet. Prof. Hall's report contains two proposed specific names of fossils, namely, *Exogyra foliacea* and *Gryphæa shephardi*, which were not subsequently described and which are therefore invalid.

The present writer has not been able to learn what disposition was made of the fossils from this old well.

CORRELATION OF THE STRATA PENETRATED.

STRATA OF PLEISTOCENE AND PLIOCENE AGE.

The fossil mollusks in samples Nos. 1 to 4 were submitted to Dr. Paul Bartsch, of the United States National Museum, who regards those obtained from samples 1 to 3, representing depths from 40 to 75 feet, as of probable Pleistocene age and those from sample 4, depth 82–83 feet, as certainly of Pliocene age.

STRATA OF UPPERMOST EOCENE OR OLIGOCENE AGE.

Samples 5 to 8, representing depths from 86 to 220 feet, contain a rich foraminiferal fauna, the species of which have been identified by Joseph A. Cushman. The names of the species and their distribution in the well are given in the table on pages 79–80 and the fauna is discussed in the quotation that follows the table. The lithology of the samples shows that they belong to the Cooper marl, which outcrops in the vicinity of Charleston and which is referable to either the uppermost Eocene or the Oligocene. R. S. Bassler states that he has recognized ostracodes in the Cooper marl which appear to indicate that it is of Vicksburg age. On the other hand, the formation has yielded mollusks and the vertebrate genus Basilosaurus, which Vaughan and others have regarded as indicating its Jackson age.

STRATA OF EOCENE AGE.

A part of the samples numbered from 9 to 24, representing depths ranging from 262 to 447 feet, were obtained as concentrates from the overflow. These consist largely of fragments of limestone, fragments of shells, echinoid spines, and Bryozoa. Samples 9, 11, and 13, depths 262 to 350 feet, were derived from layers of rather soft limestone or marl, but they yielded no determinable fossils. Samples 17, 20, 22, 23, and 24, depths 363 to 447 feet, are made up chiefly of fragments of hard gray sandy limestone containing numerous indeterminable fragments of mollusks and a few fragments of echinoids and Bryozoa. These samples appear to be essentially alike lithologically and probably represent one geologic formation. From samples 22 to 24, depths 435 to 447 feet, R. S. Bassler has identified the species of Bryozoa listed on page 81. He reports that the fauna is closely related to the bryozoan fauna in the Castle Hayne limestone,[1] of Jackson (Eocene) age, exposed near Wilmington, N. C., and to a similar fauna in the Mount Hope marl of Sloan,[2] exposed near Eutawville (Eutaw Springs), 70 miles north of Charleston, S. C.

Vaughan,[3] because of the presence of *Ostrea sellæformis* Conrad, has correlated the Mount Hope marl of Sloan with the Claiborne group, but evidence afforded by the Bryozoa indicates that it may be of Jackson age.

Although the stratigraphic and age relations of the upper Eocene and Oligocene deposits of this area have not been definitely determined, the fact that normally the strata dip coastward and the evidence afforded by the fossil bryozoans seem to support the view that the limestones and marls penetrated in the Charleston well between depths of 262 and 447 feet represent the buried coastward extension of the Mount Hope marl of Sloan. However, the evidence cited on page 85, which appears to indicate the Jackson age of the Cooper marl, necessitates questioning the correlations here suggested.

Sample 25, depth 454 feet, contains ostracodes belonging to the genus Cytheridea and closely related to the species *C. perarcuata*, which occurs in the Eocene of Maryland in both the Aquia and Nanjemoy formations.

STRATA OF EOCENE OR UPPER CRETACEOUS AGE.

Samples 26 to 42, representing depths between 478 and 742 feet, yielded no fossils of sufficient diagnostic value to permit the determination of the age of the beds. A few specimens of Ostracoda and Foraminifera were obtained, but it was not certain that they belonged in place at the levels from which they were taken; indeed, it seemed highly probable that they fell from higher levels. Lithologically, the samples present no features of value for correlation. The upper part of the thickness represented (264 feet) is probably Eocene and the lower part Cretaceous, but without more exact data the point of contact can not be determined. The samples obtained as concentrates consist chiefly of gray shaly, finely arenaceous, micaceous, calcareous clay containing more or less loose sand. One sample (No. 29, depth 504 feet) is a highly glauconitic loose sand. The samples obtained as mud from the bit consist of gray calcareous, more or less sandy clays. The lithology of these samples indicates that they may belong to either the Eocene or Cretaceous. The basal beds of the Eocene that outcrop in the Coastal Plain of South Carolina along the borders of the Cretaceous areas north and northwest of Charleston consist in part of dark shaly clays, the buried extension of which some of these samples might well represent. The glauconitic sand (sample 29, depth 504 feet) may perhaps represent the glauconite-bearing Warley Hill marl of Sloan (part of Claiborne group). Many of the samples below the glauconitic layer are not essentially different from those above it.

STRATA OF UPPER CRETACEOUS AGE.

The first definite paleontologic evidence of strata of Cretaceous age was afforded by species of Foraminifera found in sample 43, depth 750 feet. Dr. Cushman has discussed this evidence in the quotation given on page 81. From this depth to a depth of 920 feet the samples indicate

[1] Miller, B. L., The Coastal Plain of North Carolina; the Tertiary formations: North Carolina Geol. and Econ. Survey, vol. 3, pp. 185-197, 1912.
[2] Sloan, Earle, Catalogue of the mineral localities of South Carolina: South Carolina Geol. Survey Bull. 2, ser. 4, p. 462, 1908.
[3] Vaughan, T. W., in Willis, Bailey, Index to the stratigraphy of North America: U. S. Geol. Survey Prof. Paper 71, p. 737, 1912.

that the drill encountered sands and clays, more or less calcareous and glauconitic, containing small black phosphatic pebbles. Some hard layers were penetrated, as is shown by fragments of sandstone in the samples.

The first identifiable mollusk of undoubted Cretaceous age, *Anomia argentaria* Morton, was found in sample 50, taken at a depth of 920 feet. The strata penetrated from 920 feet to the bottom of the well, as represented by the samples, are typical marine Upper Cretaceous materials, consisting of marls, more or less calcareous and glauconitic, sands, and shaly clays, with indurated layers at intervals. These samples yielded the identifiable fossils listed on preceding pages.

The writer has heretofore attempted [1] to explain the lithologic variations and age relations of the Cretaceous deposits of the eastern Gulf region and to correlate them with the Cretaceous deposits of the North Atlantic region. Figure 11, which indicates the terms employed in that report to designate the paleontologic zones recognized and the relations of these zones to formation units, is introduced in order that the Charleston well section may be compared with the Chattahoochee and Carolina sections. In figure 12 the correlation of the Cretaceous portion of the Charleston well sections, in terms of the faunal zones recognized in these regions, is indicated diagrammatically.

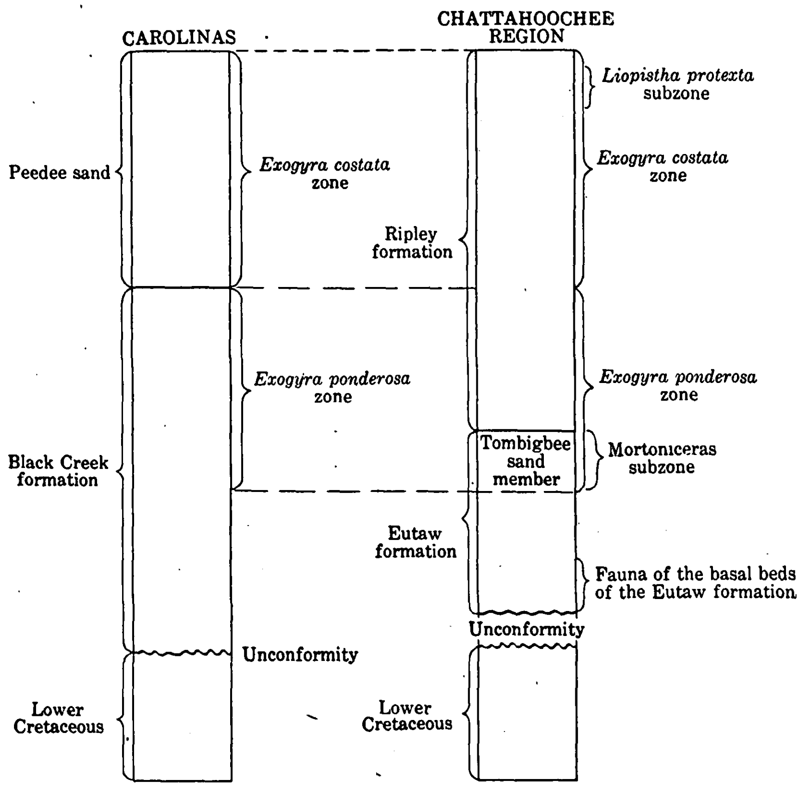


FIGURE 11.—Diagram indicating the terms used to designate paleontologic zones and the relation of these zones to formation units in the Chattahoochee region and the Carolinas. Horizontal dashed lines indicate age equivalencies within the Upper Cretaceous. Not drawn to scale, and relative thicknesses of formations not indicated accurately. The Ripley formation of the Chattahoochee region is approximately the time equivalent of the Selma chalk of western Alabama and east-central Mississippi and of the combined Ripley formation, Selma chalk, and upper part of the Eutaw formation of northern Mississippi.

The following fossils were identified specifically in samples taken between depths of 920 and 1,550 feet:

Mollusca: *Ostrea larva* Lamarck, *Ostrea plumosa* Morton, *Pecten venustus* Morton, *Lima reticulata* Forbes ?, and *Belemnitella americana* (Morton) ?.

Vertebrata: *Corax falcatus* Agassiz (a shark).

Of the fossils listed, *Ostrea plumosa* Morton and *Lima reticulata* Forbes range through both the zone of *Exogyra costata* and the zone of *Exogyra ponderosa,* and *Ostrea plumosa* Morton has been questionably identified from the basal beds of the Eutaw formation; *Ostrea larva* Lamarck ranges from the zone of *Exogyra costata* downward into the upper part of the zone of *Exogyra ponderosa. Corax falcatus* Agassiz is a wide-ranging species in the Upper Cretaceous. In known sections *Pecten venustus* Morton and *Belemnitella americana* (Morton) are restricted to the zone of *Exogyra costata,* and upon the evidence of these fossils this portion of the section is correlated with that zone. Heretofore the species *Pecten venustus* Morton has not been found below the horizon of *Belemnitella americana* (Morton). As it was found here 300 feet below the level at which the fragment of Belemnitella was obtained, it is considered probable that it fell to that position from some higher level. In terms of the formation units recog-

[1] Stephenson, L. W., Cretaceous deposits of the eastern Gulf region and species of Exogyra from the eastern Gulf region and the Carolinas: U. S. Geol. Survey Prof. Paper 81, 1914.

nized in the Upper Cretaceous deposits of the Carolinas this portion of the section (depth 920–1,550 feet) is correlated with the Peedee sand.

Between the depths of 1,725 and 1,862 feet the following fossils were identified specifically:

Vermes: *Hamulus onyx* Morton.

Mollusca: *Ostrea cretacea* Morton, *Exogyra ponderosa* Roemer?, and *Pecten quinquecostatus* (Sowerby).

Vertebrata: *Corax falcatus* Agassiz (a shark).

Of these fossils, *Hamulus onyx* Morton and *Pecten quinquecostatus* (Sowerby) range throughout both the zone of *Exogyra ponderosa* and the zone of *Exogyra costata* but are not found in the basal beds of the Eutaw formation; *Ostrea cretacea* Morton ranges from the basal beds of the Eutaw formation upward into the lower half of the zone of *Exogyra ponderosa; Corax falcatus* Agassiz has a wide vertical range in the Upper Cretaceous; and *Exogyra ponderosa* Roemer is restricted to the zone that bears its name. On the evidence afforded by the range of these fossils this part of the section is correlated with the zone of *Exogyra ponderosa* of the Chattahoochee and Carolina regions.

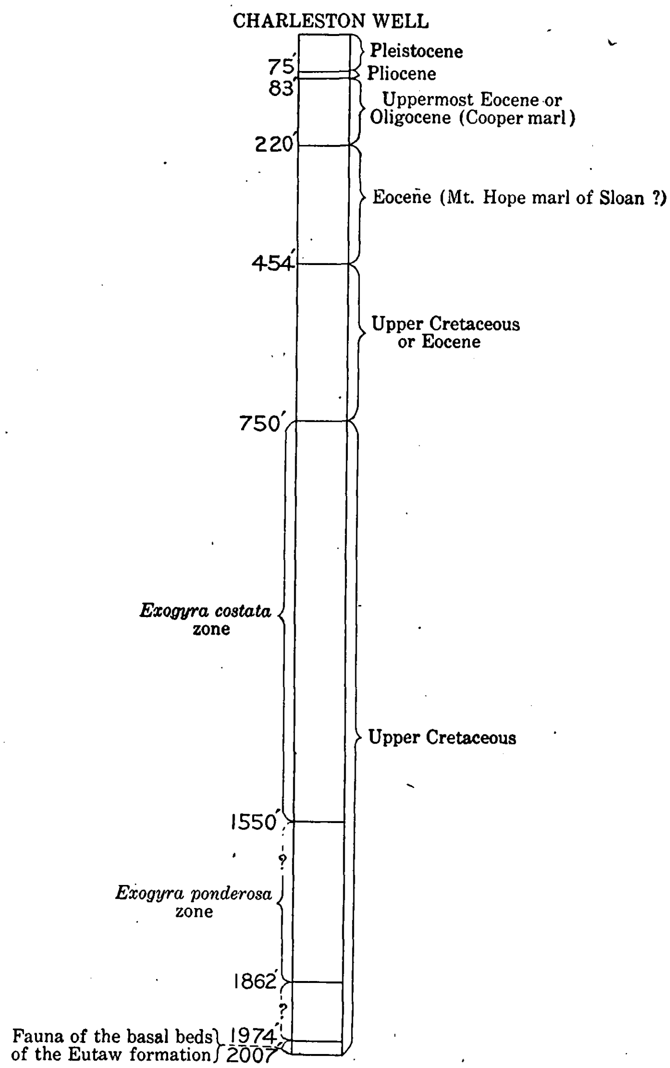


FIGURE 12.—Diagram showing correlation of Cretaceous portion of the Charleston well section in terms of the faunal zones recognized in the Cretaceous deposits of the eastern Gulf region. All measurements were made from the top of the rotary jaws, which was 6 feet above the surface of the ground.

The best specimens obtained from the Cretaceous strata penetrated by the boring were those brought to the surface by the natural flow of water from depths between 1,974 and 2,007 feet. The fossils identified specifically from this horizon are the following:

Mollusca: Ostrea sp. nov. *a* (four fairly good specimens and other fragments), Ostrea sp. nov. *b*, *Ostrea cretacea* Morton, *Exogyra upatoiensis* Stephenson[1] (three fairly good specimens and several fragments), Anomia sp. nov. (same as sp. nov. from Snow Hill, N. C.).

Of the species listed, Ostrea sp. nov. *a* and *b* are new to science, and their value in correlation has not been determined. *Ostrea cretacea* Morton ranges upward into the lower half of the zone of *Exogyra ponderosa; Exogyra upatoiensis* Stephenson has been found heretofore only in the basal beds of the Eutaw formation in the Chattahoochee region; Anomia sp. nov. (same as a new species from Snow Hill, N. C.) ranges upward into the zone of *Exogyra ponderosa*. The particular localities at which *Exogyra upatoiensis* Stephenson have been found are the following: Broken Arrow Bend, Chattahoochee River 10½ miles below Columbus, Ga.; Chattahoochee River, one-half mile below Broken Arrow Bend; and a bluff on Upatoi Creek 7 miles southeast of Columbus, Ga., below the Cusseta road bridge.

On the evidence of *Exogyra upatoiensis* Stephenson this horizon is correlated with the basal beds of the Eutaw formation in the Chattahoochee region. Exposures of these beds occur in

[1] This species was described by the writer in U. S. Geol. Survey Prof. Paper 81, p. 46, pl. 13, figs. 1–4, 1914.

bluffs on Upatoi Creek, which forms the boundary between Muscogee and Chattahoochee counties, Ga., and on Chattahoochee River from a place a short distance below the mouth of Upatoi Creek, 9 miles below Columbus, Ga., nearly to the mouth of Euchee Creek, about 16 miles below Columbus.

In terms of the formation units recognized in the Carolinas, that portion of the section between a depth of 1,550 feet and the bottom of the well represents a part—perhaps the greater part—of the Black Creek formation.

ORIGIN AND GEOLOGIC HISTORY OF THE WATER.

The strata underlying the Atlantic Coastal Plain in the Carolinas consist of a series of sands, clays, and marls, largely unconsolidated, and subordinately of impure limestones. These rest unconformably upon a basement complex of ancient crystalline rocks of pre-Cambrian age and locally upon Triassic sedimentary strata which occupy depressions in the crystalline rocks. These older rocks outcrop in the Piedmont Plateau, along the eastern border of which their upper eroded surface dips slightly southeastward and passes beneath the deposits of the Coastal Plain, becoming deeper toward the coast.

At Fort Caswell, N. C., which is on the coast at the mouth of Cape Fear River, the crystalline basement rocks lie about 1,535 feet below sea level, as is shown by a well boring. At Charleston they lie more than 2,000 feet below sea level, for the deep wells there have failed to reach the basement.

The formations above the basement rocks in South Carolina in the longitude of Charleston embrace deposits comprising in ascending order Lower Cretaceous, Upper Cretaceous, Eocene, Oligocene (?), Pliocene, and Pleistocene. The strata composing the formations dip coastward at the rate of 40 feet or less to the mile. The younger formations in general lie flatter than the older, the youngest, the Pleistocene terrace deposits, having an inclination of less than 5 feet to the mile.

The materials composing the sands, clays, and marls of the formations of the Coastal Plain were derived primarily from the predominantly feldspathic rocks of the Piedmont Plateau, with the exception of the matter, chiefly calcium carbonate, that was extracted by organisms or chemically precipitated from the sea water in which the deposits were for the most part laid down. The more easily soluble minerals of the crystalline rocks of the Piedmont were in part leached out and carried to the sea in solution by the streams, but some of the feldspathic matter was transported coastward as detrital material in different stages of decay and became incorporated in varying proportions in the formations of the Coastal Plain. The capacity of the different strata of the Coastal Plain for admitting water and their efficiency as channels for circulation differ greatly. Some of the beds are compact and almost impervious to water; some are porous and where the structural conditions are favorable permit the free circulation of water.

The underground waters in the deposits of the Coastal Plain have been derived from several sources, including water entering from the adjacent Piedmont Plateau, rainfall on the Coastal Plain, and originally included sea water.

The greater part of the run-off from the Piedmont Plateau flows to the ocean in streams which, though they cross the Coastal Plain, probably do not contribute materially to the underground supply. The mass of underground water in the deeply weathered surficial rocks of the Piedmont, however, tends by gravity to drift coastward, some of it doubtless passing into the deposits of the Coastal Plain. Of the land-derived underground water rainfall on the Coastal Plain itself is doubtless the chief original source of supply. Water from either source comes into contact with feldspathic minerals, either in the rocks of the Piedmont Plateau itself or in the formations of the Coastal Plain which were derived from the crystalline rocks of the Piedmont Plateau, and from these minerals have been derived the characters which distinguish the underground waters of the area.

The more deeply buried beds also contain water composed of a mixture of originally included sea water and subsequently included alkaline land water, both of which may properly be classed as fossil waters. The character of the fossil waters in the vicinity of Charleston is discussed by Chase Palmer on pages 90–94 of this paper.

The strata penetrated in the Charleston wells are all of marine origin, and probably the greater part of the Cretaceous deposits and the lower part of the Eocene deposits have never been above sea level since their formation, so that no opportunity has been afforded for draining these ancient waters from them. During subsequent geologic time land-derived waters have moved downward along the gently dipping strata and have become mixed with the originally included sea waters in varying proportions in the different beds and at different places. The composition of the waters has been further changed by the solution of mineral matter from the deposits in which the waters have stood and by the precipitation of mineral matter from solution.

The conditions and principles governing the origin, storage, and circulation of underground waters in North Carolina, which are equally applicable in South Carolina, have been discussed by Stephenson and Johnson.[1]

RÉSUMÉ.

1. The first 75 feet of strata penetrated in the Charleston well is probably of Pleistocene age.
2. Characteristic Pliocene fossils were found in a sample taken at a depth of 82–83 feet.
3. Sands and clays bearing Foraminifera, which have been studied by Joseph A. Cushman, were penetrated at depths of 86 to 220 feet. On the grounds of lithologic similarity these samples are referred to the Cooper marl.
4. Strata of Eocene age (the Mount Hope marl (?) of Sloan) were penetrated from depths of 262 to 454 feet.
5. The strata between depths of 454 and 750 feet yielded no determinable fossils. Their age is Upper Cretaceous or Eocene.
6. From a depth of 750 feet to the bottom of the well only strata of Upper Cretaceous age were encountered.
7. At a depth of 750 feet Foraminifera were found which are regarded by Dr. Cushman as characteristic Cretaceous species.
8. Between depths of 920 and 1,550 feet fossils characteristic of the zone of *Exogyra costata* of the eastern Gulf region and the Carolinas were obtained.
9. Between depths of 1,725 and 1,862 feet fossils characteristic of the zone of *Exogyra ponderosa* of the eastern Gulf region and the Carolinas were obtained.
10. Between depths of 1,974 and 2,007 feet fossils characteristic of the fauna of the basal beds of the Eutaw formation in the Chattahoochee region were brought to the surface by the natural flow of water immediately after the well was completed.
11. In view of the fact that at the lower limits of this boring, which reached a depth of nearly 2,000 feet below sea level, no Lower Cretaceous beds had been reached, it is interesting to note that at Wilmington, N. C., and at the mouth of Cape Fear River, N. C., borings which reached basement crystalline rocks at 1,100 feet and approximately 1,535 feet, respectively, below sea level, failed to encounter strata older than Upper Cretaceous.

MINERALOGY OF WATERS FROM ARTESIAN WELLS AT CHARLESTON, S. C.

By Chase Palmer.

PRIMARY ALKALINE FOSSIL WATERS.

The writer made a complete analysis of the water from the new well at the power plant of the Charleston Consolidated Railway & Lighting Co. at the foot of Charlotte Street and a parallel analysis of the water from the old artesian well at the corner of Meeting and Wentworth streets, Charleston, with two objects in view—first, to compare the quality of the water of the old well (1,260 feet deep) with that of the new well (2,007 feet deep), and, second, to determine what changes, if any, might have taken place in the quality of the water of the old well since 1868, the date of its first recorded analysis. It may be stated here that no material change is shown either in the chemical character of the solution or in its concentration 44 years after it was analyzed by Charles U. Shepard, who, in 1882, published many analyses of waters of wells

[1] Stephenson, L. W., and Johnson, B. L., Water resources of the Coastal Plain of North Carolina: North Carolina Geol. and Econ. Survey vol. 3, pt. 2, pp. 342-348, 1912.

in and near Charleston.[1] The mineralogy of these artesian waters is here briefly outlined and is compared with that of one other well water underneath Charleston and with that of the water of surface streams of the Piedmont Plateau.

On Citadel Green, in Charleston, in 1876, a well was sunk to a depth of 1,980 feet, and a fairly complete analysis of the water coming from that depth was then made by S. T. Robinson, jr. The Citadel Green well evidently reached the same underground water that supplies the new 2,007-foot well of the Consolidated Railway & Lighting Co., for the waters of the two wells exhibit a close resemblance in mineralization. This resemblance is not confined to the degree of concentration of mineral substances but extends to the chemical qualities of the two solutions, for the reaction properties of the water of the 2,007-foot well are proportionally the same as those of the water of the 1,980-foot well, which was analyzed 35 years ago.

The waters at the 1,260-foot level and at the 1,980-foot level under Charleston differ markedly in the proportions of their reaction properties. This fact, taken in connection with the fact that the character of each solution remains practically unchanged after an interval of several decades, leads directly to the conclusion that these two artesian waters are from independent watercourses. On the other hand, they have in common certain peculiarities which might be expected if the natural conditions governing their original sources and their present environment were recognized.

By reason of its higher position and the impervious underlying granite the Piedmont Plateau is naturally one source of the water contained in the sands that are buried under material derived from the upland. It is therefore desirable to know, first, the quality of surface waters now flowing in the Piedmont area and of the surficial waters of the upper Coastal Plain before they enter the ground water of the Coastal Plain, and, second, the quality of the underground waters near the coast, as indicated by the waters of three artesian wells under the city of Charleston, S. C. In order to show the character of the surface waters the waters of Peedee and Wateree rivers are chosen, because they typify the river waters of the Piedmont Plateau and upper Coastal Plain of the southern Atlantic coast. The qualities of the series of surface waters from the James in Virginia to the Ocmulgee in Georgia are tabulated in a recent publication of the United States Geological Survey.[2]

The analysis of an artesian water coming from a depth of 425 feet, to be used in a comparative study of the waters from the two lower levels, is obtained from the records of the municipal report of Charleston on artesian wells, already cited.

INTERPRETATION OF ANALYSES.

As the interpretation of water analyses adopted in this report is new, its novelty warrants a preliminary statement of the principle on which it is based and justifies definitions of the terms used in its application. This chemical interpretation is based, not on the amounts of the constituents found by the analyst, but on their reaction capacities, and thus is opened a way leading directly to a consistent nomenclature of water qualities and a consistent classification of waters, as has been shown by the writer elsewhere.[3]

In recent years the geologist has relied on the statement of the results of a water analysis for information concerning the quality of the water analyzed. A mere statement of the amounts of radicles, which are only parts of substances dissolved in a water, has no chemical significance, for it tells nothing of the qualities of the solution, the characterization of which is the chief object of the analysis.

Fortunately the chemist is able to measure quantitatively four qualities of the water solution without resort to a complete analysis. The qualities capable of direct measurement are acidity, permanent hardness, temporary hardness (temporary alkalinity), and permanent alkalinity. A fifth quality of water, namely, saltness, caused by strong acid salts of the alkalies, can not be so easily determined. This quality may be found, however, by balancing the reacting

[1] Municipal report of the city of Charleston, S. C., for 1881.
[2] Palmer, Chase, The geochemical interpretation of water analyses: U. S. Geol. Survey Bull. 479, Table 2, opp. p. 16, 1911.
[3] Palmer, Chase, op. cit.

values of the positive and negative radicles found by analysis after deducting the reacting values of all the radicles that go to make up the other qualities directly measurable in the water solution. By proportionating this quality with the other qualities found in a water a rational statement of the chemical character of the water solution may be obtained.

FORMULA OF THE SOLUTION.

The reaction capacities of the radicles of the salts dissolved in water are the quotients obtained by dividing the weight of each radicle by its corresponding equivalent combining weight. The quotients thus obtained have been called the "reacting values" [1] of the radicles.

Owing to the differences in the concentration of waters the application of the reacting values to the character of water is necessarily restricted to the water under examination. If, however, the reacting values are expressed in percentages of their sum they may be used in the comparative study of different waters. This expression of the reacting values of the radicles in percentages is called the formula for the mixture of salts dissolved in a water, and on this formula rests the comparative study of waters in this report.

PROPERTIES OF NATURAL WATERS.

Nearly all natural waters have two general properties—salinity and alkalinity—on whose relative proportions their fundamental characters depend. All the radicles of the alkalies and alkaline earths tend to form alkaline solutions, but only the strong acid radicles (sulphate, chloride, nitrate) can overcome this tendency and render an alkaline solution neutral or saline. The sum of the reacting values of the strong acid radicles is therefore a measure of the salinity (saltness) of a natural water which is a solution of salts of strong and weak acids. The sum of the reacting values of the metallic radicles in excess of the values of the strong acids is a measure of the alkalinity of a water.

In the qualities of waters included in this report only two kinds of salinity and two kinds of alkalinity will be considered. In accordance with the prevalence of the reacting values of the alkali group (sodium, potassium) and the alkaline earths group (calcium, magnesium) four special properties are possible, namely:

1. Primary salinity (alkali salinity)—that is, saltness such as would be caused by sulphates and chlorides of the alkalies.
2. Secondary salinity (permanent hardness)—that is, saltness such as would be caused by sulphates and chlorides of calcium and magnesium.
3. Primary alkalinity (permanent alkalinity)—that is, alkalinity such as would be caused by hydroxides, carbonates, and bicarbonates of the alkalies.
4. Secondary alkalinity (temporary hardness)—that is, alkalinity such as would be caused by weak acid salts of calcium and magnesium.

Secondary salinity and primary alkalinity are incompatible, so that both of these qualities are not found in the same water. The waters considered in this report are represented by three qualities; for instance, an assemblage of 1, 3, 4, or an assemblage of 1, 2, 4, exemplified by ocean water.

COMPARISON OF WATERS.

The analyses of the waters of Peedee and Wateree rivers (columns 1 and 2 in the accompanying table, p. 93) show that they are very dilute solutions having practically the same concentration. Moreover, these two waters are almost identical in composition, as may be seen by comparing the amounts of the radicles in column 1 with the amounts of the radicles in column 2. This close similarity in composition of two surface waters in different river basins at points 70 miles apart cross-country is noteworthy and is in marked contrast with the evident difference in composition of the three underground waters (columns 3, 4, 5) at Charleston, at levels separated by vertical distances of only a few hundred feet.

[1] Stabler, Herman, The mineral analysis of water for industrial purposes and its interpretation by the engineer: Eng. News, vol. 60, p. 356, 1908; also, chapter on industrial application of water analyses in U. S. Geol. Survey Water-Supply Paper 274, pp. 161-181, 1911.

TABLE 1.—*Analyses and formulas of surface and artesian waters and of ocean water.*

[Analyses in parts per million; formulas in percentages of reacting values.]

Constituent.	River waters of Piedmont Plateau.				Artesian waters at Charleston, S. C.						Ocean water (formula).
	Analyses.		Formulas.		Analyses.			Formulas.			
	1	2	1a	2a	3	4	5	3a	4a	5a	6
Sodium (Na)	7.4	7.2	19.3	19.1	1,154	1,014	421	43.6	47.4	49.1	38.5
Potassium (K)	1.8	1.6	2.8	2.5	146	41	4.4	3.3	1.1	.3	.8
Calcium (Ca)	6.1	5.7	18	17.2	21	14	3	.8	.8	.4	1.8
Magnesium (Mg)	1.9	2.3	8.7	11	31	8.3	.4	2.3	.7	.1	8.9
Iron (aluminum) (Fe) (Al)	.6	.1	1.2	.1	......	Tr.	1.0	......	......	.1	......
Sulphate (SO_4)	4	4.2	5.2	5.5	271	Tr.	7.2	4.8	0	.5	4.6
Chloride (Cl)	2.1	2.2	3.8	4	1,483	944	92	36.4	27.1	6.7	45.2
Bromide (Br)	......	......	......	......	......	Tr.	Tr.	......	Tr.	Tr.	.1
Nitrate (NO_3)	.7	.4	.6	.4	......	......	......	......	......	......	......
Bicarbonate (HCO_3)	40	39	40.4	40.1	(a)	1,115	872	(a)	19.8	38.1	......
Carbonate (CO_3)	0	0	0	0	303	41	54	8.8	3.1	4.7	.1
Silica (SiO_2)	28	27	......	......	40	36	32	......	......	......	......
Total solids	72.2	69.8	100	100	3,449	2,655	1,051	100	100	100	100

a Condition in solution unknown. CO_3 estimated in residue.

1. Peedee River at Peedee, N. C. Average of 10 analyses made at U. S. Geological Survey in 1908.
2. Wateree River at Camden, S. C. Average of 15 analyses made at U. S. Geological Survey in 1908.
3. Artesian well at Chisholm's mill, Charleston, S. C. Depth, 425 feet. Analyzed in 1879 by William Robertson.
4. Old artesian well at corner Meeting and Wentworth streets, Charleston, S. C.; 1,260 feet deep. Analyzed in 1912 by Chase Palmer.
5. New artesian well at Charleston Consolidated Railway & Lighting Co.'s station, Charleston, S. C.; 2,007 feet deep. Sunk in 1911. Analyzed in 1912 by Chase Palmer.
6. Ocean water. Values obtained from average results of 77 analyses of sea water given in *Challenger* report. The average concentration of sea water is 35,000 parts per million.

TABLE 2.—*Reaction properties of Piedmont surface waters, of waters of artesian wells, and of ocean water.*

	1	2	3	4	5	6
Primary salinity	19	20	82	57	14	78.6
Secondary salinity	0	0	0	0	0	21.1
Primary alkalinity	25	23	12	40	85	0
Secondary alkalinity	56	57	6	3	1	.3
	100	100	100	100	100	100.0

Aside from such observations as these there is little to be gained by considering the amounts of the constituents found in a water, but in the formulas derived from the reacting values of the constituents the relative reaction capacities of all the constituents can be seen at a glance. For instance, the relative reaction capacity of the alkalies and alkaline earths in surface waters flowing in areas of crystalline rocks is illustrated in column 1a. The sum of the reacting values of the alkalies (Na, K) is 22.1 and the sum of the reacting values of the alkaline earths (Ca, Mg) is 26.7. Thus the aggregate values of the alkaline earths exceed the aggregate values of the alkalies by 4.6 per cent, although the alkaline earths weigh less than the alkalies (column 1). Again, the combined weights of the sulphates and chlorides (column 1) is exactly equal to the weight of calcium (6.1), yet their capacity of neutralizing calcium is notably deficient because the sum of the reacting values of chlorides and sulphates (column 1a) is 9 and the reacting value of calcium is 18.

In general, calcium and magnesium are potent factors of quality in surface streams, and their importance in this respect is due largely to their relatively high reaction capacities, which must be considered if the full chemical value of these two constituents is to be appreciated. Unfortunately, writers on the geochemistry of waters have fixed their attention on the absolute weights of the dissolved constituents, so that they have failed to observe important facts concerning the chemical character of waters, especially facts relating to geology. Too much stress can not be laid on the consideration of the reaction capacity of every constituent that contributes to the quality or character of the water solution, for it is by their measurable qualities that solutions as well as other homogeneous substances are characterized. It is surprising that, in their attempts to characterize and classify waters, hydrologists have failed to apply this basic principle of chemical science.

The summaries of reaction properties of the three artesian waters (Table 2) show remarkable regularity in the variations in the proportions of all their properties. They are all primary alkaline solutions and hence are referable to a common origin, namely, the Piedmont Plateau, whose surface streams are uniformly characterized by primary alkalinity. Again, the progressive decline in the proportion of salinity (from 82 per cent to 14 per cent) among the properties of these waters in connection with constantly increased dilution of the solutions suggests at once that at increasing distances from the surface these waters are less and less affected by still stronger saline solutions found in the Coastal Plain.

The formulas of these three artesian waters (Table 1) present a picture showing in detail the differences in the relative values of all the constituents. The preponderance of sodium in these underground waters as compared with its value in the Piedmont Plateau surface waters is noteworthy. The low values of calcium and magnesium are no less striking than the changes that appear in their relative prominence. In the water of the 425-foot well magnesium exceeds calcium. This relation is not known to exist in any of the surface waters of the Piedmont Plateau from Virginia to Georgia or in the Coastal Plain river waters entering the eastern Gulf of Mexico. In all these river waters calcium exceeds magnesium by a wide margin.[1]

The excess of magnesium over calcium in the water of the 425-foot well, taken in connection with the high proportional values of chlorides and sulphates, points directly to the presence of ocean water (column 6), in which the relations of all these constituents are similar. Although magnesium does not prevail over calcium in the waters at the two lower levels, nevertheless in the waters of the 1,260-foot and 2,007-foot wells traces of bromides have been found. Additional evidence is thus presented that water of marine origin has been retained in minimal amounts even by these deep-seated landward waters. The beds in which these waters occur were deposited in sea water, and doubtless sea water was entrapped in the rocks. In consideration of the restricted circulation underground it does not seem unreasonable to conclude that even at 1,260-foot and 2,007-foot levels mixtures of fossil primary alkaline waters with fossil sea water—that is, water of the secondary saline type—may be found.

The water of the 2,007-foot well as it emerges at the surface contains a slimy precipitate the composition of which is shown in the following analysis:

Analysis of slime from water of a well 2,007 feet deep at Charleston, S. C.

[Analysis reported Sept. 3, 1912.]

SiO_2	55.79
Al_2O_3	23.80
Fe_2O_3	4.50
FeO	1.41
CaO	2.43
MgO	1.87
K_2O	2.45
Na_2O	1.18
MnO	.02
H_2O	6.50
	99.95

Slimes of this kind are said to be present in the waters of newly drilled deep wells in this vicinity. After the waters have flowed for longer or shorter periods they gradually clarify.

The consideration of fossil waters has hitherto been restricted to solutions of the secondary saline type. A brine obtained from a well more than 5,000 feet deep in West Virginia has recently been examined by the writer. This is evidently a fossil water, a relic of a Devonian sea. Its secondary salinity represents 45 per cent of its properties, a proportion of secondary salinity more than twice as high as that of modern sea water.

It is just as reasonable to suppose that waters of the primary alkaline type are capable of fossilization as it is to suppose that secondary saline waters are fossil.

[1] U. S. Geol. Survey Bull. 479, Tables 2 and 3, 1911.

THE STRATIGRAPHY OF THE MONTANA GROUP, WITH SPECIAL REFERENCE TO THE POSITION AND AGE OF THE JUDITH RIVER FORMATION IN NORTH-CENTRAL MONTANA.

By C. F. Bowen.

INTRODUCTION.

The differences of opinion which have arisen regarding the stratigraphic position and age of the Judith River formation led the writer to undertake a study of the Montana group in order to determine, if possible, the stratigraphic relation of this formation. Stanton and Hatcher had previously announced that the Judith River formation is of Cretaceous age. Although at first this conclusion was generally accepted, doubt has since arisen as to its correctness. The investigations of the writer were therefore begun in an area where the formations are well exposed and where the stratigraphic succession can be established beyond doubt. From this area the formations were traced northward to Missouri River in the type locality of the Judith River formation. This study has demonstrated the correctness of Stanton and Hatcher's views and forms the basis of the present paper.

The area here discussed lies east of the Big Snowy and Judith mountains and extends from Musselshell, on Musselshell River, to Judith, on Missouri River, Mont. The geographic location of the area is shown by the key map on Plate X.

The investigation, which was of a reconnaissance character, was undertaken to ascertain the coal resources of this area and to make a special study of the stratigraphy of the formations of Montana age which are exposed in this part of the State. In this work the writer was assisted by Harvey Bassler, T. K. Harnsberger, and J. R. Jaquet. The economic results of the investigation have already been published.[1]

In the preparation of this paper the writer has made free use of all previously published information, for which credit is given in the proper places. He is especially indebted to Messrs. C. W. Gilmore, J. W. Gidley, O. P. Hay, F. H. Knowlton, and T. W. Stanton for assistance rendered in the preparation and arrangement of the paleontologic data. Inasmuch as the writer is not a paleontologist, it is proper to state here that the remarks regarding the synonymy and the validity of the determination of certain of the species of vertebrates have been extracted largely from the writings of E. D. Cope, J. B. Hatcher, O. P. Hay, L. M. Lambe, R. S. Lull, and H. F. Osborn and have been approved by C. W. Gilmore.

PREVIOUS WORK.

Since 1853, when Hayden did his first work on the upper part of Missouri River, many observers have contributed to the discussion of the stratigraphic position of the Judith River and underlying formations. Most of these early observers, including Hayden, Meek, Cope, C. A. White, and Peale, studied the section along Missouri River but did not attempt detailed mapping of the individual formations. In recent years more detailed work has been done in this and adjacent areas by Stanton and Hatcher,[2] Calvert,[3] and Lupton.[4]

[1] Bowen, C. F., Coal discovered in a reconnaissance survey between Musselshell and Judith, Montana: U. S. Geol. Survey Bull. 541, pp. 329-337, 1914.
[2] Stanton, T. W., and Hatcher, J. B., Geology and paleontology of the Judith River beds: U. S. Geol. Survey Bull. 257, 1905.
[3] Calvert, W. R., Geology of the Lewistown coal field, Montana: U. S. Geol. Survey Bull. 390, 1909.
[4] Lupton, C. T., The eastern part of the Bull Mountain coal field, Montana: U. S. Geol. Survey Bull. 431, pp. 163-189, 1911.

BASE MAP AND FIELD METHOD.

The United States Geological Survey is preparing a map of the United States for publication on a scale of about 16 miles to the inch. Part of this map was enlarged to a scale of 4 miles to the inch and used as the base for the geologic map (Pl. X). The land lines and the drainage on this map are fairly accurate. The slight discrepancies which occur are so small that they do not appreciably affect the accuracy of the map on the scale on which it is here published, and therefore no adjustments were made.

Horizontal control for the geologic mapping was based on township surveys of the General Land Office. A main stadia traverse tied to land corners, generally not less than once in each township, was carried throughout the area, this part of the work being done with a Johnson plane table and a Gale telescopic alidade. Side lines, tied to the main traverse and to land corners, were made by horse pacing and by triangulation, with a 15-inch plane table and an open-sight alidade. By these methods the structure was platted and the boundaries of the formations were mapped. On the map thus prepared (Pl. X) the portions of the boundaries that were located with considerable accuracy are represented by solid lines and the portions that were located only approximately are represented by broken lines.

STRATIGRAPHY.

GENERAL SECTION.

The formations represented in the area here considered are the Colorado shale, Eagle sandstone, Claggett formation, Judith River formation, and Bearpaw shale, of Upper Cretaceous age, and the Lance formation, of Tertiary (?) age. The geologic age and stratigraphic relations of the Eagle, Claggett, Judith River, and Bearpaw formations in north-central Montana were worked out by Stanton and Hatcher[1] in 1903, but Peale[2] in a recent article dissents from the conclusions they reached. The sequence, thickness, and characteristics of these formations, as determined by the studies of the writer in this field, are shown in the following generalized section:

Generalized section of the sedimentary rocks in the area between Judith and Musselshell, Mont.

System and series.	Group.	Formation.	Characteristics.	Thickness (feet).
Tertiary(?), Eocene(?).		Lance formation.	Alternating gray sandstone and clay shale, with thin beds of coal near the top.[a]	700–800
Cretaceous (Upper Cretaceous).	Montana.	Bearpaw shale.	Marine shale, dark gray to black in upper part but with greenish tinge in lower part in southern portion of the field; contains numerous calcareous concretions which yield *Baculites ovatus*, *Baculites compressus*, *Scaphites nodosus*, *Inoceramus barabini*, and other species characteristic of the Pierre shale.	1,100±
		Judith River formation.	Alternating beds of sandstone, clay, and shale, including carbonaceous members, mainly of brackish or fresh water origin. In the northern part of the area a more or less persistent coal bed occurs near the top of the formation and is in most places overlain by a bed of marl or breccia, containing great numbers of *Ostrea subtrigonalis*. The formation also contains bones of vertebrates, fragments of leaves and stems, and much silicified wood.	250–500
		Claggett formation.	An upper division consisting of alternating beds of sandstone and shale, becoming predominantly sandstone at top. Marine fossils occur in these sandstones along Missouri and Judith rivers but have not yet been found in the southern part of the area. The common forms are *Tancredia americana*, *Cardium speciosum*, *Mactra formosa*, *Mactra alta*, and other species formerly considered as characteristic of the Fox Hills sandstone.	200±
			A lower division of dark marine shale which can not be easily distinguished lithologically or paleontologically from the Bearpaw shale. The most common fossils are *Baculites ovatus*, *Baculites compressus*, *Gervillia borealis*, *Inoceramus barabini*, and *Leda evansi*—species characteristic of the Pierre shale.	500±

[a] Lupton, C. T., The eastern part of the Bull Mountain coal field, Montana: U. S. Geol. Survey Bull. 431, pp. 169–170, 1911.

[1] Op. cit., p. 63.

[2] Peale, A. C., On the stratigraphic position and age of the Judith River formation: Jour. Geology, vol. 20, pp. 530–549, 640–652, 738–757, 1912.

Generalized section of the sedimentary rocks in the area between Judith and Musselshell, Mont.—Continued.

System and series.	Group.	Formation.	Characteristics.	Thickness (feet).
Cretaceous (Upper Cretaceous)—Continued.	Montana—Continued.	Eagle sandstone.	In the northern part of the field the upper member of the Eagle sandstone consists of thin-bedded sandstone with some interbedded shale, and the middle member consists principally of dark-colored shale in which there are a few thin beds of carbonaceous shale, coal, and sandstone. In the southern part of the field the middle member consists of thin-bedded shaly sandstone and contains no coal or carbonaceous beds.	100–180
			Virgelle sandstone member, a massive to heavy bedded sandstone which is highly cross-bedded in some places. In the northern part of the field it is prevailingly of a white color and contains numerous small rusty concretions. In the southern part of the field the color is gray to light brown. It forms conspicuous ledges or hogback ridges wherever exposed.	100–120
		Colorado shale.	In its upper part the Colorado is a black marine shale, alternating with thin beds of sandy shale and sandstone. At one locality examined a calcareous fossiliferous sandstone occurs in the upper part of the formation. The lower part of the formation was not studied. Baculites sp., *Dosinia orbiculata, Gyrodes conradi, Inoceramus deformis, Inoceramus labiatus, Scaphites ventricosus*, and other forms were obtained from this formation.	Not measured.

CRETACEOUS SYSTEM.

COLORADO SHALE.

Position and character.—Conformably beneath the Montana group lies black laminated shale in which are thin beds of arenaceous material. The shale at several localities has yielded fossils which T. W. Stanton has pronounced of Colorado age.

Distribution and topographic expression.—The Colorado shale is somewhat widely distributed to the west and south of the area mapped, where it is exposed around the anticline of the Big Snowy Mountains. From Willow Creek, in the southern part of this field, to the North Moccasin Mountains the shale is well exposed immediately beneath the Montana group, and at two localities it occurs as an inlier, brought up by subordinate folds, within the area occupied by the younger rocks. Because of its slightly resistant character the shale is easily eroded and occupies valleys bordered by the more resistant beds of overlying sandstone.

Relation to overlying formations.—The Colorado shale lies conformably beneath the Eagle sandstone and is separated from the typical sandstone by a transitional zone of sandy shale. The boundary between the two formations was drawn at the top of the transitional zone, because this horizon marks the most abrupt lithologic change and is most easily recognized in the field.

EAGLE SANDSTONE.

Definition.—The name Eagle sandstone was given by Weed[1] to the formation overlying the Colorado shale in north-central Montana and typically exposed on Missouri River at the mouth of Eagle Creek, 40 miles below Fort Benton. In the type locality the formation as defined by Weed consists of three more or less distinct units, comprising an upper member of thin-bedded sandstone, a middle member of shale, and a lower member of massive ledge-making sandstone. This lower member is so persistent and characteristic over a large area in north-central Montana, even where the other divisions of the formation are not recognizable, that it seems desirable for purposes of description and correlation to give it a name. It is well exposed along Missouri River from the town of Virgelle, a few miles below Fort Benton, eastward, and the name Virgelle sandstone member of the Eagle sandstone has therefore been adopted by the United States Geological Survey for this division of the formation. The Virgelle sandstone member is the lower massive ledge-making sandstone of the Eagle sandstone as defined by Weed.

According to Stanton and Hatcher, the Eagle sandstone constitutes the lowest formation of the Montana group, and the fossils collected from it by the writer have been determined by Mr. Stanton to be of Montana age.

[1] Weed, W. H., U. S. Geol. Survey Geol. Atlas, Fort Benton folio (No. 55), 1899.

Character and thickness.—In the southern part of the field the Virgelle sandstone member of the Eagle consists of a dull-gray to brownish massive, ledge-making sandstone about 100 feet thick; the middle division of the Eagle is a thin-bedded shaly sandstone; and the upper division is a thick-bedded, resistant sandstone in which large rusty-brown concretions are locally very numerous. As the formation is traced northward a change in the lithologic character may be noted about 12 miles east of Black Butte, where carbonaceous beds and thin streaks of coal begin to appear in the middle division of the formation. From Black Butte westward thin beds of carbonaceous shale and coal occur in this part of the formation at several places, and near Deerfield (about 8 miles southwest of the area mapped on Pl. X) coal is being mined from a bed which, according to descriptions given by residents, overlies the Virgelle sandstone member. On Missouri River the formation shows still further changes in lithology; the Virgelle sandstone member is glistening white to dull white in color, the middle division of the formation has changed to dark shale containing several thin beds of coal, and the upper division consists of thin-bedded sandstone and sandy shale.

The total thickness of the Eagle sandstone ranges from 200 feet in the southern part of the field to 250 or 300 feet on Missouri River.

Distribution and topographic expression.—The Eagle sandstone occupies a narrow belt overlying the Colorado shale from Willow Creek to the North Moccasin Mountains. West of these mountains (beyond the area mapped) it is more widespread, because of the decrease in the dip of the beds. The formation is also exposed at several places on Judith and Missouri rivers north of Fullerton. In these places it has been brought up by faulting.

From Willow Creek north to Boxelder Creek the Eagle sandstone forms ledges 25 to 100 feet high. Throughout the rest of the area the beds are inclined at angles of 20° to 70° and the formation produces narrow ridges with sandstone ribs along their crests. A characteristic topographic feature of the Eagle is a double ridge, formed by the sandstones of the upper and lower divisions of the formation, separated by a shallow depression that is occupied by the more easily eroded beds of the middle division.

Because of its ledge-making habit, the Eagle sandstone is well exposed and easily traced throughout the area, except on the north side of the Judith and North Moccasin mountains, where it is partly obscured by gravel washed down from the mountains.

Relation to Claggett formation and correlation.—The Eagle is conformable with the overlying Claggett formation, from which it is distinguished by its lithologic character. The correlation of the Eagle on Missouri River with that mapped from the North Moccasin Mountains to the south side of the field is rendered certain because of its stratigraphic position, between the Colorado shale below and the shale of the Claggett formation above.

CLAGGETT FORMATION.

The name Claggett was given by Stanton and Hatcher[1] to the formation overlying the Eagle sandstone because the formation is well exposed in the neighborhood of Judith (old Fort Claggett), on Missouri River, which therefore becomes the type locality. As originally defined, the Claggett is separable into two divisions—a lower one of shale and an upper one consisting predominantly of sandstone. This definition will be followed in the present paper, though the writer believes that the upper division belongs more naturally to the Judith River formation.

Character and thickness.—The lower division of the Claggett consists of dark marine shale similar both lithologically and paleontologically to the Bearpaw shale, which will be described later. It is about 750 feet thick in the southern part of the field, as determined by stadia measurement. Just north of Fullerton, on Judith River, an aneroid measurement gave a thickness of about 500 feet, and at this locality the upper division is about 120 feet thick.

The upper division consists of alternating beds of sandstone and shale, becoming predominantly sandstone in the upper part. At the top there is a bed of massive rusty-brown sandstone ranging from 1 foot to 20 feet in thickness. These beds were included in the Claggett by Stanton and Hatcher because they contain a marine fauna.

[1] Stanton, T. W., and Hatcher, J. B., Geology and paleontology of the Judith River beds: U. S. Geol. Survey Bull. 257, p. 13, 1905.

The dark shale constituting the lower division of the Claggett contains *Baculites ovatus*, *Baculites compressus*, *Inoceramus barabini*, *Leda evansi*, and other forms characteristic of the Pierre shale, most of which also occur in the Bearpaw shale. At the type locality of the Claggett its upper division contains *Cardium speciosum*, *Mactra alta*, *Mactra formosa*, *Tancredia americana*, and some other forms, all marine types, many of which occur in the Fox Hills sandstone. This fauna led the earlier geologists to assign the beds to the Fox Hills.

Distribution and topographic expression.—The surface distribution of the Claggett is shown on the accompanying map (Pl. X). Along the southern margin of the field and also along the north side nearly as far west as Black Butte the outcrop of the formation is very narrow, because the dip of the beds is steep. West of Black Butte the dip gradually decreases and the width of outcrop increases, so that north of the North Moccasin Mountains the formation is very widespread. Its western boundary was not mapped in this part of the field, but a complete section of the formation is exposed in the valley of Judith River between a point a few miles north of Deerfield and Missouri River.

The soft shale of the lower division of the Claggett is easily eroded and generally occupies a depression between the ridges formed by the underlying Eagle sandstone and the overlying sandstone of the upper division of the Claggett and the Judith River. The formation is in general well exposed throughout the area described, but along the north side of the Judith and North Moccasin mountains the exposures are not so good, the formation being covered in places by gravel washed down from the mountains. There is also a narrow gap in the outcrop north of Boxelder Creek, where the Claggett has been eroded from the axis of the Cat Creek anticline.

The lower division of the Claggett is easily recognized and traced in the field, because of its lithologic character and its effect on the topography. The upper division is less readily recognized and traced, because of its resemblance to the Judith River formation, which it immediately underlies, but north of the North Moccasin Mountains it is very prominent in the upper part of the bluffs of the Judith River valley and is identified by the marine fossils which it contains. East of the North Moccasin Mountains no fossils were found in this division of the formation, but it was recognized in many places, notably south of Flat Willow Creek, by its rusty-brown color and its resistance to erosion, because of which it forms a cap protecting the underlying softer rocks.

Relation to other formations.—The gradual transition from the marine Claggett to the overlying fresh-water Judith River formation is adequately expressed by the following quotation from Stanton and Hatcher.[1] Describing the exposures on Dog Creek, they say:

For considerable distances the Judith River beds are nearly or quite horizontal and conformably overlie the Claggett formation in such a manner that it is difficult to determine where one formation ends and the other begins, although in the field a bed of yellowish-brown sandstone varying in thickness from 1 foot to 20 feet or more was regarded as the upper limit of the Claggett formation. * * * From the persistence of this sandstone and from the fact that it marked the beginning of a decided change in the lithology of the underlying and overlying beds, it would certainly form a convenient delimitation between the two series of deposits and should perhaps be considered as the uppermost member of the Claggett formation, notwithstanding that in a number of instances typically marine fossils extended for some distance above in the basal members of those lighter-colored sandstones and shales usually referred to the Judith River beds and generally considered as entirely of fresh or brackish water origin.

Cope's observations also agree with those of Stanton and Hatcher. He says:[2]

From what has preceded the general conclusion is reached that the series of beds from the lowest of the Fort Pierre epoch to the summit of the Judith River is continuous and uninterrupted by any nonconformity or hiatus. They appear to have been deposited in regular sequence, and without any other disturbance than that oscillation of the bed of the sea which causes change in the character of the sediment.

On the other hand, Peale[3] says that there is a suggestion of an unconformity between the upper division of the Claggett (called Fox Hills by him) and the Judith River beds in the valley of Judith River below Fullerton.

[1] Stanton, T. W., and Hatcher, J. B., op. cit., p. 36.

[2] Cope, E. D., Report on the geology of the region of the Judith River, Montana, and on vertebrate fossils obtained on or near the Missouri River: U. S. Geol. and Geog. Survey Terr. Bull. 3, p. 574, 1877.

[3] Peale, A. C., On the stratigraphic position and age of the Judith River formation: Jour. Geology, vol. 20, p. 543, 1912.

The writer's observations agree with those of Stanton and Hatcher and those of Cope. He was unable to detect any evidence of unconformity either between the Claggett and Judith River formations or at any other horizon in the section from the Colorado shale up to and including the Lance formation. He is of the opinion, however, that the upper division of the Claggett more properly belongs with the Judith River formation. Stanton and Hatcher included this upper division in the Claggett formation because it contains a marine fauna, but the preceding quotation from them shows that there is no sharp line of demarkation either in lithology or paleontology between it and the overlying fresh-water beds. On the other hand, there is a rather marked lithologic change between the upper and lower divisions of the Claggett. Furthermore, in the southern part of this field no marine fossils have been found in the upper division of the Claggett formation, and therefore the distinction between Claggett and Judith River as at present defined is even less marked here than on Missouri River. In fact, in the southern part of the field it is not practicable to separate the sandstone that has been included in the Claggett formation from the Judith River formation. Similarly, 35 miles northwest of the mouth of Judith River, in the Big Sandy coal field, where the same formations are involved, no marine fossils occur in the sandstone immediately overlying the shale of the Claggett formation. Instead of containing marine fossils the sandstones, which there seem to be the equivalent of the upper division of the Claggett at the mouth of Judith River, contain carbonaceous beds and fresh or brackish water shells and are, therefore, of fresh or brackish water origin. Inasmuch as the occurrence of marine fossils in the upper division of the Claggett seems to be a local phenomenon, inasmuch as these marine fossils are not limited strictly to the Claggett as now defined but in some places extend up into the overlying Judith River formation, and inasmuch as the most striking lithologic change in the beds is at the base of the upper division of the Claggett, it seems to the writer that this is the most logical horizon to designate as the boundary between the Claggett and Judith River formations. It also constitutes a horizon that may be readily recognized in the field because of the striking difference between the dark fossiliferous marine shale and the overlying lighter-colored sandstone. It is true, however, that these marine strata were excluded from the Judith River formation in all the early descriptions of the type area, and this fact doubtless influenced Stanton and Hatcher in fixing the upper boundary of the Claggett formation when they described it in the same area.

Prior to the work of Stanton and Hatcher the upper division of the Claggett was called Fox Hills, and that assignment has recently been reiterated by Peale.[1] This correlation is based on the fact that many of the fossils occurring in the upper division of the Claggett at the mouth of Judith River are identical with those that occur elsewhere in the typical Fox Hills. The relations of this fauna are discussed more fully in the paleontologic part of this paper (pp. 114–115), and it will suffice here to point out that this so-called Fox Hills sandstone has been traced by means of its fauna from Missouri River southward as far as the North Moccasin Mountains and has been recognized by its color and lithology at other places as far south as Flat Willow Creek and that it is positively known to be overlain at these places by the Judith River formation and a marine shale (the Bearpaw) which has a Pierre fauna. The sandstone therefore does not occupy the stratigraphic position of the Fox Hills sandstone at the type locality.

JUDITH RIVER FORMATION.

The Judith River formation is chiefly of fresh or brackish water origin and lies between two marine shales. The formation was named by Hayden in 1871,[2] but at that time its stratigraphic position was not understood. In 1903 Stanton and Hatcher [3] determined that the formation is a member of the Montana group and is the time equivalent of a part of the Pierre shale.

Character and thickness.—The Judith River formation consists of alternating beds of light-colored sandstone and clay, in which occur thin beds of carbonaceous shale. In the northern

[1] Peale, A. C., On the stratigraphic position and age of the Judith River formation: Jour. Geology, vol. 20, pp. 755–756, 1912.
[2] Hayden, F. V., Geology of the Missouri Valley: U. S. Geol. Survey Terr. [Fourth Ann.] Prel. Rept., p. 97, 1871.
[3] Op. cit., p. 257.

part of the area the formation contains some coal but is not known to be coal bearing east of Armells Creek. It yields fresh and brackish water invertebrates and locally some of marine origin. At many places there is near the top of the formation a bed ranging from less than 1 foot to several feet in thickness that is made up almost wholly of shells of *Ostrea subtrigonalis* and is therefore called the Ostrea marl or breccia. The formation also contains bones of vertebrates, much silicified wood, and stems and fragments of plants, though well-preserved leaves are exceedingly rare.

The thickness of the formation on Willow Creek in the southern part of the area, as determined by stadia measurements, is 250 to 275 feet. It seems gradually to thicken northward, and in the northern part of the area it is about 500 feet thick.

Distribution and topographic expression.—The surface distribution of the Judith River formation from the south side of the field to T. 20 N. is shown on the accompanying map (Pl. X). North of T. 20 N. its upper boundary was not mapped. The variations in the width of the outcrop of the formation coincide in a general way with those of the underlying Claggett formation.

Where the beds are nearly flat-lying, as in the areas south of Flat Willow Creek and northwest of Roy, the Judith River weathers into badland forms, but where the beds dip steeply the formation gives rise to narrow ridges with sandstone ribs along their crests, very similar to the ridges formed by the Eagle sandstone. The Judith River is well exposed and its outcrop is easily traced because of its position between the shaly Claggett and the Bearpaw shale, both of which occupy low ground. The formation was traced from the southern border of the field northward nearly to Boxelder Creek, where it passes beyond the eastern limit of the area mapped. It reenters the area in T. 15 N., R. 29 E. There is no doubt that if followed farther east the formation could be traced continuously around this gap[1] and that all the formations exposed south of Boxelder Creek could be connected directly with those on the north border of the field. The sequence, character, and fauna of the formations are identical in these two areas. From T. 15 N., R. 29 E., the Judith River formation was traced continuously to the mouth of Judith River and was there found to be identical with the Judith River formation of Hayden, this locality being in the western part of his original area. As far west as Roy the formation, because of its highly inclined attitude, makes a hogback ridge and may be traced almost as readily as a turnpike. West of Roy it is well exposed along the main drainage lines, such as Boxelder Creek, Armells Creek, and Dog Creek, though it is commonly not well exposed on the divides. West of Dog Creek the exposures are continuous along the east side of the valley of Judith River and its tributaries from the North Moccasin Mountains north to Judith. The tracing of the formation across the field is therefore rendered very certain.

As the possibility of mistaken identification of formations in the faulted area north of Fullerton may be urged and doubt therefore cast on the above statements, it may be well to point out again that the correlations in this part of the field do not rest on the tracing of the Judith River formation alone, but that the underlying Claggett formation, composed of two distinct members (the Pierre and Fox Hills of Peale and many of the earlier geologists), each containing a characteristic fauna, can be traced with equal certainty. (See quotation from Peale, p. 111.) On page 104 it is stated that the maximum displacement due to the faults north of Fullerton is probably about 650 feet, and that therefore the key rocks—the two members of the Claggett formation—are in no place lost to sight. In view of these conditions it seems to the writer that no valid objection can be raised as to the correlation of the formations across this faulted zone.

Relation to other formations.—The relation of the Judith River to the Claggett is considered on pages 99–100. The formation lies beneath the Bearpaw shale, with which it shows conformable relations throughout this field. The evidences of the stratigraphic position and age of the Judith River formation are considered more in detail in another part of this paper.

[1] Since this paper was prepared the writer has traced the Judith River formation around this gap and has thus positively proved its continuity throughout this field.

BEARPAW SHALE.

The Bearpaw shale overlies the Judith River formation and is equivalent to the upper part of the Pierre shale. The formation was named and its stratigraphic relations were determined by Stanton and Hatcher[1] in 1903.

Character and thickness.—The Bearpaw is a dark marine shale of the same lithologic character as the Claggett of this field and the Pierre shale of other localities. It contains numerous calcareous concretions from which *Baculites ovatus, Baculites compressus, Scaphites nodosus, Leda evansi,* and other fossils characteristic of the Pierre are obtained. The formation has a thickness of 1,150 feet south of Willow Creek, and this thickness seems to be fairly constant throughout the field so far as the entire formation was studied.

Distribution and topographic expression.—The Bearpaw has a similar distribution to that of the Judith River. The upper boundary of the formation was mapped as far west as R. 24 E., and the lower boundary to about the center of T. 20 N., R. 19 E.; at that point the outcrop bears off to the east, and a few miles beyond it becomes involved in extensive faults.

The Bearpaw weathers easily and its outcrop generally occupies a depression between the Judith River and Lance formations, but this feature becomes less distinctive as the width of the outcrop increases. The formation is well exposed throughout most of the area in which it was mapped, but, like the Judith River, the Bearpaw passes beyond the eastern margin of the field and therefore was not traced continuously throughout the area.

Relation to other formations.—The Bearpaw is similar in lithology and paleontology to the Pierre shale of other localities and to the shale of the Claggett formation in this field. Because of this similarity the Bearpaw and Claggett were confused by the early geologists who visited this region and both were called Pierre shale. The following differences have been observed between the Bearpaw and the Claggett: (1) The Bearpaw is much thicker, as shown by the table on page 96. (2) The Bearpaw is more fossiliferous and contains a more diversified fauna. (3) In many places in this field a bed consisting almost wholly of brackish-water shells, largely *Ostrea subtrigonalis,* lies immediately beneath the Bearpaw. In this field no shells of this kind are found immediately beneath the Claggett.

The similarity in the fauna of the Bearpaw and the shale of the Claggett is shown by the following list of fossils:

TABLE 1.—*Invertebrate fossils from the shale of the Claggett formation and the Bearpaw shale.*

NOTE.—Species marked "1" were collected by Stanton and Hatcher. Species marked "2" are those collected by the writer and his assistants in 1912 which are not included in Stanton's list.

	Claggett.	Bearpaw.		Claggett.	Bearpaw.
Acmæa occidentalis M. and H.	....	×[1]	Nucula cancellata M. and H.	×[1]	×[1]
Anchura americana (E. and S.)	....	×[1]	Nucula planimarginata M. and H.	....	×[1]
Anisomyon centrale Meek	....	×[1]	Nucula subplana? H. and M.	....	×
Anisomyon alveolus M. and H.	....	×[1]	Ostrea pellucida M. and H.	....	×[1]
Avicula linguiformis E. and S.	....	×[1]	Pecten nebrascensis M. and H.	....	×[1]
Avicula nebrascana E. and S.	×[2]	×[1]	Placenticeras intercalare M. and H.	....	×[1]
Baculites compressus Say	×[1]	×[1]	Placenticeras sp.	....	....
Baculites ovatus Say	×[1]	×[1]	Placenticeras whitfieldi Hyatt	×[1]	×[1]
Cinulia concinna M. and H.	....	×[1]	Protocardia rara E. and S.	....	×[1]
Cuspidaria ventricosa M. and H.	....	×[1]	Protocardia subquadrata E. and S.	....	×[2]
Haminea subcylindrica M. and H.	....	×[1]	Scaphites nodosus Owen	....	×[1]
Inoceramus barabini Morton	×[1]	×[1]	Scaphites subglobosus Whiteaves	....	×[1]
Inoceramus sagensis Owen	....	×[2]	Syncyclonema rigida M. and H.	....	×
Leda (Yoldia) evansi M. and H.	×[1]	×[1]	Thetis? circularis M. and H.	....	×[1]
Liopistha (Cymella) undata M. and H.	×[1]	×[1]	Trigonarca exigua.	....	×[1]
Lucina subundata H. and M.	....	×[1]	Vanikoro ambigua M. and H.	....	×[1]
Lunatia occidentalis M. and H.	×[1]	×[1]?	Gervillea borealis Whiteaves	×[1]	×[1]

An inspection of this table shows that all the species found in the shale of the Claggett formation are also represented in the Bearpaw, but that the fauna of the latter is more varied than that of the former. This coincides with the field observations that fossils are more numerous in the Bearpaw than in the Claggett.

[1] Op. cit., p. 13.

TERTIARY (?) SYSTEM.

LANCE FORMATION.

No detailed study was made of the Lance formation, though its lower boundary was traced nearly halfway across the area mapped. The following statement concerning it is taken from the report by C. T. Lupton on the eastern part of the Bull Mountain coal field,[1] which adjoins this area on the south:

It consists of 700 to 800 feet of yellowish-gray sandstone, clay of various colors, and grayish sandy shale. Sandy material predominates. The lower part is noticeably micaceous; the upper part contains thin beds of coal. Where the formation dips steeply it makes hogbacks with narrow valleys between, and where it is nearly level it makes a series of scarps. Few fossils have been found in this formation.

Two detailed sections were measured south of Willow Creek for the purpose of showing the transition from the Bearpaw to the Lance. One of these is given below.

Section of transitional beds between typical Bearpaw shale and typical Lance formation, T. 29 N., R. 9 E., Montana.

	Feet.
Typical Lance.	
Sandstone, buff to rusty, slightly cross-bedded	8
Shale, drab	6
Shale, sandy	4
Shale, carbonaceous; contains fragments of stems of plants	8
Sandstone, yellow, massive	20
Shale, with carbonaceous member near middle	10
Sandstone, white, friable	5
Shale, black, carbonaceous at top	8
Shale, drab	15
Sandstone, shaly, ferruginous	1
Shale, black	2
Sandstone, yellow to brown	4
Shale, drab	40
Shale, with intercalated shaly sandstone members	8
Shale, typical Bearpaw, drab, concretionary, containing Baculites and other forms.	
	139

STRUCTURE.

FOLDS AND DOMES.

The dominant structure in the eastern part of the area is a broad symmetrical fold—the Big Snowy anticline—on which are superimposed several smaller folds, thus producing the type of fold known as an anticlinorium. The axis of the Big Snowy anticline trends northwest and pitches to the southeast. Out on the plains the strata on opposite limbs of this fold dip at angles ranging from 20° to 70°. Toward the mountains the dips decrease in amount and from Black Butte westward along the north base of the Judith and Moccasin mountains they do not exceed 45° and the anticline loses its distinctive character.

The minor folds, consisting of the Devils Basin, Flat Willow, and Cat Creek anticlines with intervening synclines, are also open symmetrical folds whose axes pitch to the southeast and trend roughly northwest but are somewhat sinuous in outline. The dips on opposite limbs of these folds as a rule range from 2° to 6° and rarely exceed 10°.

A dome structure has been produced by the laccoliths which have given rise to Black Butte and the North Moccasin Mountains. So far as traced, the beds dip steeply away from these uplifts, except at the southeast side of Black Butte, where they dip steeply toward the butte, probably as the result of faulting.

Out on the plains north of the Judith and North Moccasin mountains the strata dip at a low angle to the north or northeast.

[1] U. S. Geol. Survey Bull. 431, p. 170, 1911.

FAULTS.

In this region faults are important structural features only in the area north of T. 20 N. Two minor faults on the north side of the Judith Mountains are shown on the map (Pl. X), and, as already pointed out, there is probably a small fault at the southeast side of Black Butte. Between Fullerton and Missouri River three prominent faults and some minor ones, striking a little west of north, cross the valley of Judith River. These faults all appear to be of the normal type. At the first and second faults north of Fullerton the beds dip steeply to the north near the fault plane but are nearly flat a short distance away. At the fault nearest Missouri River they dip to the south, and there is evidence of some minor faults, the details of which were not worked out. The northernmost fault exhibits the maximum throw observed, and at that place the white massive Virgelle sandstone member at the base of the Eagle is brought into juxtaposition with the sandstone beds constituting the upper part of the Claggett formation. If a thickness of 150 feet is allowed for that part of the Eagle above the white massive Virgelle sandstone and 500 feet for the lower or shaly portion of the Claggett, the throw of the fault would be about 650 feet.

Fault lines were seen also on the east side of Dog Creek, in T. 21 N., R. 19 E., where the structure seems more complicated than on Judith River. The maximum disturbance is probably shown along Missouri River between Armells Creek and Dog Creek. Speaking of this area Hayden[1] says:

> It presents perhaps the most rugged scenery on the Missouri River, the denudation and erosion having been much greater than at the badlands of White River. But the most remarkable feature of this basin is the wonderful disturbance of the strata. So much are the beds disturbed and blended together by forces acting from beneath that it seems almost hopeless to obtain a section showing with perfect accuracy the order of superposition of the different strata.

STRATIGRAPHIC POSITION AND AGE OF THE JUDITH RIVER FORMATION.

SCOPE OF DISCUSSION.

In the foregoing pages the discussion has been confined chiefly to the stratigraphy of the formations in the area represented by the shaded portion of the accompanying map (Pl. X). In presenting the evidence now at hand bearing on the position and age of the Judith River formation it is necessary to give a brief review of previous opinions as to the age of these beds and the stratigraphic succession in the type area of the Judith River formation, to correlate the formations in the type area with those in the area herein considered, and to present the paleontologic evidence as to the age of the Judith River and associated formations.

HISTORICAL SUMMARY.

The literature bearing on the stratigraphic position and age of the Judith River formation has been fully and carefully reviewed by Stanton and Hatcher.[2] For that reason only a brief synopsis, sufficient to give the reader an understanding of the various opinions held, is presented here.

NAME.

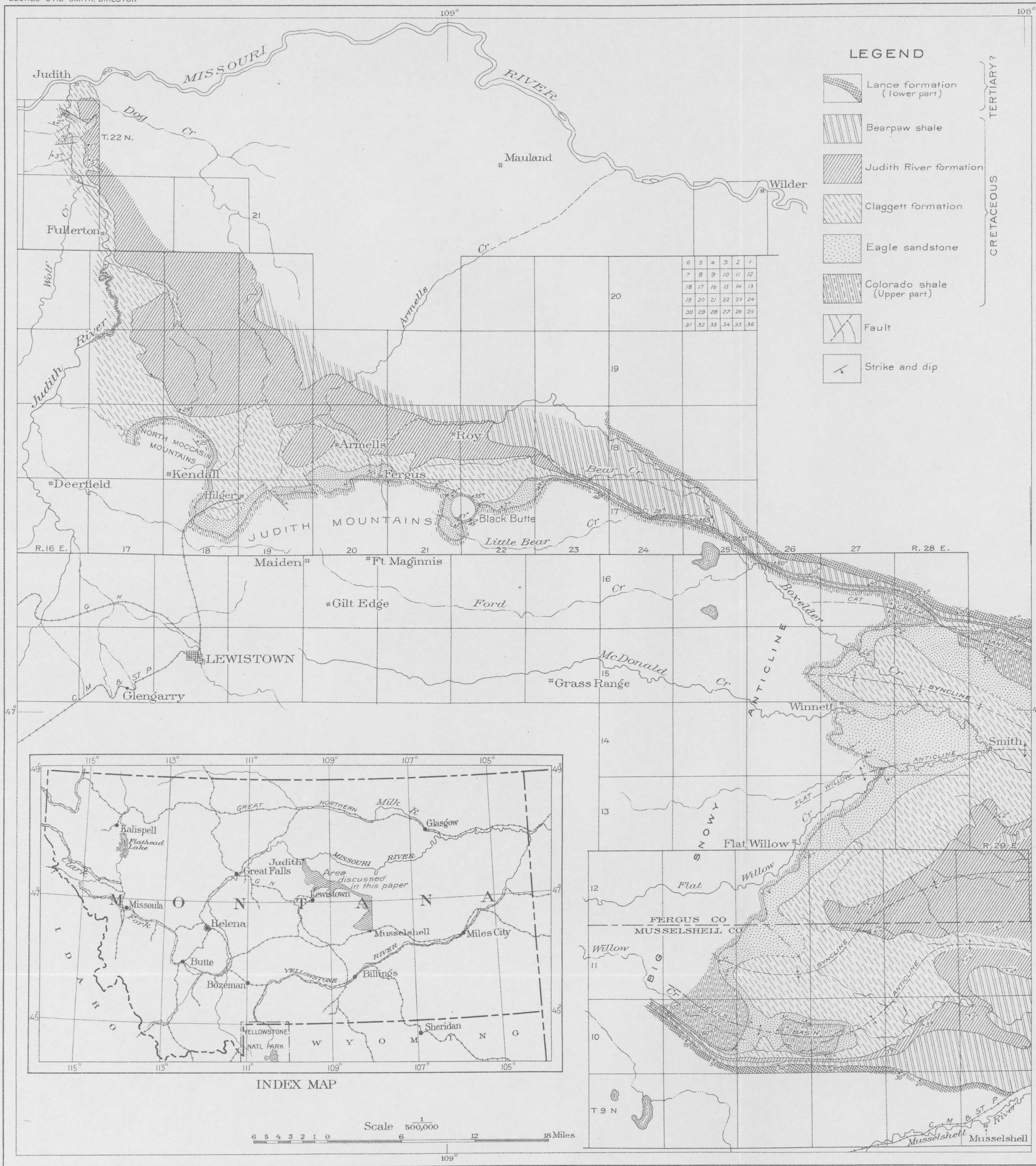
The name Judith River group was first given to this formation by Hayden[3] in 1871. After discussing the Fort Union "group," he says:

> There is another basin near the sources of the Missouri River which has already yielded many fossils of great interest but which seems to be isolated from the others. This is what I have called the Judith Basin, and inasmuch as it seems to be one of the ancient lake deposits, and characterized by a peculiar group of organic remains, I will designate the strata as the Judith group. The sediments do not differ materially from those of the Fort Union group and they contain impure beds of lignite, fresh-water Mollusca, and a few leaves of deciduous trees. But the most remarkable feature of

[1] Hayden, F. V., Notes explanatory of a map and section illustrating the geological structure of the country bordering on the Missouri River from the mouth of the Platte River to Fort Benton: Acad. Nat. Sci. Philadelphia Proc., vol. 9, pp. 115-117, 1857.

[2] Stanton, T. W., and Hatcher, J. B., op. cit., pp. 14-31.

[3] Hayden, F. V., Geology of the Missouri Valley: U. S. Geol. Survey Terr. [Fourth Ann.] Prel. Rept., p. 97, 1871.



GEOLOGIC MAP OF AREA EXAMINED, BETWEEN MUSSELSHELL AND JUDITH, MONTANA

By C. F. Bowen

this group is the number and variety of the curious reptilian remains, of which we have only yet caught a glimpse. There is probably no portion of the West that furnishes such a harvest of fossil remains and instructive geological facts as the country bordering the Missouri River from the mouth of the Yellowstone to the foot of the mountains above the Great Falls of the Missouri; and as this country is reserved for examination the coming season I will leave the obscurity which now invests it to be cleared in the next annual report.

Prior to that time the term Judith River beds had been used in a general way[1] to include all the formations exposed near the mouth of Judith River. Since the strata were named by Hayden the terms Judith River beds and Judith River formation have been used as synonymous with Hayden's term Judith River group, which has finally been supplanted by the term Judith River formation.

ORIGINAL AREA AND TYPE LOCALITY.

No exact locality was designated by Hayden as representing the type of this formation. It is evident, however, as the following quotation[2] will show, that the area in which his Judith River group occurs lies along Missouri River between Judith River on the west and the mouth of Musselshell River on the east.

Near the mouth of the Judith River, not far from the sources of the Missouri, in latitude 47° 30′, longitude 109° 30′, is a wild, desolate, and rugged region, which I have called the "Badlands of the Judith," in contradistinction to those of White River. * * *

The area occupied by this peculiar basin I could not determine with precision, but have estimated it at about 40 miles from east to west and from 15 to 30 from north to south, and it is separated into two nearly equal portions by the Missouri. The Judith River rises in the Judith Mountains, pursues a course nearly due north, for the most part through Cretaceous strata, and empties into the Missouri in latitude 48°, longitude 106° [about 110°]. The Judith River forms the north [western] boundary of this basin. The Muscle Shell River also rises near the Judith Mountains but takes a course a little east of north, flows through Cretaceous formation No. 4, and empties into the Missouri near latitude 47° 30′ and longitude 108°. That portion of the "Badlands" which is formed of the estuary deposit under consideration lies between these two streams.

PREVIOUS OPINIONS OF STRATIGRAPHIC POSITION AND AGE.

In 1856 Meek and Hayden[3] correlated the marine formation immediately underlying the Judith River formation at the mouth of Judith River with the base of the Cretaceous. This correlation was based on the lithologic similarity of this formation to formation No. 1 (Dakota) and on the fossil evidence, especially that of the vertebrates, as determined by Leidy. In another paper[4] in the same volume Meek and Hayden suggest that this marine sandstone probably represents the older members of the Cretaceous but that it may be as old as Jurassic. In 1857 Hayden[5] described and mapped the badlands of Judith River as occupying a Tertiary basin. Later in the same year Meek and Hayden,[6] on the basis of the invertebrate fauna, again assigned the Judith River formation to the Tertiary but said that the saurian and fish remains ally it to the Wealden. In 1858 Hayden,[7] after studying a fresh-water fauna at the base of the Cretaceous in the Black Hills region, assigned the Judith River to the Cretaceous, thus reversing his former opinion, and said that it may be the American representative of the Wealden. After a reexamination of the invertebrates of the Judith River formation and a comparison of these fossils with the forms from the Black Hills, Meek and Hayden referred the

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[1] Meek, F. B., and Hayden, F. V., Descriptions of new fossil species of Mollusca collected by Dr. F. V. Hayden in Nebraska Territory, together with a complete catalogue of all remains of Invertebrata hitherto described and identified from the Cretaceous and Tertiary formations of that region: Acad. Nat. Sci. Philadelphia Proc., vol. 8, pp. 265-286, 1856.

[2] Hayden, F. V., Geological sketch of the estuary and fresh-water deposit of the badlands of the Judith, with some remarks upon the surrounding formations: Am. Philos. Soc. Trans., new ser., vol. 11, p. 123, 1860.

[3] Meek, F. B., and Hayden, F. V., Some general remarks on the geology of the country about the sources of the Missouri River: Acad. Nat. Sci. Philadelphia Proc., vol. 8, p. 114, 1856.

[4] Acad. Nat. Sci. Philadelphia Proc., vol. 8, p. 267, 1856.

[5] Hayden, F. V., Notes explanatory of a map and section illustrating the geological structure of the country bordering on the Missouri River from the mouth of the Platte River to Fort Benton: Acad. Nat. Sci. Philadelphia Proc., vol. 9, pp. 109-116, map, 1857.

[6] Meek, F. B., and Hayden, F. V., Descriptions of new species and genera of fossils collected by Dr. F. V. Hayden in Nebraska Territory, under the direction of Lieut. G. K. Warren, U. S. Topographical Engineer: Idem, pp. 117-148.

[7] Hayden, F. V., Explanations of a second edition of a geological map of Nebraska and Kansas: Acad. Nat. Sci. Philadelphia Proc., vol. 10, pp. 139-158, map, 1858.

Judith River back to the Tertiary. Speaking of the fresh-water Jurassic of the Black Hills, they said:[1]

At the time we published these facts [concerning the fresh-water Jurassic of the Black Hills] we were led by the discovery here of fresh-water shells, in such a position, to think that some estuary deposits of doubtful age, near the mouth of Judith River, on the Missouri, from which Dr. Leidy had described some saurian remains resembling Wealden types, might be older than the Tertiary. Later examinations, however, have demonstrated that the Judith beds contain an entirely different group of fossils from those found in the rock under consideration, and that they are really of Tertiary age and hold a position at the base of the great lignite series of the Northwest.

In another paper published in the same year,[2] after classifying the Tertiary basins of the Northwest, Hayden referred the Judith River formation to the Tertiary, as follows:

The estuary deposits, of which the Judith basin may be regarded as the type, are quite remarkable and of a most interesting character. Opinions of a somewhat conflicting nature have been entertained in regard to them, owing to the peculiar character of the organic remains, but recent observations have convinced me that they are all of Tertiary age, and that they are quite widely distributed throughout the far West.

In 1875 both Meek [3] and Hayden [4] announced independently that the marine sandstone immediately underlying the Judith River formation near the mouth of Judith River had been definitely correlated with the Fox Hills, but in 1876, in his last writings on the subject, Meek [5] referred the Judith River to the Cretaceous, as follows:

We have long regarded the Judith River beds as forming a distinct group older than the Fort Union deposits. * * * That these older beds (the Judith River brackish and fresh water deposits and their equivalents elsewhere) are Cretaceous is certainly highly probable, as has been suggested by the author on former occasions; yet this can scarcely be properly regarded as an established fact.

In 1856 Leidy [6] published his first determinations of the vertebrate collection made by Hayden in the Judith River basin, and allied the vertebrates of the Judith River formation with those of the Wealden of Europe.

In 1860 Leidy [7] made the following statement:

The association of the remains of Trachodon, Deinodon, Crocodilus, and Lepidotus, corresponding with the association of the remains of the closely allied Iguanodon, Megalosaurus, Crocodilus, and Lepidotus of the Wealden formation of England, led the author to suspect the Judith River formation was of cotemporary age, though he was fully aware of the fact that totally dissimilar animals have occupied different portions of the earth at the same period.

In 1871 Cope [8] referred the Judith River fossils to the Upper Jurassic. In 1873 he placed the Judith River formation in the Cretaceous on the basis of the fossil remains,[9] and in the following year (1874) he assigned it to the top of the Cretaceous.[10] In 1877 he assigned the black shale "No. 4" (now called Claggett) to the Pierre, and the overlying marine sandstone, which marks the transition to the Judith River, to the Fox Hills sandstone.[11] He also said:[12] "The positive age of the Judith River fauna is Cretaceous, with some Tertiary affinities."

[1] Meek, F. B., and Hayden, F. V., Descriptions of new lower Silurian (Primordial), Jurassic, Cretaceous, and Tertiary fossils collected in Nebraska, by the exploring expedition under the command of Lieut. G. K. Warren, with some remarks on the rocks from which they were obtained: Acad. Nat. Sci. Philadelphia Proc., vol. 13, pp. 415–447, 1861.

[2] Hayden, F. V., Sketch of the geology of the country about the headwaters of the Missouri and Yellowstone rivers: Am. Jour. Sci., 2d ser., vol. 31, pp. 229–245, 1861.

[3] Meek, F. B., Note on some fossils from near the eastern base of the Rocky Mountains, west of Greeley and Evans, Colo., and others from about 200 miles farther eastward, with descriptions of a few new species: U. S. Geol. and Geog. Survey Terr. Bull., vol. 1, 2d ser., p. 39, 1875.

[4] Hayden, F. V., Notes on the lignitic group of eastern Colorado and portions of Wyoming: Idem, p. 403, 1876.

[5] Meek, F. B., A report on the invertebrate Cretaceous and Tertiary fossils of the upper Missouri country: U. S. Geol. Survey Terr. Repts., vol. 9, pp. xlvii, l, 1876.

[6] Leidy, Joseph, Notices of the remains of extinct reptiles and fishes discovered by Dr. F. V. Hayden in the badlands of the Judith River, Nebraska [Montana] Territory: Acad. Nat. Sci. Philadelphia Proc., vol. 8, pp. 72–73, 1856.

[7] Leidy, Joseph, Extinct Vertebrata from the Judith River and Great Lignite formations of Nebraska: Am. Philos. Soc. Trans., new ser., vol. 11, pp. 139–140, 1860.

[8] Cope, E. D., Extinct Batrachia, Reptilia, and Aves of North America: Am. Philos. Soc. Trans., new ser., vol. 14, pp. 1–252, 1871.

[9] Cope, E. D., Report on the vertebrate paleontology of Colorado: U. S. Geol. and Geog. Survey Terr. [Seventh] Ann. Rept. [for 1873], p. 434, 1874.

[10] Cope, E. D., Review of the Vertebrata of the Cretaceous period found west of the Mississippi River: U. S. Geol. and Geog. Survey Terr. Bull., vol. 1, 1st ser., No. 2, pp. 6–8, 1874.

[11] Cope, E. D., Report on the geology of the region of the Judith River, Montana, and on vertebrate fossils obtained on or near the Missouri River: U. S. Geol. and Geog. Survey Terr. Bull., vol. 3, pp. 565–598, plates 30–34, 1877.

[12] Idem. p. 576.

While this work was being carried on in the United States, G. M. Dawson was engaged in the study of the Belly River formation of Canada, which he correlated with the Judith River formation, as follows: [1]

Briefly stated, it would appear from the investigations now reported on that considerable areas of the beds which in 1874 I called "Lignite Tertiary"—here and in previous announcements designated as Belly River series—must be relegated to a position below the Pierre shales, or at least to one below an upper portion of these shales. The beds thus separated as the Belly River series were, in 1875, by me correlated with the Judith River series of the Missouri. Additional and extensive collections of fossils since obtained and now being worked out confirm and strengthen this correlation and lead to the presumption that the so-called Judith River series must also occupy a position well down in the undoubted Cretaceous. It may be added that this was the view originally held by Messrs. Meek and Hayden and supported, it would appear, not alone on the supposed analogies of the vertebrate remains examined for them by Prof. Leidy, but also on stratigraphic evidence—evidence which perfectly agrees with the impressions resulting from such cursory examination as I was able to make of the Missouri sections from the deck of a steamer while ascending the river in 1881.

In 1885 the invertebrate fossils of the Belly River were described by J. F. Whiteaves,[2] who commented on them as follows:

Judging by their respective invertebrate faunas, it would seem impracticable to separate the "Belly River series" from the Laramie, and more especially from the "Judith River group," on purely paleontological evidence.

The invertebrate fauna of the "Belly River series" seems to be essentially the same as that of the "Laramie" of the United States and Canada, unless more than one formation has been confounded under the latter name, and * * * it is at present scarcely possible to separate the "lower dark shales" of Dr. Dawson's Bow and Belly River report from the "Fort Pierre and Fox Hills" groups on purely paleontological grounds.

In 1902 Osborn [3] made the following statements:

The Survey had established beyond question, geologically, that the Belly River series is mid-Cretaceous, that it underlies the Montana or Fort Pierre-Fox Hills group and overlies the Fort Benton and Dakota groups. * * * It soon appeared to the writer in the study of the fine collection made by Mr. Lambe that the Belly River vertebrates of the Northwest Territory were of decidedly different and apparently of older type than those from the Laramie beds of Converse County, Wyo., described by Marsh, and were rather to be compared with those described by Leidy, Cope, and Marsh from Montana, chiefly from the Judith River beds, a region by no means distant geographically.

Thus the correlation between the Belly River and Judith River series, proposed by the late Director, Dr. G. M. Dawson, in 1875, at first glance appeared to be confirmed faunistically; but this correlation is not supported by the geological records, which all place the Judith River beds proper above the Fox Hills and Fort Pierre. * * *.

There is thus very little in common between the Belly River fauna and the Laramie fauna of Wyoming and Colorado so far as described, except the dinosaur Ornithomimus and the very persistent chelonian Baena. Most of the dinosaurs will probably be found to be separated generically.

On the other hand, so far as known, the Montana fauna has much in common with the Belly River, especially the Testudinata, Iguanodontia, and Ceratopsia.

In 1903 Stanton and Hatcher [4] studied both the Judith River and Belly River formations and defined the stratigraphic position of the Judith River as follows:

Our field studies in the original Judith River area have established the stratigraphic succession of the Upper Cretaceous section and show that the Judith River beds lie beneath several hundred feet of marine Cretaceous shales with a characteristic invertebrate fauna, and that they rest upon another marine formation which also bears an abundant fauna. The overlying formation we have called the Bearpaw shales, because it is well exposed in the area south, east, and north of the Bearpaw Mountains. The name Claggett formation has been given to the underlying beds because they are well developed around the site of old Fort Claggett, near the mouth of Judith River. Wherever the exposures in this region show lower beds the lignite and conspicuous sandstone ledges of the Eagle formation are seen, and still lower the dark Benton shales with a characteristic fauna are revealed. The Judith River formation itself has yielded a fauna of both vertebrates and invertebrates, most of which are peculiar to it. Its lithologic features also are different from those of any other formation in the section and make it easily recognizable.

Beyond the typical area we found on Milk River, in the neighborhood of Havre, a similar succession of formations from the Claggett to the Bearpaw, inclusive. The formation occupying the position of the Judith River beds here has the same lithologic and paleontologic characteristics as in the original area, with which it probably has direct connections around the east end of the Bearpaw Mountains. It is therefore unhesitatingly identified with the Judith

[1] Dawson, G. M., Report on the region in the vicinity of the Bow and Belly rivers, Northwest Territory: Geol. Survey Canada Rept. Progress 1882-1884, p. 119c, maps, 1885.

[2] Contr. Canadian Paleontology, vol. 1, pt. 1, pp. 55, 89, 1885.

[3] Osborn, H. F., Distinctive characters of the mid-Cretaceous fauna: Contr. Canadian Paleontology, vol. 3, pt. 2, pp. 7-21, 1902.

[4] Stanton, T. W., and Hatcher, J. B., Geology and paleontology of the Judith River beds: U. S. Geol. Survey Bull. 257, pp. 62, 66, 1905.

River beds. From Havre this formation was traced by means of practically continuous exposures and without essential change of lithologic and paleontologic characters into an area of Belly River beds mapped by Dawson. Here again the underlying Claggett formation was recognized by its fossils and lithologic features, and above the Judith River (Belly River) beds the Pierre shales of the Canadian geologists are clearly identical with the Bearpaw shales of our Montana section.

In other areas studied by us in Montana the same succession of formations was observed. Two horizons in this region are especially well characterized by marine invertebrates—one in the upper part of the Benton shales and the other in the Bearpaw shales. Wherever these were both present in one section the succession and recognition of the intervening formations were unmistakable. * * *

Our principal conclusions from the season's work may be summarized as follows:

1. The Judith River beds are distinctly older than the Laramie, being separated from the latter by at least several hundred feet of marine shales, identical in their faunal and lithologic features with the Pierre, to which we have given the local name Bearpaw shales, from the Bearpaw Mountains, about which they are well exposed.

2. The Belly River beds of Canada are identical with the Judith River beds of Montana. The name Judith River beds, having priority, should be the accepted name for this formation, and the terms Belly River and Fish Creek beds should be dropped.

3. The marine sandstones and shales immediately underlying the Judith River beds do not represent either the Benton, as some Canadian geologists have supposed, or the Fox Hills and upper Pierre, as most geologists of the United States who have examined them have believed, but they constitute a distinct horizon within the Montana group which we have called the Claggett formation, from old Fort Claggett, at the mouth of Judith River, near which they are well developed.

4. The Eagle formation, from its stratigraphic position and faunal relations, marks the base of the Montana group in this region.

5. The Bearpaw shales, the Judith River beds, the Claggett, and the Eagle formations all belong to the Montana group and together probably form the equivalent of the Pierre as that term is generally understood, though the possibility is recognized that in the typical area the Pierre may have more restricted limits.

6. 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 use of the term Fox Hills as a formation or horizon name outside of the original area in South Dakota is therefore of doubtful propriety, as experience has shown.

In 1911 A. C. Peale, who had done work in the Judith River region in connection with the Hayden Survey, revisited that area and spent a month in the field in a special study of the Judith River formation. As a result of this study Peale in 1912 published a paper [1] in which he contended for the Tertiary age of the formation, thus reverting to the opinions which had been held by some geologists before the work of Stanton and Hatcher. His conclusions are given in the following quotation:

Our first conclusion, therefore, is that the Judith River beds and the Belly River series, although both of fresh-water origin and lithologically very similar, are entirely distinct from each other, occupying stratigraphical positions separated by 1,000 feet or more of marine sandstones and shales. * * * Our second conclusion is that the Fox Hills formation, with its characteristic fauna and flora, immediately and unconformably underlies the Judith River beds and that it rests conformably upon exposures of characteristic Pierre shales throughout the Judith Basin. * * * We have no hesitation in stating the third conclusion, viz, that the Judith River formation is the representative if not the exact equivalent of the whole or some, perhaps lower, portion of the Lance formation, and that the latter name should be replaced on the ground of priority of use by the name Judith River formation. * * * We are fully warranted in concluding, as pointed out by Dawson long ago, that the Belly River series is of Niobrara age. * * * Apparently the entire series from the base of the Eagle sandstone to the base of the Pierre shales is a unit representing the Canadian Belly River formation.

The foregoing sketch briefly summarizes the views that have been held regarding the age and position of the Judith River formation. A review of the evidence shows that on the basis of its vertebrate remains the Judith River formation has generally been assigned to the Cretaceous, although differences of opinion have been expressed as to its exact position in the Cretaceous section. Before the characteristics of the Upper Cretaceous dinosaurs were well known Leidy, Meek, Hayden, and Cope thought that the remains from the Judith River formation were closely allied to the Wealden (Lower Cretaceous) of Europe, and hence the formation was considered to be of Lower Cretaceous age. But as the Upper Cretaceous dinosaurs came to be better known it was generally recognized that the remains from the Judith River formation have their closest allies in the Upper Cretaceous. From that time on practically all vertebrate

[1] Peale, A. C., On the stratigraphic position and age of the Judith River formation: Jour. Geology, vol. 20, pp. 530–549, 640–652, 738–757, 1912.

paleontologists have regarded the Judith River formation to be of Upper Cretaceous age. On the other hand, the invertebrate evidence, though somewhat conflicting in its nature, has been regarded by the earlier writers as showing a closer affinity with the Tertiary than with the Cretaceous. Finally, the stratigraphic evidence has been interpreted, except by Dawson and by Stanton and Hatcher, as indicating that the Judith River formation is younger than the Fox Hills, and therefore at the top of the Cretaceous or the base of the Tertiary.

REVIEW OF THE STRATIGRAPHY IN THE TYPE AREA OF THE JUDITH RIVER FORMATION.

Hayden's best account of the stratigraphy in the type area of the Judith River formation, from which the following extracts are taken, was published in 1860.[1]

> So intimately do the estuary beds at the mouth of the Judith seem to be connected with Cretaceous formation No. 1 that it will be important to present such facts as are known in regard to it. * * *
>
> The Cretaceous rocks of the Upper Missouri have been separated into five divisions upon lithological and paleontological grounds, and the sandstone formation at the mouth of Big Sioux and below forms the type of No. 1,[2] Nos. 2 and 3 are seen reposing upon No. 1 at the mouth of Big Sioux, and near the mouth of the Niobrara River No. 4 appears upon the summits of the bluffs, surmounting No. 3. At the foot of the "Big Bend" No. 3 passes beneath the water level of the river and is succeeded by No. 4, which occupies the country to Grand River, where No. 5 makes its appearance on the summits of the hills. Near the mouth of the Cannonball River the Lignite Tertiary beds begin to overlap the Cretaceous strata but do not entirely conceal them along the banks of the river until we reach "Square Buttes," about 30 miles below Fort Clarke. From this point to Milk River in latitude 48°, longitude 106°, only the Miocene beds of the Great Lignite basin are exposed. * * * The Tertiary beds continue uninterrupted until we reach the mouth of Milk River, where, by a reverse dip of the strata, the Cretaceous formation rises to the surface from beneath the Tertiary. The Tertiary beds continue to overlap the Cretaceous, gradually thinning out upon the summits of the hills, until we reach the mouth of the Muscle Shell River, where the Cretaceous bed No. 4 occupies the whole country. We thus see that in ascending the Missouri the dip of the strata is northwest as far as Fort Union or some point in that vicinity, and on reaching Milk River we can very distinctly observe the dip south or southeast, by which the underlying Cretaceous beds are exposed. We can also note the basin-like form in which both Tertiary and Cretaceous rocks were deposited. Passing the mouth of the Muscle Shell we soon observe a somewhat remarkable bed rising above the water level of the Missouri, near the mouth of Little Rocky Mountain Creek, which, from its lithological character and position, we have hitherto considered as belonging to formation No. 1. It first makes its appearance as a seam of carbonaceous grit, of a dull-reddish color, very light and loose, like ashes, about 1 foot in thickness, separating No. 4 from a bed of sandstone beneath. As we ascend the river a bed of sandstone rises rapidly above the water level, very variable in its lithological character. * * *
>
> Thus far up the river we have observed no indications of disturbance of strata by subterranean influences, but on reaching a point about 5 miles above Grand Island a great thickness of rocks not before seen is uplifted so as to exhibit the beds, inclining at every angle from a horizontal to a vertical position. The beds are composed of variegated sands, clays, and earthy lignite, and some of them are fully charged with organic remains. * * *
>
> About 10 miles below the mouth of the Judith River the marine strata of No. 1 are seen to rise rapidly from beneath the estuary and fresh-water beds, and on reaching the mouth of the Judith we have the following vertical section of No. 1,[3] the estuary and fresh-water beds only capping the hills and soon ceasing to appear.

It is evident that Hayden realized that the beds exposed along Missouri River from Little Rocky Mountain Creek west to Judith River are older than his No. 4 (now called Bearpaw). The stratigraphic succession between the mouth of Musselshell River and Judith River as given in the above quotation is—

No. 4.
Fresh and brackish water beds.
No. 1.

In 1875 Meek and Hayden announced independently (see p. 106) that the upper part of Hayden's No. 1 had been definitely correlated with the Fox Hills. In 1877 Cope[4] corroborated

[1] Hayden, F. V., Geological sketch of the estuary and fresh-water deposit of the badlands of the Judith, with some remarks upon the surrounding formations: Am. Philos. Soc. Trans., new ser., vol. 11, pp. 126-130, 1860.

[2] Nos. 1 to 5 correspond to Dakota, Benton, Niobrara, Pierre, and Fox Hills, respectively.—C. F. B.

[3] The No. 1 of this paragraph refers to what are now called the Eagle and Claggett formations.—C. F. B.

[4] Cope, E. D., Report on the geology of the region of the Judith River, Montana, and on vertebrate fossils obtained on or near the Missouri River; U. S. Geol. and Geog. Survey Terr. Bull., vol. 3, p. 568, 1877.

the succession established by Hayden, but divided Hayden's No. 1 into three formations. Discussing the section at the mouth of Judith River, Cope said:

> The ferruginous soft sandstone of the Fox Hills group is everywhere the line of demarkation between the black shales of No. 4 below and the Judith River beds above.

and, in the preceding paragraph,

> A question remains as to the light-colored (buff or white) sandstone underlying No. 4. * * * Geographically considered it is approximately No. 3, since it occupies a region between that occupied by Nos. 4 and 5 and Fort Benton, where No. 2 is extensively exposed.

With these changes and additions the above section becomes:

6. "No. 4" (Pierre shale).
5. Judith River formation.
4. "No. 5" (Fox Hills sandstone).
3. "No. 4" (Pierre shale).
2. "No. 3" (?), sandstone tentatively referred to the Niobrara formation.
1. "No. 2" (Benton shale).

Cope[1] recognized, however, that No. 4 at the mouth of Judith River does not agree in all respects with No. 4 exposed farther east on Missouri River. After discussing the underlying beds (now called Eagle) he says the characteristic overlying shale (Claggett) "is from 50 to 200 feet in thickness in the region of the Judith River, while on the lower river [Missouri] * * * it exhibits a thickness of nearly 1,000 feet above the water level."

Substituting lithologic terms for names, the above section is as follows:

6. Marine shale.
5. Fresh-water formation.
4. Marine sandstone.
3. Marine shale.
2. Marine sandstone.
1. Marine shale.

This is identically the same lithologic succession as that established on Missouri River in 1903 by Stanton and Hatcher, and as that which occurs throughout the area described by the writer in the first part of this paper. Moreover, the work of Pepperberg[2] in 1908 and of the writer[3] in 1912 shows that the same succession occurs east of the Bearpaw Mountains from Missouri River north to Milk River.

It is thus evident that this succession of formations prevails over a large area in north-central Montana. In part of that area the normal sequence is undisturbed by faulting, so that the succession is established beyond question. This succession is shown in the following section, in which the lithologic designations of the preceding section are replaced by the geologic names now applied by the United States Geological Survey to the formations:

6. Bearpaw shale (marine).
5. Judith River formation (fresh water).
4. Claggett formation (marine sandstone member).
3. Claggett formation (marine shale member).
2. Eagle sandstone (principally marine).
1. Colorado shale (marine).

CORRELATION OF JUDITH RIVER FORMATION ON MISSOURI RIVER WITH THE FORMATION IMMEDIATELY UNDERLYING THE BEARPAW SHALE FARTHER SOUTH.

That the formations described by Hayden and Cope which occur at the mouth of Judith River are identical with those shown on the accompanying map (Pl. X) has been shown in the discussion of the stratigraphy (pp. 96–103). Two of these formations—the Claggett (including the so-called Fox Hills sandstone) and the Judith River—were traced continuously for more than 100 miles and were found to be exact equivalents of those at the mouth of Judith River.

[1] Op. cit., p. 566.
[2] Pepperberg, L. J., The Milk River coal field, Montana: U. S. Geol. Survey Bull. 381, pp. 82–107, 1910.
[3] Bowen, C. F., The Cleveland coal field, Blaine County, Montana: U. S. Geol. Survey Bull. 541, pp. 338–353, 1914.

Peale has also shown the continuity of the Claggett (called by him Pierre and Fox Hills) from the mouth of Judith River southward to Deerfield and has recognized that the formations in the type area of the Judith River formation can be traced with certainty as far south as the North Moccasin Mountains, so that the correlation here made seems to be well established. Peale's statement [1] in this connection is as follows:

The dark-colored shales of the Pierre resting on these sandstones [Eagle, but called Belly River by Peale] form the surface of the bench beginning several miles to the eastward of the coal mine [near Deerfield] and the road to Kendall passes over them, several good outcrops showing, especially to the north of the road, but they do not show on the Judith south of the mouth of Warm Spring Creek. However, the Pierre shales appear in the valley long before Fullerton is reached and at the latter place form the bluffs on both sides of Judith River in typical exposures containing characteristic fossils. The entire thickness does not show at Fullerton, but there is here an exposure of at least 400 feet. The total thickness is probably from 600 to 900 feet. Immediately below the Judith River beds, which form the summit of the bluffs and the surface of the bench reaching to the eastward, there are from 50 to 100 feet of sandstone with *Halymenites major* and the following invertebrate fossils: *Avicula nebrascana* E. and S., *Tancredia americana* M. and H., *Lunatia subcrassa* M. and H., *Tellina equilateralis* M. and H., and Mactra sp. These are identified by Dr. Stanton and referred by him to the Claggett, but it seems to me they are undoubtedly of Fox Hills age, the beds containing them resting on Pierre shales and being immediately followed above by the Judith River beds. * * *

A short distance below Fullerton the first of three well-marked faults that occur south of Judith Landing crosses Judith River. The direction of this fault is nearly east and west and the dip of the beds thrown down is quite steep (about 20°) toward the northwest. This outcrop, mainly of Fox Hills sandstone and a smaller part of Judith River beds, is underlain by Pierre shales, and above the faulted beds are Pierre shales capped by Fox Hills sandstones (containing invertebrates and *Halymenites major*) which underlie the undisturbed Judith River beds, which have a very slight inclination to the north or northwest. The lower slope of the hill back to the faulted beds is composed of Pierre shales capped with Fox Hills sandstones and overlying Judith River beds. This fault line was afterward crossed 12 miles to the eastward, near the crossing of Dog Creek. The second fault line parallel to this one is exactly like the first, but the third one, a few miles south of Judith Landing, is a block fault of Fox Hills sandstone with a steep dip on the southwest side.

In order to establish further the correlation of the Judith River formation in Hayden's type area of that formation with the formation which the writer has mapped as Judith River in the area represented on Plate X, the following list of fossils is presented. This list shows the fossils collected from the Judith River formation in the type area and those collected east and south of T. 19 N., R. 19 E.

Fossils collected from the Judith River formation.

In Hayden's type area.	East and south of T. 19 N., R. 19 E.
Ostrea subtrigonalis E. and S.	Ostrea subtrigonalis E. and S.
Corbicula cytheriformis M. and H.	Corbicula cytheriformis M. and H.
Corbicula occidentalis M. and H.	Corbicula occidentalis M. and H.
Corbula subtrigonalis M. and H.	Corbula subtrigonalis M. and H.
Goniobasis convexa M. and H.	
Goniobasis invenusta M. and H.	
Goniobasis sublævis M. and H.	Goniobasis sublævis M. and H.
Goniobasis judithensis Stanton.	
Goniobasis gracilinta Meek.	
Goniobasis subtortuosa M. and H.	Goniobasis subtortuosa M. and H.
Campeloma vetula M. and H.	
Sphærium planum M. and H.	Sphærium sp.
Sphærium recticardinale M. and H.	
Anomia gryphorhynchus Meek.	Anomia sp.
Unio danæ M. and H.	Unio sp.
Unio primævus White.	
Physa copei White.	
Hyalina occidentalis M. and H.	
Hyalina evansi M. and H.	
Valvata montanaensis Meek.	
Viviparus conradi M. and H.	Viviparus conradi M. and H.
Anodonta propatoris White.	Anodonta propatoris White.

[1] Peale, A. C., On the stratigraphic position and age of the Judith River formation: Jour. Geology, vol. 20, pp. 542-543, 1912.

The list of fossils from the southern part of the field differs from the Missouri River list only in being less complete. A full collection from the southern area and a specific determination of all the forms would doubtless duplicate most if not all of those in the Missouri River list.

In addition to this duplication of species there is at many places, both on Missouri River and in the southern part of the field, a bed of *Ostrea subtrigonalis* at the top of the Judith River formation. This Ostrea bed is perhaps the best index bed in the Judith River formation, as it occurs immediately beneath the Bearpaw shale. The widespread occurrence of this bed at the same geologic horizon is therefore of itself sufficient evidence to establish the correlation of the formation in which it occurs within a single basin of deposition, although it may not be sufficient to establish a correlation of beds in separate basins.

It seems to the writer that the evidence presented in the foregoing discussion shows conclusively that the Judith River formation in the type area along Missouri River is the exact equivalent of the beds which immediately underlie the Bearpaw shale in the adjacent areas north and south of Missouri River, and therefore that the Judith River formation is of Montana age. This evidence may be briefly summarized as follows:

1. The stratigraphic succession in the two areas is identical.

2. The invertebrate fossils of the Judith River formation on Missouri River are identical with those in the formation underlying the Bearpaw shale farther south.

3. The bed of *Ostrea subtrigonalis* which occurs at the top of the Judith River formation on the Missouri also occurs at many places at the top of the formation underlying the Bearpaw shale in the area south of Missouri River.

4. Two of the formations, the Claggett and Judith River, have been traced from Willow Creek, in the southern part of the area, to the mouth of Judith River and found to be the exact equivalents of the Judith River and underlying formations at that place.

One question may still be raised, namely, May there not be two formations (Belly River and Judith River of Peale and some others) which in Hayden's "type area" have been confused and included under one name? As there has never been a complete detailed survey of Hayden's "type area," this question can not be unequivocally answered in the negative. If this confusion exists, Hayden's section (see p. 109) would need to be revised so as to show two fresh-water formations below his "lignite Tertiary." Such a succession is hardly probable, however, as it is now well known that no such sequence of formations occurs either north or south of Hayden's "Judith River area." Furthermore, Stanton and Hatcher failed to find any such succession in that part of the "type area" which they examined in 1903. It is possible, however, that, owing to the highly disturbed condition of the strata, down-faulted blocks of the Lance formation may occur in some places in Hayden's "original area." If such blocks exist they are undoubtedly of small extent, and it is confidently believed that most if not all of the "estuarine deposits" described by Hayden belong, as indicated by him, to the same formation which he describes as capping the hills at the mouth of the Judith. This formation, as previously shown, is the equivalent of the Judith River formation on Willow Creek and there undoubtedly underlies the Bearpaw shale. (See Pl. X.)

PALEONTOLOGIC EVIDENCE OF THE AGE OF THE JUDITH RIVER FORMATION.

As shown in the historical summary (pp. 104–110), the Judith River formation was regarded by the earlier geologists as overlying the Fox Hills sandstone and was therefore supposed to be of late Cretaceous or early Tertiary age, notwithstanding the fact that the vertebrate remains were regarded as indicating a close relationship with the Cretaceous.

The stratigraphic relation of the Judith River to the inclosing formations has been discussed above. In the following pages the paleontologic evidence of the age of the Judith River formation is submitted. In this connection it is necessary to compare the fauna of the so-called Fox Hills sandstone of the Judith River area (the marine sandstone forming the upper part of the Claggett) with the fauna of the underlying Eagle sandstone, and also with that of the Fox Hills at its type locality, and to compare the fauna of the Judith River formation with that of the Belly River formation on the one hand and with that of the Lance formation on the other. The writer has therefore assembled as complete lists as possible of the fauna of these formations, which are presented in tabular form in order to facilitate comparison. But before proceeding with this comparison the paleobotanic evidence of the age of the Judith River formation is briefly considered.

THE FLORA OF THE JUDITH RIVER FORMATION.

Although stems and fragments of plants are common in the Judith River formation, well-preserved leaves which will serve for purposes of identification are extremely rare and have been obtained at only two localities—on Cow Creek near Missouri River, and on Willow Creek about 10 miles north of Musselshell post office. Both collections were made by Stanton and Hatcher in 1903 and were submitted to F. H. Knowlton for identification and determination of age. Knowlton's descriptions and conclusions are published in Survey Bulletin 257, pages 129 to 168, and the final paragraph of his article is quoted here:

> From this review it appears that the flora of the Judith River beds that has thus far come to light shows very little affinity with the true Laramie or the Fort Union but does exhibit an undoubted relationship with that of the Dakota group or with the Cenomanian and Senonian of the Old World, or, in broad terms, with the lower and middle portions of the Upper Cretaceous.

Knowlton's statements regarding the specimens collected on Cow Creek are rather guarded, and Peale [1] has argued that the species represented by this collection is of Fort Union age. Knowlton's statement regarding this species is therefore quoted here in full: [2]

> From the base of the Judith River beds, at a point on Cow Creek, about 13 miles above its mouth, Mr. Stanton has obtained about 15 specimens of small detached leaves or leaflets that I am not able to distinguish from this species [*Trapa microphylla*]. While they are all smaller than the usual examples from the type locality (Point of Rocks, Wyo.), they agree well in shape and the marginal dentation, but unfortunately have not retained the nervation, or, at most, but slight traces of it. This species, or at least what has been so identified, has been figured by Dawson, in Tyrrell's collections from Bad Lands, Red Deer, and Rosebud rivers, and Pincher Creek, Canada, the age of which he regards as "Lower Laramie," and also a single doubtful example "from the Upper Laramie of Great Valley."
>
> Prof. Ward found this species abundantly at Burns ranch, on lower Yellowstone River, Mont., in beds supposed to be of Fort Union age, but, as I have shown in the "Flora of the Montana formation," I can not believe that these should be referred to *T. microphylla*, for the reason that they are clearly compound leaves, rarely detached, whereas at the type locality and at all the points mentioned by Dawson they are always separated and show no evidence of having been compound. I found examples that are not to be distinguished, apparently, from the Burns ranch forms, on Wolverine Creek, in the Yellowstone National Park, in beds regarded as of true Laramie age, and in 1896 Mr. Stanton and myself found a large number of detached leaves in Converse County, Wyo., in clay beds in the lower portion of the true Laramie. It may be that my presumption of two forms being mixed under this name is not valid, but it is certainly remarkable that at two localities they should always give evidence of being compound and at all the other localities appear as detached leaves, with no indication of being compound, especially as the material is ample in most cases. It must be confessed, however, that when dealing with isolated leaves or leaflets it is impossible to draw any satisfactory line between them.

This quotation shows that there is no doubt as to the Montana age of the plants from Willow Creek, and that Knowlton also favors the correlation of the species from Cow Creek with the Montana rather than the Fort Union flora. Peale,[3] in discussing the Willow Creek section, from which the leaves identified by Knowlton were obtained, says that the "Belly River beds [Judith River formation of this paper] pass conformably beneath the soft dark shales of the Pierre," and "there can be no doubt as to the Belly River age of these beds." There is thus a unanimity of opinion regarding the Belly River age of the formation exposed on Willow Creek. The writer has endeavored to show (pp. 101, 110–112) that this so-called Belly River formation (Judith River of this paper) on Willow Creek is the exact stratigraphic equivalent of the Judith River formation at the mouth of Judith River. The invertebrate fossils listed on page 111 bear similar evidence. The stratigraphic evidence and the evidence furnished by the fossil plants and invertebrates, therefore, point to the same conclusion, namely, that the Judith River formation is older than the Bearpaw shale and is of Montana age.

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[1] Jour. Geology, vol. 20, p. 739, 1912.
[2] U. S. Geol. Survey Bull. 257, pp. 144–145, 1905.
[3] Op. cit., p. 549.

INVERTEBRATES OF THE UPPER PART OF THE CLAGGETT FORMATION (SO-CALLED FOX HILLS OF THE JUDITH RIVER AREA) COMPARED WITH THOSE OF THE EAGLE SANDSTONE AND THE FOX HILLS PROPER.

The following table gives a complete list of invertebrates from the Eagle sandstone and the sandstone member constituting the upper part of the Claggett at the mouth of Judith River; also a comprehensive list of Fox Hills fossils collected near the type locality in the Cheyenne and Standing Rock Indian reservations of North and South Dakota.

TABLE 2.—*Invertebrate fossils from the Eagle sandstone, the upper part of the Claggett formation, and the type locality of the Fox Hills sandstone.*

NOTE.—References indicated by figures in the table are as follows: [1] Calvert, W. R., and others, Geology of the Cheyenne and Standing Rock Indian reservations, North and South Dakota: U. S. Geol. Survey Bull. 575, 1914. [2] Stanton, T. W., and Hatcher, J. B., Geology and paleontology of the Judith River beds: U. S. Geol. Survey Bull. 257, 1905. [3] Collected by C. F. Bowen, 1912. [4] Meek, F. B., U. S. Geol. and Geog. Survey Terr. Bull., vol. 1, 2d ser., pp. 39, 40, 1875. [5] Meek, F. B., U. S. Geol. and Geog. Survey Terr. Final Repts., vol. 9, 1876.

	Eagle sandstone.	Upper part of Claggett formation.	Fox Hills sandstone.
Anchura americana (E. and S.)			×[1]
Anomia micronema Meek			×[1]
Avicula linguiformis E. and S.	×[2]		×[1]
Avicula nebrascana E. and S.	×[3]	×[2,3]	×[1,4]
Baculites ovatus Say	×[3]	×[3]	
Callista deweyi M. and H.	×[2] (?)		×[1]
Callista owenana M. and H.		×[5]	
Callista pellucida M. and H.	×[3]		
Cantharus vaughani M. and H.			×[1]
Cardium speciosum M. and H.	×[2,3]	×[2,3,5]	×[4]
Cerithiopsis moreauensis M. and H.			×[1]
Cinulia concinna M. and H.			×[1]
Corbicula cytheriformis M. and H.			×[1]
Corbicula occidentalis M. and H.			×[1]
Corbicula subelliptica var. moreauensis M. and H.			×[1]
Cucullæa nebrascensis Owen			×[1]
Cucullæa shumardi M. and H.			×[1]
Cuspidaria ventricosa M. and H.			×[1]
Cylichna volvaria M. and H.			×[1]
Dentalium gracile H. and M.			×[1]
Entalis paupercula M. and H.			×[1]
Fasciolaria buccinoides M. and H.			×[1]
Fasciolaria (Piestochilus) culbertsoni M. and H.			×[1]
Fasciolaria (Piestochilus) scarboroughi E. and S.			×[1]
Fusus (Serrifusus) dakotensis M. and H.			×[1]
Gervillia subtortuosa M. and H.			×[1]
Glycimeris occidentalis M. and H.		×[5]	
Goniomya americana M. and H.			×[1]
Haminea minor M. and H.			×[1]
Inoceramus cripsii Mantell		×[5]	
Inoceramus pertenuis M. and H.		×[3,5]	
Leda (Yoldia) evansi M. and H.			×[1,4]
Leda (Yoldia) scitula M. and H.			×[1]
Limopsis striato-punctata E. and S.			×[1]
Linearia? formosa M. and H.			×[1]
Liopistha undata M. and H.		×[2,5]	
Lucina occidentalis Morton			×[1]
Lucina subundata H. and M.	×[2]		
Lunatia concinna H. and M.			×[1]
Lunatia occidentalis M. and H.			×[1]
Lunatia subcrassa M. and H.	×[2]	×[2,3,5]	×[1]
Mactra alta M. and H.	×[2]	×[2,4,5]	×[4]
Mactra formosa M. and H.	×[2,3]	×[2,3,4]	×[4]
Mactra warrenana M. and H.			×[1]
Martesis cuneata M. and H.			×[1]
Melania insculpta Meek			×[1]
Mytilus subarcuatus M. and H.		×[5]	
Nautilus dekayi Morton	×[2]		×[1,5]
Nucula cancellata M. and H.			×[1,4]
Nucula planimarginata M. and H.			×[1,4]
Ostrea glabra M. and H.			×[1]
Ostrea pellucida M. and H.			×[1]
Ostrea subalata Meek			×[1]
Ostrea subtrigonalis E. and S.			×[1]
Pholadomya subventricosa M. and H.		×[5]	
Placenticeras whitfieldi	×[2]		
Protocardia subquadrata E. and S.			×[1]
Pyrifusus newberryi M. and H.			×[1]
Pyropsis bairdii M. and H.			×[5]
Scaphites cheyennensis Owen			×[1]
Scaphites conradi Morton			×[1]
Scaphites hippocrepis DeKay	×[2]		
Scaphites mandanensis Morton			×[1]
Scaphites nicolleti Morton			×[1]
Scaphites abyssinus Morton			×[1]
Sphæriola endotrachys Meek		×[2,5]	
Sphenodiscus lenticularis Owen			×[1]
Spironema tenuilineata M. and H.			×[1]

TABLE 2.—*Invertebrate fossils from the Eagle sandstone, the upper part of the Claggett formation, and the type locality of the Fox Hills sandstone*—Continued.

	Eagle sandstone.	Upper part of Claggett formation.	Fox Hills sandstone.
Tancredia americana M. and H.	....	× [2,4,5]	× [1,5]
Tellina equilateralis M. and H.	....	× [2,3,5]	....
Tellina montanaensis	× [2]	....	....
Tellina scitula M. and H.	....	....	× [1]
Thetis (?) circularis M. and H.	× [2]	× [3]	....
Thracia gracilis M. and H.	....	× [2,5]	....
Thracia prouti M. and H.	....	× [5]	....
Thracia subtortuosa M. and H.	....	× [5]	....
Turris contortus M. and H.	....	....	× [1]
Vanikoro ambigua M. and H.	....	....	× [1]
Vanikoropsis tuomeyana M. and H.	....	× [2,3,5]	....

In order to facilitate the interpretation of this table it is summarized in the table below, which gives all the forms that occur in more than one of the formations under discussion.

TABLE 3.—*Forms common to two or more of the formations represented in Table 2.*

Eagle sandstone.	Upper part of the Claggett formation.	Fox Hills sandstone.
Avicula linguiformis	....	Avicula linguiformis.
Avicula nebrascana	Avicula nebrascana	Avicula nebrascana.
Baculites ovatus	Baculites ovatus.	
Callista deweyi (?)	....	Callista deweyi.
Cardium speciosum	Cardium speciosum	Cardium speciosum.
Lunatia subcrassa	Lunatia subcrassa	Lunatia subcrassa.
Mactra alta	Mactra alta	Mactra alta.
Mactra formosa	Mactra formosa	Mactra formosa.
Nautilus dekayi	....	Nautilus dekayi.
	Tancredia americana	Tancredia americana.
Thetis circularis	Thetis circularis.	

This table shows that there are more species common to the Eagle and Fox Hills in its type locality than to the sandstone in the upper part of the Claggett (so-called Fox Hills) and the Fox Hills proper. It also shows that with one exception (*Tancredia americana*) every species common to the Claggett and Fox Hills also occurs in the Eagle. Only four specifically determined forms occurring in the Eagle are not found in the higher formations and 12 specifically determined forms found in the Claggett are not found in the Fox Hills. The tables seem to indicate a closer relationship between the faunas of the sandstone division of the Claggett (so-called Fox Hills) and the Eagle than between the former and the Fox Hills proper. They also show that the fauna of the Fox Hills, while related to that of the two older formations, is more diversified, just as the fauna of the Bearpaw shale is related to that of the shales of the Claggett formation but more diversified. From the paleontologic evidence there seems to be no basis for assigning the marine sandstone in the upper part of the Claggett formation to the Fox Hills sandstone, and therefore one of the principal arguments for assigning the Judith River formation to a position at the top of the Cretaceous or base of the Tertiary—namely, that it overlies the Fox Hills sandstone—loses its force. As shown on preceding pages the stratigraphic evidence is conclusive that the Judith River formation is much older than the Fox Hills as represented at its type locality.

INVERTEBRATES OF THE JUDITH RIVER FORMATION COMPARED WITH THOSE OF THE BELLY RIVER AND LANCE FORMATIONS.

A comparison of the invertebrates from the Belly River and Judith River formations with those from the Lance formation of Hell Creek, Mont., and Converse County, Wyo., is given in the following table. This list has been compiled from the lists published by Hayden and Stanton and from the collections made by the writer and his assistants in 1912.

TABLE 4.—*Invertebrate fossils from the Belly River and Judith River formations and the Lance formation of Hell Creek, Mont., and Converse County, Wyo.*

References indicated by figures in the table are as follows: [1] Stanton, T. W., U. S. Geol. Survey Bull. 257, pp. 104–119, 1905. [2] Stanton, T. W., Washington Acad. Sci. Proc., vol. 11, pp. 243–247, 1909. [3] Collected by C. F. Bowen, 1912. [4] Hayden, F. V., Am. Philos. Soc. Trans., vol. 11, p. 132, 1860.

	Belly River formation.	Judith River formation.	Lance formation.
Anodonta parallela White	×[1]?		×[2]
Anodonta propatoris White	×[1]	×[1]	
Anomia gryphorhynchus Meek	×[1]	×[1]	
Anomia micronema Meek	×[1]	×[3]	
Avicula nebrascana E. and S.	×[1]		
Bulinus atavus White	×[1]	×[1]	
Bulinus rhomboideus M. and H.			×[2]
Bulinus subelongatus M. and H.		×[1]	
Campeloma multilineata M. and H.	×[1]		×[2]
Campeloma producta White	×[1]		×[2]
Campeloma vetula M. and H.	×[1]	×[1]	×[2]
Cassiopella turricula White			×[2]
Corbicula cytheriformis M. and H.	×[1]	×[1,3]	
Corbicula occidentalis M. and H.	×[1]	×[1,3]	×[1]
Corbicula subelliptica M. and H.			×[2]
Corbula perundata M. and H.	×[1]	×[1,3]	
Corbula subtrigonalis M. and H.	×[1]	×[1,3]	
Crenella parvula Whiteaves	×[1]		
Goniobasis convexa M. and H.	×[1]	×[1,3]	
Goniobasis convexa var. impressa M. and H.		×[1]	
Goniobasis gracilenta Meek		×[1]	
Goniobasis invenusta M. and H.	×[1]	×[1]	
Goniobasis judithensis n. sp.	×[1]	×[1]	
Goniobasis (?) omitta M. and H.		×[1]	
Goniobasis sublævis M. and H.	×[1]	×[1,3]	
Goniobasis subtortuosa M. and H.	×[1]	×[1,3]	
Goniobasis tenuicarinata M. and H			×[2]
Helix occidentalis		×[4]	
Helix vetusta M. and H.		×[1]	×[2]?
Helix vitrinoides		×[4]	
Hyalina (?) evansi M. and H.	×[1]	×[1]	
Hyalina (?) occidentalis M. and H.	×[1]	×[1]	
Hydrobia subconica Meek		×[1]	
Hydrobia subcylindracea Whiteaves	×[1]		
Liopistha (Cymella) undata M. and H.		×[1]	
Mactra (Cymbophora) alta M. and H.	×[1]?		
Mactra (Cymbophora) warrenana M. and H.		×[1]?	
Melania whiteavesi n. sp	×[1]	×[1]	
Mytilus subarcuatus M. and H.	×[1]	×[1]?	
Ostrea glabra M. and H.	×[1]	×[1]	×[1]
Ostrea subtrigonalis E. and S.	×[1,3]	×[1]	×[1]
Panopæa simulatrix Whiteaves	×[1]?	×[1]	
Physa copei White	×[1]	×[1]	×[2]
Physa subelongata		×[4]	
Planorbis (Bathyomphalus) amplexus M. and H.	×[1]	×[1,4]	
Planorbis paucivolvis Whiteaves	×[1]		
Planorbis tenuivolvis		×[4]	
Rhytophorus (?) glaber Whiteaves	×[1]		
Sphærium formosum M. and H.	×[1]?		
Sphærium planum M. and H.	×[1]	×[1,3]	×[2]
Sphærium recticardinale M. and H.	×[1]	×[1]	
Thaumastus limnæiformis M. and H.	×[1]		×[2]
Tulotoma thompsoni White			×[2]
Unio æsopiformis Whitfield			×[2]
Unio aldrichi White			×[2]
Unio biesopoides Whitfield			×[1,2]
Unio brachyopisthus White			×[2]
Unio browni Whitfield			×[2]
Unio consuetus Whiteaves	×[1]	×[1]?	
Unio corbiculoides Whitfield			×[2]
Unio couesi White			×[2]
Unio cryptorhynchus White		×[1]	×[2]
Unio cylindricoides Whitfield			×[2]
Unio danæ M. and H.	×[1]	×[1,3,4]	×[1]?
Unio endlichi White			×[2]
Unio gibbosoides Whitfield			×[2]
Unio holmsianus White			×[2]
Unio letsoni Whitfield			×[2]
Unio percorrugata Whitfield			×[2]
Unio postbiplicata Whitfield			×[2]
Unio primævus White	×[1]	×[1,3]	
Unio priscus M. and H.	×[1]	×[1]	
Unio priscus var. abbreviatus n. var	×[1]		
Unio proavitus White			×[1]
Unio pyramidatoides Whitfield			×[2]
Unio pyramidellus			×[2]
Unio retusoides Whitfield			×[2]
Unio senectus White	×[1]	×[1]	
Unio stantoni (danæ) White			×[1]
Unio subspatulatus M. and H.	×[1]	×[1,4]?	
Unio subtrigonalis Whitfield			×[2]
Unio supenawensis n. sp	×[1]		
Unio supragibbosus Whiteaves	×[1]		
Unio verrucosiformis Whitfield			×[2]
Valvata montanaensis Meek		×[1]	
Vitrina obliqua M. and H.		×[1,4]	
Viviparus conradi M. and H.	×[1]	×[1,3]	
Viviparus plicapressus White			×[2]

This table is summarized in the following complete list of the forms common to two or more of the formations involved:

TABLE 5.—*Forms which occur in more than one of the formations represented in Table 4.*

Belly River formation.	Judith River formation.	Lance formation.
Anodonta parallela White		Anodonta parallela White.
Anodonta propatoris White	Anodonta propatoris White	
Anomia gryphorhynchus Meek	Anomia gryphorhynchus Meek	
Anomia micronema Meek	Anomia micronema Meek	
Bulinus atavus White	Bulinus atavus White	
Campeloma multilineata M. and H		Campeloma multilineata M. and H.
Campeloma producta White		Campeloma producta White.
Campeloma vetula M. and H	Campeloma vetula M. and H	Campeloma vetula M. and H.
Corbicula cytheriformis M. and H	Corbicula cytheriformis M. and H	
Corbicula occidentalis M. and H	Corbicula occidentalis M. and H	Corbicula occidentalis M. and H.
Corbula perundata M. and H	Corbula perundata M. and H	
Corbula subtrigonalis M. and H	Corbula subtrigonalis M. and H	
Goniobasis convexa M. and H	Goniobasis convexa M. and H	
Goniobasis invenusta M. and H	Goniobasis invenusta M. and H	
Goniobasis judithensis n. sp	Goniobasis judithensis n. sp	
Goniobasis sublævis M. and H	Goniobasis sublævis M. and H	
Goniobasis subtortuosa M. and H	Goniobasis subtortuosa M. and H	
	Helix vetusta M. and H	Helix vetusta M. and H.
Hyalina (?) evansi M. and H	Hyalina (?) evansi	
Hyalina (?) occidentalis M. and H	Hyalina (?) occidentalis M. and H	
Melania whiteavesi n. sp	Melania whiteavesi n. sp	
Mytilus subarcuatus M. and H	Mytilus subarcuatus M. and H	
Ostrea glabra M. and H	Ostrea glabra M. and H	Ostrea glabra M. and H.
Ostrea subtrigonalis E. and S	Ostrea subtrigonalis E. and S	Ostrea subtrigonalis E. and S.
Panopæa simulatrix Whiteaves	Panopæa simulatrix Whiteaves	
Physa copei White	Physa copei White	Physa copei White.
Planorbis (Bathyomphalus) amplexus M. and H	Planorbis (Bathyomphalus) amplexus M. and H	
Sphærium planum M. and H	Sphærium planum M. and H	Sphærium planum M. and H.
Sphærium recticardinale M. and H	Sphærium recticardinale M. and H	
Thaumastus limnæiformis M. and H		Thaumastus limnæiformis M. and H.
Unio consuetus Whiteaves	Unio consuetus Whiteaves	
	Unio cryptorhynchus White	Unio cryptorhynchus White.
Unio danæ M. and H	Unio danæ M. and H	Unio danæ M. and H. (?).
Unio primævus White	Unio primævus White	
Unio priscus M. and H	Unio priscus M. and H	
Unio senectus White	Unio senectus White	
Unio subspatulatus M. and H	Unio subspatulatus M. and H	
Viviparus conradi M. and H	Viviparus conradi M. and H	

This summary shows that of 88 forms listed in the preceding table 19 genera and 38 species occur in two or more of the formations involved. Of these 38 species only 2 occur in the Judith River and Lance which do not also occur in the Belly River and 4 species occur in the Belly River and Lance but not in the Judith River. There are 32 species common to the Judith River and Belly River, 9 common to the Judith River and Lance, and 7 common to all three formations. Although it is generally conceded that fresh and brackish water invertebrates are of less value than marine invertebrates for the determination of age and correlation of formations, except in local basins, the large number of forms common to the Judith River and Belly River as contrasted with those common to the Judith River and the Lance seems to be significant, and if the fresh-water forms have any weight whatever they certainly favor the correlation of the Judith River and Belly River rather than that of the Judith River and the Lance, and therefore they tend to establish the Cretaceous age of the Judith River formation.

VERTEBRATES OF THE JUDITH RIVER FORMATION COMPARED WITH THOSE OF THE BELLY RIVER AND LANCE FORMATIONS.

In Table 6 is presented a complete list of vertebrates from the Belly River formation; the Judith River formation; the Lance formation of Hell Creek, Mont., Converse County, Wyo.,[1] and adjacent localities; the Denver and Arapahoe formations of the Denver Basin; and the "Laramie" formation of Black Buttes, Wyo. A similar but less comprehensive table was published by Osborn,[2] and most of the literature and determinations have been reviewed by Hatcher[3] and Hay.[4]

These publications have served as a basis for the present compilation, though the writer has examined also most of the original descriptions and for doubtful species practically all the literature available. The table gives the name of the species, the formations in which it is reported to have been found, the finder and date (where known), the location at which each specimen has been found, the material on which each determination is based, the authority and reference for the determination, and a column of remarks in which is given mainly a synopsis of the views of the authorities who have reviewed and criticized the original determinations and the material on which those determinations were based.

[1] Converse County has been subdivided and the areas referred to in the table are now in Niobrara County.

[2] Osborn, H. F., Distinctive characters of the mid-Cretaceous fauna: Contr. Canadian Paleontology, vol. 3, pt. 2, pp. 11-15, 1902.

[3] Hatcher, J. B., Geology and paleontology of the Judith River beds: U. S. Geol. Survey Bull. 257, pp. 67-103, 1905; The Ceratopsia: U. S. Geol. Survey Mon. 49, 1907.

[4] Hay, O. P., The fossil turtles of North America: Carnegie Inst. Washington Pub. 75, 1908.

TABLE 6.—*Geologic distribution of vertebrates in the Belly River, Judith River, Lance*

[The numbers 1 to 6 used in the last six columns correspond to the numbers printed in heavy type over

Species.	1 Belly River formation.	2 Judith River formation.	3 "Hell Creek beds" (Lance formation), Montana.	4 Lance formation, Wyoming.	5 "Laramie" formation, Black Buttes, Wyoming.	6 Denver and Arapahoe formations, Colorado.	Finder.	Date.
PISCES.								
Acipenser albertensis Lambie	t×	×		×			1. Lambe 2. Not given. 4. Not given.	1. 1901
Ceratodus (Rhineastes) eruciferus Cope.	×	t×					1. Lambe 2. Sternberg.	1. 1901
Rhineastes sp. indet			×					
Ceratodus hieroglyphus Cope		t×					Not given	
Diphyodus longirostris Lambe	t×	×		×			1. Lambe	1901
Diphyodus sp			×					
Hedronchus sternbergii Cope		×					Sternberg	
Lepisosteus (Lepidotus) occidentalis Leidy.	×	t×	×	×		×	1. Lambe 2. Hayden.	1. 1901
Lepisosteus (Lepidotus) haydeni Leidy		t×					Hayden	
Myledaphus bipartitus Cope	×	t×		×			1. Sternberg 2, 4. Hatcher.	

("Hell Creek beds" and "Ceratops beds"), and Denver and Arapahoe formations.

the locality columns. The letter t indicates that the observation relates to the type of the species.]

Locality and stratigraphic position as given by the authors cited.	Material on which determination is based.	Authority and reference.	Remarks.
t1. Red Deer River district, Canada. 2. Judith River formation [locality not given]. 4. Laramie formation, Converse County, Wyo.	t1. Strongly keeled dermal shield. 2. Similar ossifications. 4. Not given.	t1. Lambe, Contr. Canadian Paleontology, vol. 3, pt. 2, p. 29, 1902. 2. Hatcher, U. S. Geol. Survey Bull. 257, p. 69, 1905. 4. Hatcher, loc. cit. Williston, Science, new ser., vol. 16, p. 952, 1902.	2, 4. Of this and the 7 species which follow, Hatcher (op. cit., p. 67) says: "They are at present known from such insufficient material as to render them of little value for purposes of correlation." Hatcher says ossifications similar to the type material from Canada are common in the Judith River formation and in the Laramie (Lance formation) of Converse County, Wyo.
1. Belly River series, Red Deer River, Alberta. 2. Fort Union beds, Montana.	1. A number of fragments of cranial bones. t2. A basal and dentigerous lamina.	1. Lambe, Contr. Canadian Paleontology, vol. 3, pt. 2, p. 29, 1902. t2. Cope, Acad. Nat. Sci. Philadelphia Proc., vol. 28, p. 259, 1876; U. S. Geol. and Geog. Survey Terr. Bull. 3, p. 574, 1877. 3. Hatcher, U. S. Geol. Survey Bull. 257, p. 68, 1905.	2. Although Cope gives the locality and horizon as Fort Union, Mont., the horizon is Judith River. Cope at that time was using Fort Union in the same broad sense that was given to Laramie. On page 253 of the Acad. Nat. Sci. Philadelphia Proc., vol. 28, he uses the expression "Fort Union badlands of the Judith River," and on pages 512-574 of U. S. Geol. and Geog. Survey Terr. Bull. 3 he gives a list of fossils from the Judith River formations, which includes all but one of the species described in the article in the Academy Proceedings. He therefore used the terms Judith River formation and Fort Union formation indiscriminately when referring to the Judith River area. (See also remarks on *Acipenser albertensis.*)
Hell Creek beds, Montana.	Not given.	Brown, Am. Mus. Nat. Hist. Bull., vol. 23, p. 842, 1907.	See remarks on *Acipenser albertensis*.
t. Fort Union beds, Montana.	t. A dentigerous plate.	t. Cope, Acad. Nat. Sci. Philadelphia Proc., vol. 28, p. 260, 1876. Hatcher, U. S. Geol. Survey Bull. 257, p. 68, 1905.	See remarks on *Acipenser albertensis* and *Ceratodus eruciferus.*
t1. Belly River series, Red Deer River, Alberta. 2. Judith River beds, Montana. 4. Laramie deposits, Converse County, Wyo.	t1. A jaw with numerous teeth scars. 2. Fragments of similar jaws. 4. Fragments of similar jaws.	t1. Lambe, Contr. Canadian Paleontology, vol. 3, pt. 2, p. 30, 1902. 2, 4. Hatcher, U. S. Geol. Survey Bull. 257, p. 69, 1905.	2, 4. Referring to the type material, Hatcher says: "Fragments of similar jaws are found both in the Judith River beds and in the Laramie of Converse County." (See also remarks on *Acipenser albertensis.*)
Hell Creek beds, Montana.	Not given.	Brown, Am. Mus. Nat. Hist. Bull., vol. 23, p. 842, 1907.	
Fort Union beds, Montana.	Founded on the crown of a young tooth.	Cope, Acad. Nat. Sci. Philadelphia Proc., vol. 28, p. 258, 1876. Hatcher, U. S. Geol. Survey Bull. 257, p. 69, 1905.	See remarks on *Acipenser albertensis* and *Ceratodus eruciferus.*
1. Belly River series, badlands, Red Deer River, Alberta. t2. Badlands of Judith River, Montana. 3. Hell Creek, Mont. 4. Converse County, Wyo. 6. Ceratops beds near Denver, Colo.	1. Numerous scales. t2. Type founded on 5 specimens of thick lozenge-shaped scales. 3. Not given. 4. Numerous scutes associated with opisthocœlous vertebræ. 6. Not given.	1. Lambe, Contr. Canadian Paleontology, vol. 3, pt. 2, p. 29, 1902. t2. Leidy, Acad. Nat. Sci. Philadelphia Proc., vol. 8, p. 73, 1856. 3. Brown, Am. Mus. Nat. Hist. Bull., vol. 23, p. 842, 1907. 4. Williston, Science, new ser., vol. 16, p. 953, 1902. 6. Marsh, U. S. Geol. Survey Mon. 27, p. 527, 1896.	See remarks on *Acipenser albertensis.*
t. Badlands of Judith River, Mont.	t. Founded on a single specimen of a thick oblong square scale.	t. Leidy, Acad. Nat. Sci. Philadelphia Proc., vol. 8, p. 73, 1856.	Cope (U. S. Geol. and Geog. Survey Terr. Bull. 3, p. 574, 1877) makes *L. occidentalis* and *L. haydeni* synonymous.
1. Belly River series, Red Deer River, Alberta. t2. Fort Union beds, Montana. 4. Laramie of Converse County, Wyo.	1. Represented by many detached and isolated teeth. t2. Type founded on detached and isolated teeth. 4. Similar teeth.	1. Lambe, Contr. Canadian Paleontology, vol. 3, pt. 2, p. 28, 1902. t2. Cope, Acad. Nat. Sci. Philadelphia Proc., vol. 28, p. 260, 1876. 4. Hatcher, U. S. Geol. Survey Bull. 257, p. 68, 1905; Williston, Science, new ser., vol. 16, p. 953, 1902.	2. Given also in list from Judith River formation, Cope, U. S. Geol. and Geog. Survey Terr. Bull. 3, p. 574, 1877. Hatcher (U. S. Geol. Survey Bull. 257, p. 68) says: "It would be impossible to identify either genera or species from teeth of such simple form."

TABLE 6.—*Geologic distribution of vertebrates in the Belly River, Judith River, Lance*

Species.	1 Belly River formation.	2 Judith River formation.	3 "Hell Creek beds" (Lance formation), Montana.	4 Lance formation, Wyoming.	5 "Laramie" formation, Black Buttes, Wyoming.	6 Denver and Arapahoe formations, Colorado.	Finder.	Date.
PISCES—continued.								
Platacodon nanus Marsh				t×			Hatcher	
Lamna sp			×				Brown	
AMPHIBIA.								
Hemitrypus jordanianus Cope		×					Not given	
Scapherpeton tectum Cope	×	t×	×	×			1. Lambe. 2, 3, 4, not given.	1. 1901
Scapherpeton laticolle Cope		t×						
Scapherpeton excisum Cope		t×						
Scapherpeton favosum Cope		t×						
PLESIOSAURIA.								
Cimoliasaurus magnus Leidy	×						Lambe	1901
Ischyrosaurus (Ischyrotherium) antiquum Leidy.		×		×			2. Stanton and Hatcher. 4. Hatcher. t. Hayden.	2. 1903
Uronautes cetiformis		t×(?)					Cope	

("*Hell Creek beds*" *and* "*Ceratops beds*"), *and Denver and Arapahoe formations*—Continued.

Locality and stratigraphic position as given by the authors cited.	Material on which determination is based.	Authority and reference.	Remarks.
t. Laramie of Converse County, Wyo.	t. Detached teeth, two dental plates with teeth in position.	Marsh, Am. Jour. Sci., 3d ser., vol. 38, p. 178, 1889. Hatcher, Science, new ser., vol. 12, p. 719, 1900; Carnegie Mus. Annals, vol. 1, p. 128, 1901.	When first described by Marsh this animal was regarded as a mammal. The finding of more complete remains enabled Hatcher to determine its true relationship.
Hell Creek beds, Montana.	Not given.	Brown, Am. Mus. Nat. Hist. Bull., vol. 23, p. 842, 1907.	
Judith River beds, Montana.	A single vertebra.	Cope, Acad. Nat. Sci. Philadelphia Proc., vol. 28, p. 358, 1876. Hatcher, U. S. Geol. Survey Bull. 257, p. 71, 1905.	Distinguished from Scapherpeton by the position of the foramen chordæ dorsalis.
1. Belly River series, Red Deer River, Canada, between Berry Creek and Dead Lodge Canyon. t2. Judith River beds, Montana. 3. Hell Creek beds, Montana. 4. Laramie of Converse County, Wyo.	1. Several trunk vertebræ and atlases. t2. Type founded on a single vertebra; this was accompanied by a fragment which resembles the articular portion of the mandible. 3. Not given. 4. Numerous vertebræ and fragments of the mandible.	1. Lambe, Contr. Canadian Paleontology, vol. 3, pt. 2, p. 31, 1902. t2. Cope, Acad. Nat. Sci. Philadelphia Proc., vol. 28, p. 355, 1876. 3. Brown, Am. Mus. Nat. Hist. Bull., vol. 23, p. 823, 1907. 4. Williston, Science, new ser., vol. 16, pp. 952-953, 1902.	
t. Judith River beds, Montana.	t. Founded on an atlas and several dorsal vertebræ of different individuals; vertebræ may belong to *S. tectum*.	t. Cope, Acad. Nat. Sci. Philadelphia Proc., vol. 28, p. 356, 1876. Hatcher, U. S. Geol. Survey Bull. 257, p. 70, 1905.	
t. Judith River beds, Montana.	t. Species founded on scattered vertebræ from three individuals of different sizes.	t. Cope, Acad. Nat. Sci. Philadelphia Proc., vol. 28, p. 357, 1876. Hatcher, U. S. Geol. Survey Bull. 257, p. 70, 1905.	
t. Judith River beds, Montana.	t. Species founded on a single vertebra.	t. Cope, Acad. Nat. Sci. Philadelphia Proc., vol. 28, p. 357, 1876. Hatcher, U. S. Geol. Survey Bull. 257, p. 70, 1905.	
Belly River series, below Berry Creek on Red Deer River, Alberta.	Fourteen cervical vertebræ, probably belonging to one individual.	Lambe, Contr. Canadian Paleontology, vol. 3, pt. 2, p. 32, 1902.	The type of this species is founded on vertebræ from the greensands of New Jersey described by Leidy in 1853. Hatcher (U. S. Geol. Survey Bull. 257, p. 71) says: "It is not improbable that Lambe's material belongs to a different genus and species."
2. Judith River beds, Cow Creek 6 or 7 miles above its mouth, Montana. 4. Laramie of Wyoming. [Found with mammals and reptiles described by Marsh, probably all from Converse County, though no exact locality is given.] t. Between Grand and Moreau rivers, S. Dak.	2. A number of vertebral centra. 4. Several vertebræ.	2. Hatcher, U. S. Geol. Survey Bull. 257, p. 72, 1905. 4. Marsh, Am. Jour. Sci., 3d ser., vol. 38, p. 83, 1889.	2. Hatcher says the material is so incomplete that the determination is uncertain. The type specimen was found by Hayden in South Dakota between Grand and Moreau rivers from an "outlier of the great lignite beds." Hatcher says the horizon was more nearly that of the Fox Hills or Pierre.
Near Armells Creek, Judith River district, Mont.	Cervical, dorsal, and caudal vertebræ and portions of limb and rib bones.	Cope, Acad. Nat. Sci., Philadelphia Proc., vol. 28, p. 346, 1876.	Cope regards the horizon as Fox Hills, but his Fox Hills would be the upper part of the Claggett formation. Hatcher says that the specimen came either from the top of the Claggett or from the base of the Judith River.

TABLE 6.—*Geologic distribution of vertebrates in the Belly River, Judith River, Lance*

Species.	1 Belly River formation.	2 Judith River formation.	3 "Hell Creek beds" (Lance formation), Montana.	4 Lance formation, Wyoming.	5 "Laramie" formation, Black Buttes, Wyoming.	6 Denver and Arapahoe formations, Colorado.	Finder.	Date.
CHELONIA.								
Adocus (Compsemys) lineolatus Cope	×	×	×	×	....	t×(?)	1. Lambe 2. Sternberg. 3. Brown. 4. Isaacs. 6. Cope.	1. 1901 2. 1876. 4. 1877.
Neurankylus eximius Lambe	t×	....	....	....	....	....	Lambe	1901
Basilemys (Compsemys) imbricaria (Cope).	....	t×	....	....	....	....	Sternberg	1876
Basilemys (Compsemys) variolosa (Cope).	×	t×	....	....	....	....	1. Lambe 2. Sternberg.	1. 1901 2. 1876.
Basilemys (Compsemys) ogmius (Cope).	t×	....	....	....	....	....	t. Dawson	1873–74
Basilemys sinuosa Riggs	....	....	×	....	....	....	3. Brown t. Riggs.	.... t. 1905.
Baena antiqua Lambe	t×	....	....	....	....	....	t1. Lambe	1. 1901
Baena callosa Lambe	....	t×	....	....	....	....	t. Hatcher	1903
Baena hatcheri Hay	....	....	....	t×	....	....	t. Hatcher	1900
Baena marshi Hay	....	....	....	t×	....	....	t. Hatcher	1889
Boremys pulchra Lambe	t×	....	....	....	....	....	t. Lambe	1901

(*"Hell Creek beds" and "Ceratops beds"*), *and Denver and Arapahoe formations*—Continued.

Locality and stratigraphic position as given by the authors cited.	Material on which determination is based.	Authority and reference.	Remarks.
1. Belly River series, Red Deer River, Alberta. 2. Judith River formation, Montana. 3. Hell Creek, Mont. 4. Laramie of Converse County, Wyo. t6. Lignite beds of Colorado [Cross (U. S. Geol. Survey Mon. 27, p. 244) gives the horizon as probably Arapahoe. In a personal communication to the writer G. B. Richardson says: "No vertebrate remains are known to occur in the Laramie of the Denver Basin." Cross's interpretation of the horizon is therefore probably right.]	1. Fragments of right hypoplastral, and margin of carapace. 2. Fragments of costals. 3. Fragment of a costal and peripheral (Hay, loc. cit.). 4. Fragments of costal and plastral. t6. Two fragments, a vertebral and sternal, which constitute the type.	1. Lambe, Contr. Canadian Paleontology, vol. 2, p. 38, 1902. 2. Hay, Fossil turtles of North America, p. 248, 1908. Cope, U. S. Geol. and Geog. Survey Terr. Bull. 3, p. 573, 1877. 3. Brown, Am. Mus. Nat. Hist. Bull., vol. 23, p. 823, 1907. 4. Hay, Fossil turtles of North America, p. 248, 1908. t6. Cope, U. S. Geol. and Geog. Survey Terr. Bull. 1, No. 2, p. 30, 1874. Hatcher, U. S. Geol. Survey Bull. 257, p. 75, 1905.	This species was also reported from the mouth of Bighorn River, Mont. Hatcher thinks Lambe's determination of the Belly River specimens may be incorrect. Hay (loc. cit.) says: "It is unsafe to identify as belonging to *Adocus lineolatus* specimens from the Judith River and Laramie [Lance] beds before far better materials * * * have been collected from the type locality [Bijou Creek, Colo.] * * * It is improbable that the species continued from the Judith River epoch to the Arapahoe epoch."
t. Belly River series, Red Deer River, Alberta.	t. Several costals representing a part of the carapace.	t. Lambe, Contr. Canadian Paleontology, vol. 3, pt. 2, p. 42, 1902.	
t. Judith River beds, Montana.	Founded on unsatisfactory material, only three fragments of which can now be referred to the type. These fragments are probably costal plates.	Hay, Fossil turtles of North America, p. 231, 1908. t. Cope, Acad. Nat. Sci. Philadelphia Proc., vol. 28, p. 257, 1876.	Hay (loc. cit.) says that the species is founded on very unsatisfactory material, that the fragments described belong to more than one species, and that better material will be required to determine the structure and generic position of Cope's *C. imbricarius.*
1. Belly River series, Red Deer River below Berry Creek, Alberta, and Willow Creek subdivision of the Laramie. t2. Judith River beds, Montana. [Also by Stanton and Hatcher in the same formation.]	1. By Lambe, portions of a plastron and anterior half of shell. t2. Founded on carapace and plastron.	1. Lambe, Contr. Canadian Paleontology, vol. 3, pt. 2, p. 39, 1902. 2. Cope, Acad. Nat. Sci. Philadelphia Proc., vol. 28, p. 257, 1876. Hatcher, U. S. Geol. Survey Bull. 257, p. 76, 1905.	Eugene Stebinger, of the U. S. Geological Survey, who has recently mapped the area from which Dawson obtained the type specimen of *B. ogmius*, says that the beds are undoubtedly of Belly River age. The material obtained by Dawson was very fragmentary. Hay (op. cit. p. 229) says: "It is doubtful whether new materials could be identified by means of the type."
t. Belly River series, six miles west of the first branch of Milk River near latitude 49° and between longitude 112° and 113°.	t. Two small, poorly preserved fragments of costal bones.	t. Dawson, British North America Boundary Comm. Rept., p. 130, 1875.	*B. ogmius* is made a synonym of *B. variolosus* by Hay (loc. cit.) and Lambe (op. cit., p. 39.)
3. Hell Creek, Dawson County, Mont. t. Ceratops beds, Chalk Buttes, near Powderville, Custer County, Mont.	3. Fragments of epiplastral lip. t. Whole shell.	3. Brown, Am. Mus. Nat. Hist. Bull., vol. 23, p. 823, 1907. Hay, Fossil turtles of North America, p. 229, 1908. t. Riggs, Field Columbian Mus. Pubs., Geol. ser., vol. 2, p. 249, 1906.	
t1. Belly River series, Red Deer River below Berry Creek, Canada.	1. Part of a carapace, also the anterior end of a plastron probably belonging to the same individual.	1. Lambe, Contr. Canadian Paleontology, vol. 3, pt. 2, p. 44, 1902. Hay, Fossil turtles of North America, p. 62, 1908.	
Judith River beds, Willow Creek, Mont.	An imperfect carapace and the greater portion of a plastron.	Hay, Carnegie Mus. Annals, vol. 3, 1906; Fossil turtles of North America, p. 60, 1908.	
Ceratops beds, Converse County, Wyo., south side of Lance Creek, opposite the mouth of Doegie Creek.	t. A carapace and plastron nearly complete.	t. Hay, Carnegie Mus. Annals, vol. 1, p. 325, 1902; Fossil turtles of North America, p. 63, 1908.	A specimen from Red Deer River (Belly River formation), Canada, referred by Lambe to this species has since been referred to *Boremys pulchra.*
Laramie deposits, Converse County, Wyo., between Lance and Buck creeks.	Cast of the greater portion of the interior of the shell; the greater part of the central portion of the carapace and most of the left side, and a large part of the plastron.	t. Hay, Am. Jour. Sci., 4th ser., vol. 18, p. 261, 1904; Fossil turtles of North America, p. 63, 1908.	
Belly River series, mouth of Berry Creek, Red Deer River, Alberta.	The anterior half of the carapace and the complete plastron.	t. Lambe, Ottawa Naturalist, vol. 19, p. 323, 1906. Hay, Fossil turtles of North America, p. 92, 1908.	Originally referred by Lambe to *Baena hatcheri*, later to *B. pulchra*, and finally to the present genus and species. Hay also describes it as *Boremys pulchra.*

TABLE 6.—*Geologic distribution of vertebrates in the Belly River, Judith River, Lance*

Species.	1 Belly River formation.	2 Judith River formation.	3 "Hell Creek beds" (Lance formation), Montana.	4 Lance formation, Wyoming.	5 "Laramie" formation, Black Buttes, Wyoming.	6 Denver and Arapahoe formations, Colorado.	Finder.	Date.
CHELONIA—continued.								
Compsemys obscura Leidy			×				3. Brown t. Hayden.	3. 1902 1855 or earlier.
Compsemys victa Leidy			×	×		×(?)	3. Brown 4. Isaacs, Hatcher. 6. (?). t. Hayden.	3. 1902 4. 1877. 6. (?). t. 1855 or earlier.
Aspideretes beecheri Hay		×	×	t×			2. Hatcher 3. Brown. t4. Hatcher and Beecher.	2. 1889
Aspideretes (Trionyx) foveatus (Leidy)	×	t×	×			×	1. Lambe t2. Hayden. 3. Brown. 6. (?).	1. 1901
Aspideretes ? (Trionyx) vagans (Cope)						t×(?)	t6. Cope, Hayden	6. 1873
Aspideretes splendidus Hay		t×					Sternberg	1876
Aspideretes granifer Hay		t×					Hatcher	1887

(*"Hell Creek beds" and "Ceratops beds"*), *and Denver and Arapahoe formations*—Continued.

Locality and stratigraphic position as given by the authors cited.	Material on which determination is based.	Authority and reference.	Remarks.
3. Hell Creek, Dawson County, Mont. t. Long Lake, N. Dak. [In beds now regarded as Lance formation.]	3. The proximal ends of two costals. t. Type part of a costal plate.	3. Brown, Am. Mus. Nat. Hist. Bull., vol. 23, p. 823, 1907. Hay, Fossil turtles of North America, p. 235, 1908. t. Leidy, Acad. Nat. Sci. Philadelphia Proc., vol. 8, p. 312, 1856.	This species is included in Osborn's Montana list (Contr. Canadian Paleontology, vol. 3, pt. 2, p. 12, 1902), and in Peale's Judith River list (Jour. Geology, vol. 20, p. 754, 1912), presumably on the authority of Cope's list (U. S. Geol. and Geog. Survey Terr. Bull. 3, p. 573, 1877) of "Vertebrate fossils obtained on or near the Missouri River." Cope's descriptions of the species are given in Am. Philos. Soc. Trans., vol. 14, p. 124, 1869; U. S. Geol. and Geog. Survey Terr. Bull. 1, No. 2, p. 30, 1874; U. S. Geol. Survey Terr. Rept., vol. 2, p. 261, 1875. In each of these descriptions Cope cites Leidy's original description, in which the locality is given as Long Lake. Clearly Cope did not find any specimens of this species in the Judith River collections.
3. Hell Creek, Dawson County, Mont. 4. Lance Creek, Wyo. 6. Northeast Colorado, probably Bijou Creek, in Denver or Arapahoe formation. t. Long Lake, N. Dak. [In beds now regarded as Lance formation.]	3. Fragments including the right peripheral and the outer extremity of the hypoplastron. 4. A right costal and a neural. t. A neural and parts of two costals.	3. Brown, Am. Mus. Nat. Hist. Bull., vol. 23, p. 823, 1907. Hay, Fossil turtles of North America, p. 233, 1908. 4. Hay, op. cit., p. 234. 6. Hay, op. cit., pp. 233, 234. t. Leidy, Acad. Nat. Sci. Philadelphia Proc., vol. 8, p. 312, 1856; Am. Philos. Soc. Trans., 1860, p. 153. Cross, U. S. Geol. Survey Mon. 27, p. 227, 1896.	The reference of this species to the Judith River formation by Peale is based on the same authority as the preceding species, the remarks concerning which apply here, except that in the Am. Philos. Soc. Trans., vol. 14, p. 124, 1869, Cope gives the locality as "Bad land, Judith River, Nebr.," but, as in the other references cited, he refers to Leidy's original description, in which the locality is given as Long Lake. Cope has absolutely no record of having found this species in the Judith River formation. It is also doubtfully reported by Cope from a locality south of Woody Mountain, Canada (British North America Boundary Comm. Rept., p. 33, 1875; U. S. Geol. Survey Terr. Rept., vol. 2, p. 261, 1875). Knowlton (Washington Acad. Sci. Proc., vol. 13, 1911) regards the formation as Lance, hence there is no basis for including this species in the list from the Judith River formation.
2. Fish Creek, Mont., south of Musselshell River. 3. Hell Creek, Mont. t4. Lance Creek, Converse County, Wyo.	2. Two carapaces. 3. Not given. t4. A nearly complete individual.	2. Hay, Carnegie Mus. Annals, vol. 3, p. 178, 1905. 3. Brown, Am. Mus. Nat. Hist. Bull., p. 842, 1907. t4. Hay, Am. Jour. Sci., 4th ser., vol. 18, p. 224, 1904.	2. Hay (loc. cit.) says that it may belong to a distinct species. 4. The species was also collected by Marsh from the "Laramie" (Lance) of Wyoming, but was called by him *Trionyx foveatus*.
1. Belly River series, Red Deer River, Alberta. t2. Judith River beds, Montana; also near Long Lake, N. Dak., from Laramie. 3. Hell Creek, Mont. 6. Ceratops beds near Denver, Colo.	1. A nearly complete carapace, also hyposternal and plastral bones. t2. Several costal and sternal plates. 3. Three neurals and portions of costals. 6. Not given.	1. Lambe, Contr. Canadian Paleontology, vol. 3, pt. 2, p. 33, 1902. t2. Leidy, Acad. Nat. Sci. Philadelphia Proc., vol. 8, pp. 73, 312, 1856; Am. Philos. Soc. Trans., vol. 11, p. 148, 1860. 3. Brown, Am. Mus. Nat. Hist. Bull., vol. 23, p. 842, 1907. Hay, Fossil turtles of North America, p. 488, 1908. 6. Marsh, U. S. Geol. Survey Mon. 27, p. 527, 1896.	2. Also reported in Cope's collection from the Judith River basin (Hay, Fossil turtles of North America, p. 488, 1908). 3. Hay (loc. cit.) says: "Had they been found in the Judith River formation they would without hesitation be referred to *A. foveatus*. * * * Only a complete shell of this Laramie form will settle the questions involved." There is therefore doubt as to the specific identification of the specimens from Hell Creek. 6. Hay (loc. cit.) says that this probably belongs to *Aspiderctes beecheri*.
t6. Lignite Cretaceous (probably Arapahoe formation, according to Cross, U. S. Geol. Survey Mon. 27), Bijou Creek, 40 miles east of Denver, Colo. Laramie formation, near mouth of Bighorn River, Mont., and Long Lake, N. Dak., by Hayden.	t6. A number of fragments of costals and sternals.	t6. Cope, U. S. Geol. and Geog. Survey Terr. Ann. Rept., p. 453, 1874.	Hay (loc. cit.) refers Lambe's specimen of *T. vagans* to *Aspideretes coalescens*.
t. Judith River basin, Mont.	A large but imperfect carapace.	Hay, Fossil turtles of North America, p. 490, 1908.	Cope's reference of *T. vagans* to the Judith River formation may have been based on this specimen (Acad. Nat. Sci. Philadelphia Proc., p. 9, 1875; U. S. Geol. and Geog. Survey Terr. Bull. 3, p. 573, 1877).
Judith River beds, Cow Island, Mont.	Nearly complete costal and fragments of other costals.	Hay, U. S. Nat. Mus. Proc., vol. 35, pp. 168–169, 1908.	

TABLE 6.—*Geologic distribution of vertebrates in the Belly River, Judith River, Lance*

Species.	1 Belly River formation.	2 Judith River formation.	3 "Hell Creek beds" (Lance formation), Montana.	4 Lance formation, Wyoming.	5 "Laramie" formation, Black Buttes, Wyoming.	6 Denver and Arapahoe formations, Colorado.	Finder.	Date.
CHELONIA—continued.								
Aspideretes (Plastomenus) coalescens (Cope) Hay.	×						1. Lambe and McConnell. t. Dawson.	1. 1897, 1898, and 1901. t. 1873 or 1874.
Plastomenus costatus Cope			×				3. Brown t. Dawson.	3. 1902. t. 1873?
Plastomenus punctulatus Cope						t×(?)	Cope	1873
Plastomenus insignis Cope						t×(?)	Cope	1873
Eubaena cephalica Hay				t×			Hatcher	(?)
Eubaena latifrons Hay				×			Brown	
Thescelus insiliens Hay				t×			Brown	
Helopanoplia distincta Hay				t×			Hatcher	
Gyremys spectabilis Hay		t×					Sternberg t. Isaacs.	1876
Polythorax missouriensis Cope		t×						1876
Glyptops depressus Hay						t×(?)	Cannon	1889

(*"Hell Creek beds" and "Ceratops beds"*), *and Denver and Arapahoe formations*—Continued.

Locality and stratigraphic position as given by the authors cited.	Material on which determination is based.	Authority and reference.	Remarks.
1. Belly River series, Red Deer River, Canada. t. South of Woody Mountain, Canada, latitude 49°, longitude between 106° and 107°. [In beds regarded by Knowlton as the equivalent of the Lance formation.]	1. In 1897 part of dorsal and ventral shields. In 1901 a carapace originally described as *Trionyx vagans*. t. Type a part of the plastron, insufficient for final generic determination. Hay says that Cope erred in thinking a part of this belonged to the carapace.	1. Lambe, Ottawa Naturalist, vol. 13, p. 68, 1899; Contr. Canadian Paleontology, vol. 3, pt. 2, p. 36, 1906 (*T. vagans*). Hay, Fossil turtles of North America, p. 438, 1908. t. Cope, British North America Boundary Comm. Rept., p. 237, 1875. Knowlton, Washington Acad. Sci. Proc., vol. 13, pp. 53–54.	1. Hay (loc. cit.) provisionally refers Lambe's specimens of *Trionyx vagans* and *Plastomenus coalescens* from the Belly River formation to this genus and species. t. Knowlton (loc. cit.) regards the formation from which Cope's type specimen was obtained as Lance instead of Belly River or Judith River. Until the specific characters and geologic horizon of the specimens referred to this species are accurately determined it can not be positively asserted whether or not this species occurs in both the Belly River and Lance formations.
3. Hell Creek, 12 miles south of Missouri River, Mont. t. South of Woody Mountain, Canada, same locality and horizon as *Aspideretes* (*Plastomenus*) *coalescens*, above.	3. Carapace and plastron, parts of each. t. Fragments of a costal and a hypoplastron too fragmentary for final determination.	3. Hay, Fossil turtles of North America, p. 468, 1908. t. Cope, British North America Boundary Comm. Rept., p. 334, 1875; U. S. Geol. Survey Terr. Rept., vol. 2, p. 94, Pl. VIII, fig. 8, 1875.	No weight can be attached to the specimens of this and the preceding species obtained south of Woody Mountain, because the material, according to Cope (loc. cit.), is too fragmentary for final determination, and the geologic horizon is doubtful. Hatcher regards it as Belly River; Knowlton (loc. cit.) as Lance. The preceding species has been identified from the Belly River only and this one from the Lance.
Northeastern Colorado, probably Bijou Creek. [See comment by G. B. Richardson under *Adocus lineolatus*.]	Fragments of a costal plate.	t. Cope, U. S. Geol. and Geog. Survey Terr. Seventh Ann. Rept., p. 453, 1873. Hay, Fossil turtles of North America, p. 468, 1908. Knowlton, Washington Acad. Sci. Proc., vol. 13, p. 56, 1911.	Cope also reports the species from the vicinity of Long Lake, N. Dak. [probably Lance]. The species was also included in the Judith River [Belly River] by Hatcher, but Knowlton (loc. cit.) has pointed out the error in Hatcher's reference.
Northeastern Colorado, probably Bijou Creek. [See comment by G. B. Richardson under *Adocus lineolatus*.]	t. Fragment of the hypoplastron.	t. Cope, U. S. Geol. and Geog. Survey Terr. Seventh Ann. Rept., p. 453, 1873. Hay, Fossil turtles of North America, p. 468, 1908.	The reference of this species to the Judith River by Hatcher was an error. See Knowlton, op. cit., p. 56.
Laramie of Converse County, Wyo.	A fine skull.	Hay, Fossil turtles of North America, p. 82, 1908. t. Hay, Am. Jour. Sci., 4th ser., vol. 18, p. 263, Pl. XII, 1904.	
Laramie of Sevenmile Creek, Weston County, Wyo., 5 miles north of Cheyenne River and 40 miles northwest of Edgemont, S. Dak.	A skull without the lower jaw.	Hay, Fossil turtles of North America, p. 83, 1908.	
Laramie of Sevenmile Creek, Weston County, Wyo., 5 miles north of Cheyenne River and 40 miles northwest of Edgemont, S. Dak.	A very complete specimen presenting both carapace and plastron.	t. Hay, Fossil turtles of North America, p. 95, pls. 24–25, 1908.	
Lance Creek, Converse County, Wyo.	A fragment of a costal plate and a portion of a hypoplastron or hyoplastron.	t. Hay, Fossil turtles of North America, p. 485, pl. 88, figs. 4, 5, 1908.	
t. Judith River deposits, Montana.	Complete plastron and part of a carapace.	t. Hay, Fossil turtles of North America, p. 288, pl. 44, figs. 1, 2; text figs. 357, 358, 1908.	
Fort Union beds, Montana. [See remarks on *Ceratodus* (*Rhineastes*) *cruciferus* p. 119.]	Plastron, carapace, mandible, and some other material.	t. Cope, Acad. Nat. Sci. Philadelphia Proc., vol. 28, p. 258, 1876. Hay, Fossil turtles of North America, p. 100, 1908.	Hatcher (U. S. Geol. Survey Bull. 257, p. 77, 1905) says that the species is founded on ample material.
Denver beds (?).	t. Fairly complete carapace and plastron.	t. Hay, Fossil turtles of North America, p. 55, 1908.	

TABLE 6.—*Geologic distribution of vertebrates in the Belly River, Judith River, Lance*

Species.	1 Belly River formation.	2 Judith River formation.	3 "Hell Creek beds" (Lance formation), Montana.	4 Lance formation, Wyoming.	5 "Laramie" formation, Black Buttes, Wyoming.	6 Denver and Arapahoe formations, Colorado.	Finder.	Date.
RHYNCHOCEPHALIA.								
Champsosaurus annectens Cope	×	t×					1. Lambe. Macoun. Dawson. Weston. 2. Not given.	1901. 1880. 1881. 1884.
Champsosaurus brevicollis Cope		t×					2. Cope	
Champsosaurus profundus Cope		t×					2. Cope (?)	
Champsosaurus vaccinsulensis Cope		t×					2. (?)	
Champsosaurus ambulator Brown			t×				Brown	1902
Champsosaurus laramiensis Brown			t×				Brown	1902
Champsosaurus sp	×			×			1. Gilmore	
SQUAMATA.								
Chamops segnis Marsh				t×			Hatcher	
Coniophis precedens Marsh				t×			Hatcher	
Iguanavus teres Marsh				t×			Hatcher	
CROCODILIDÆ.								
Brachychampsa (Bottosaurus) perrugosa (Cope).						t×(?)		

(*"Hell Creek beds" and "Ceratops beds"*), *and Denver and Arapahoe formations*—Continued.

Locality and stratigraphic position as given by the authors cited.	Material on which determination is based.	Authority and reference.	Remarks.
1. Belly River series, Red Deer River, Mackay Creek, near Walsh station, Canadian Pacific Ry., on Belly River; Ross Coulee, near Irwin station, Canada. 2. Judith River beds, Montana, and Fox Hills [Claggett formation], Armells Creek (east of Judith River), Mont.	1. A large number of vertebræ, none of which were found together in their proper relative positions. t2. Several vertebræ concerning which Cope says he "can not certainly connect the vertebræ of a series as those of a single individual." Brown (loc. cit.) says that the specimen gives good generic characters, but specific definition must await better material from these beds.	1. Lambe, Contr. Canadian Paleontology, vol. 3, pt. 2, p. 45, 1902. t2. Cope, Acad. Nat. Sci. Philadelphia Proc., vol. 28, p. 351, 1876. Brown, Am. Mus. Nat. Hist. Mem., vol. 9, pt. 1, p. 6, 1905.	2. Regarding the specimen from the so-called Fox Hills [Claggett formation], Cope (op. cit., p. 352) says: "I can not account for this circumstance, as it is the most abundant fossil of the Judith River beds." As the Judith River formation is now known to overlie so-called Fox Hills conformably, the occurrence is not remarkable.
2. Judith River beds, Montana.	t2. A weathered axis centrum of an immature individual, considered invalid by Brown (loc. cit.).	t2. Cope, Acad. Nat. Sci. Philadelphia Proc., vol. 28, p. 352, 1876. Brown, Am. Mus. Nat. Hist. Mem., vol. 9, pt. 1, p. 6, 1905.	Brown (loc. cit.) says that *C. brevicollis* is invalid. Hatcher (U. S. Geol. Survey Bull. 257, pp. 81, 82, 1905) says of these species: "Owing to the fact that these Judith River forms are known almost exclusively from disarticulated vertebral centra, and considering the usually very simple structure of these throughout the entire vertebral column in this group, it may at present be considered difficult, if not impossible, to distinguish the Judith River forms from one another or from the later Laramie forms." "It has yet to be shown that most of the characters mentioned by Cope as distinguishing his species are not present in vertebræ from different regions of the vertebral column in the same individual."
2. Judith River beds, Montana.	t2. A sacral, a cervical, and 3 dorsal vertebræ believed to belong to the same animal, and isolated vertebræ of separate individuals. Considered valid by Brown (loc. cit.).	t2. Cope, Acad. Nat. Sci. Philadelphia Proc., vol. 28, p. 350, 1876. Brown, Am. Mus. Nat. Hist. Mem., vol. 9, pt. 1, p. 6, 1905.	
2. Judith River beds, Montana.	2. One-half of a vertebral centrum which Brown (loc. cit.) refers to the order Plesiosauria.	2. Cope, Acad. Nat. Sci. Philadelphia Proc., vol. 28, p. 353, 1876. Brown, Am. Mus. Nat. Hist. Mem., vol. 9, pt. 1, p. 6, 1905.	
Hell Creek beds, Montana.	Fairly complete skeleton.	Brown, Am. Mus. Nat. Hist. Bull., vol. 23, p. 829, 1907. t. Brown, Am. Mus. Nat. Hist. Mem., vol. 9, pt. 1, pp. 4, 22–25, pl. 4, fig. 2, pl. 5, figs. 3, 3a, 5, 5a, 6, 6a, 14, 15, 1905.	
Hell Creek beds, Hell Creek, Mont.	Nearly complete skull and skeleton.	t. Brown, Am. Mus. Nat. Hist. Mem., vol. 9, pt. 1, pp. 4, 8–22, pls. 1–5, 1905; Am. Mus. Nat. Hist. Bull., vol. 23, p. 842, 1907.	
1. Beds of Belly River age [Two Medicine formation], Milk River, Mont. 4. Laramie deposits, Converse County, Wyo.	Not given.	1. C. W. Gilmore, oral communication. 4. Williston, Science, new ser., vol. 16, pp. 952–953, 1902.	
Laramie of Wyoming. [Presumably Converse County.]	t. Maxillary bone containing teeth; various other parts of the skull and skeleton, including vertebræ, have been found at different localities.	t. Marsh, Am. Jour. Sci., 3d ser., vol. 43, p. 450, 1892.	
Ceratops beds, Wyoming.	A single vertebra, but several other vertebræ that may not belong to the same individual were found at the same locality.	t. Marsh, Am. Jour. Sci., 3d ser., vol. 43, p. 450, 1892.	The materia described with the type listed was found according to Marsh at different localities. It is not certain that it all pertains to the same species.
Laramie of Wyoming. [Probably Converse County.]	t. Vertebræ.	t. Marsh, Am. Jour. Sci., 3d ser., vol. 43, p. 450, 1892.	
6. Eastern Colorado. [Cross, (U. S. Geol. Survey Mon. 27, p. 244, 1896) regards the formation as Arapahoe. See also comment by G. B. Richardson under *Adocus lineolatus*, p. 123.	t6. Numerous fragments with vertebræ and portions of skull.	t6. Cope, U. S. Geol. and Geog. Survey Terr. Seventh Ann. Rept., p. 452, 1874. Hatcher, U. S. Geol. Survey Bull. 257, p. 82, 1905.	Referred provisionally to this genus by C. W. Gilmore. The specimen originally described by Lambe as *B. perrugosus*, from the Belly River formation, has since been referred by him to *Leidyosuchus canadensis* Lambe.

TABLE 6.—*Geologic distribution of vertebrates in the Belly River, Judith River, Lance*

Species.	1 Belly River formation.	2 Judith River formation.	3 "Hell Creek beds" (Lance formation), Montana.	4 Lance formation, Wyoming.	5 "Laramie" formation, Black Buttes, Wyoming.	6 Denver and Arapahoe formations, Colorado.	Finder.	Date.
CROCODILIDÆ—continued.								
Brachychampsa montana Gilmore	....	....	t×	×	....	....	t3. Brown	....
Crocodilus humilis Leidy	....	t×	....	×	....	×	2. Hayden 4. (?). 6. (?).	....
Crocodilus sp	....	....	×	....	....	....	Brown	....
Deinosuchus hatcheri Holland	....	t×	....	....	....	....	Hatcher and Utterback.	1903
Leidyosuchus sternbergi Gilmore	....	....	t×	×	....	....	3. Brown 4. Sternberg.	4. 1910.
Leidyosuchus canadensis Lambe	t×	....	....	....	....	....	Lambe	1897, 1901
DINOSAURIA.								
Zapsalis abradens Cope	....	×	....	×	....	....	2. (?) 4. Hatcher.	....
Troodon formosus Leidy	×	t×	....	×	....	....	1. Lambe 2. Hayden. 4. Hatcher.	1. 1901
Aublysodon mirandus Leidy	....	t×	....	×	....	....	2. Hayden 4. Hatcher.	....
Paronychodon lacustris Cope	....	t×	....	....	....	....	....	....

("*Hell Creek beds*" *and* "*Ceratops beds*"), *and Denver and Arapahoe formations*—Continued.

Locality and stratigraphic position as given by the authors cited.	Material on which determination is based.	Authority and reference.	Remarks.
3. Hell Creek beds, 25 miles southeast of Lismas, Dawson County, Mont.	t3. The greater part of a skull.	t3. Gilmore, U. S. Nat. Mus. Proc., vol. 41, p. 297, 1912.	4. "Teeth which can not be distinguished from those of the type have been found in the Lance formation of Converse County, Wyo." (Oral statement by C. W. Gilmore.)
2. Badlands of Judith River [Judith River formation], Mont. 4. Ceratops beds, Converse County, Wyo. 6. Ceratops beds (on p. 527), near Denver, Colo.; Denver formation (on p. 227).	t2. Ten specimens of shed crowns of teeth. 4. Not given. 6. Not given.	t2. Leidy, Acad. Nat. Sci. Philadelphia Proc., vol. 8, p. 73, 1856. 4. Williston, Science, new ser., vol. 16, pp. 952–953, 1902. 6. Marsh, U. S. Geol. Survey Mon. 27, pp. 227, 527, 1896.	2. Of Leidy's material Hatcher (U. S. Geol. Survey Bull. 257, p. 82, 1905) says: "The simple conical teeth on which the species was based furnished no characters for the positive identification of other material." This species, therefore, seems to be of little value for correlation. The material from the Belly River formation originally referred by Lambe to this species was later referred by him to *Leidyosuchus canadensis*. (See below.)
Hell Creek beds, Montana.	Not given.	Brown, Am. Mus. Nat. Hist. Bull., vol. 23, p. 842, 1907.	
t. Judith River beds, Willow Creek, Musselshell County, Mont., 3 miles west of Nolan & Archer's ranch (stage crossing to Flat Willow).	t. Several scutes, 2 vertebræ, 1 cervical rib, 1 dorsal rib, fragments of ribs and pubis, and several hundred fragments of bones belonging to the skull, vertebræ, and ribs, all badly broken.	t. Holland, Carnegie Mus. Annals, vol. 6, p. 281, 1909.	A dermal scute referred to this species was found by C. H. Wegemann in sec. 23, T. 41 N., R. 79 W., Natrona County, Wyo., in the Parkman sandstone member of the Pierre formation, of Montana age (U. S. Geol. Survey Bull. 452, p. 48, 1911).
3. Hell Creek beds, Gilbert Creek, Dawson County, Mont., 135 miles northwest of Miles City. 4. Ceratops beds, Converse County, Wyo., north side of Cheyenne River, 3 miles west of McKeow's ranch.	t3. Greater part of skull. 4. Greater part of skull, left ramus almost entire, anterior part of right ramus, 8 vertebræ, both humeri, right fibula, metatarsal and other fragments.	t3. Gilmore, U. S. Nat. Mus. Proc., vol. 38, pp. 485–502, 1911. 4. Gilmore, idem, p. 497.	
Belly River series, Red Deer River, Alberta.	t. A left mandibular ramus, posterior part of a cranium, portions of the skull, teeth, and a number of vertebræ and scutes.	t. Lambe, Roy. Soc. Canada Trans., 3d ser., vol. 1, sec. 4, p. 219, 1907.	Lambe says: "The jaw was originally described as *Bottosaurus perrugosus* and the teeth as *Crocodilus humilis*." He now concludes that all the material represents a single species, to which he gives a new name. It thus appears that *L. canadensis* replaces *B. perrugosus* and *C. humilis* in the Belly River list of Lambe and Osborn.
2. Judith River beds, Montana. 4. Laramie beds, Wyoming.	2. Detached teeth. 4. Numerous small teeth.	2. Cope, Acad. Nat. Sci. Philadelphia Proc., vol. 28, p. 345, 1876. 4. Hatcher, U. S. Geol. Survey Bull. 257, p. 84, 1905.	4. Hatcher (loc. cit.) says: "The meager description given by Cope, without figures, renders it impossible to certainly identify any of the forms of teeth known from these deposits with those referred to by Cope in his description. * * * Their exact nature must, for the present at least, remain uncertain."
1. Belly River series, Red Deer River, below mouth of Berry Creek, Alberta. 2. Badlands of Judith River, Mont. 4. Laramie of Converse County, Wyo.	1. Two teeth which agree in every particular with Leidy's type. t2. A single tooth, which constitutes the type. 4. Teeth similar to those described by Leidy.	1. Lambe, Contr. Canadian Paleontology, vol. 3, pt. 2, p. 47, 1902. t2. Leidy, Acad. Nat. Sci. Philadelphia Proc., vol. 8, p. 72, 1856. 4. Hatcher, U. S. Geol. Survey Bull. 257, p. 83, 1905.	Of this and the three succeeding genera Hatcher (U. S. Geol. Survey Bull. 257, p. 83, 1905) says: "They are all founded on such fragmentary material as to be of little value except as bearing evidence of the diversity of the fauna."
2. Badlands of Judith River, Mont. 4. Laramie of Wyoming.	t2. Several problematical teeth originally included by Leidy in his type of *Deinodon horridus*. 4. Teeth.	t2. Leidy, Acad. Nat. Sci. Philadelphia Proc., vol. 20, p. 198, 1868. 4. Hatcher, U. S. Geol. Survey Bull. 257, p. 83, 1905.	2. Probably synonymous with *Deinodon horridus*. (See remarks on that species.) 4. Hatcher (loc. cit.) says: "Similar teeth are common both in the Judith River and Laramie."
Fort Union of Montana. [Beds now identified as Judith River formation.]	t. Detached teeth with subconic crowns.	t. Cope, Acad. Nat. Sci. Philadelphia Proc., vol. 28, p. 256, 1876.	Hatcher (U. S. Geol. Survey Bull. 257, p. 84, 1905) regards this species as a synonym of *Aublysodon mirandus*. It seems probable, therefore, that *Deinodon horridus*, *Aublysodon mirandus*, and *Paronychodon lacustris* are synonyms. Osborn (Am. Mus. Nat. Hist. Bull., vol. 5, p. 320, 1893) says that the teeth described by Cope "resemble those which we have referred to as the probable lower incisors of Meniscoessus." Apparently on this ground alone Peale (Jour. Geology, vol. 20, p. 720, 1912) has included *P. lacustris* in his Converse County list.

TABLE 6.—*Geologic distribution of vertebrates in the Belly River, Judith River, Lance*

Species.	1 Belly River formation.	2 Judith River formation.	3 "Hell Creek beds" (Lance formation), Montana.	4 Lance formation, Wyoming.	5 "Laramie" formation, Black Buttes, Wyoming.	6 Denver and Arapahoe formations, Colorado.	Finder.	Date.
DINOSAURIA—continued.								
Deinodon horridus Leidy	×	t×					1. Lambe 2. Hayden.	1897, 1901 2. Not given.
Deinodon (Lælaps) incrassatus Cope	×	t×					1. Lambe 2. Isaacs.	1. 1897, 1898
Deinodon (Aublysodon) lateralis Cope		×					Sternberg	
Deinodon (Lælaps) explanatus Cope	×	t×		×			1. Lambe 2. (?). 4. Hatcher.	1. 1901
Deinodon (Lælaps) falculus Cope		t×					Isaacs	
Deinodon (Lælaps) hazenianus Cope		t×		×			2. Not given 4. Hatcher.	
Deinodon (Lælaps) lævifrons Cope		t×					Not given	
Deinodon (Aublysodon) amplus Marsh				t×			Hatcher	
Deinodon (Lælaps) cristatus Cope		×		t×			2. Not given 4. Hatcher.	
Ornithomimus tenuis Marsh		t×					Hatcher	

(*"Hell Creek beds" and "Ceratops beds"), and Denver and Arapahoe formations*—Continued.

Locality and stratigraphic position as given by the authors cited.	Material on which determination is based.	Authority and reference.	Remarks.
1. Belly River series, Red Deer River, Canada. 2. Badlands of Judith River, Mont.	1. A number of teeth; a few phalanges and a metatarsal are also probably referred to this species. t2. A number of teeth.	1. Lambe, Contr. Canadian Paleontology, vol. 3, pt. 2, p. 49, 1902. 2. Leidy, Acad. Nat. Sci. Philadelphia Proc., vol. 8, p. 72, 1856. Osborn, Am. Mus. Nat. Hist. Bull., vol. 21, p. 261, 1905.	2. The uncertainty regarding the material on which Leidy founded the type is shown by the fact that later (Acad. Nat. Sci. Philadelphia Proc. for 1868, p. 198) he referred part of the teeth to a new genus and species (*Aublysodon mirandus*); whereas Lambe (loc. cit.) says that Leidy's first determination was correct and that the teeth used at a later date for the foundation of the genus Aublysodon are probably the anterior teeth of Deinodon. Osborn concurs in this view.
1. Belly River beds near mouth of Berry Creek, Red Deer River. 2. Judith River beds, Montana.	1. Separate teeth and terminal phalanges. t2. Two teeth of different sizes, found near each other but not sufficiently near to warrant the belief that they belong to the same individual.	1. Lambe, Ottawa Naturalist, vol. 13, p. 69, 1899; Contr. Canadian Paleontology, vol. 3, pt. 3, p. 5, 1904. t2. Cope, Acad. Nat. Sci. Philadelphia Proc., vol. 28, pp. 248, 341, 1876. 1 and 2. Hay, U. S. Nat. Mus. Proc., vol. 35, p. 356, 1909.	Two skulls from the Edmonton formation of Knee Hills Creek, Red Deer River, Canada, were originally described by Cope (Am. Philos. Soc. Proc., vol. 30, p. 240, 1892) as *Læelaps incrassatus*. In 1904 Lambe (Contr. Canadian Paleontology, vol. 3, pt. 3, pp. 5-27) bestowed on these specimens the name *Dryptosaurus incrassatus*. In 1905 Osborn (Am. Mus. Nat. Hist. Bull., vol. 21, p. 265) gave them the name *Albertosaurus sarcophagus*. Whatever the final disposition of these specimens it is evident that they do not belong to *Læelaps incrassatus*. 2. Hatcher (U. S. Geol. Survey Bull. 257, p. 86, 1905) says: "These teeth are probably from near the anterior and posterior extremities of the series in some representative of *D. horridus* Leidy."
Fort Union beds, Montana.	Detached teeth.	Cope, Acad. Nat. Sci. Philadelphia Proc., vol. 28, p. 248, 1876.	
1. Belly River series, Red Deer River, Alberta, Canada. 2. Fort Union (Judith River) beds, Montana. 4. Laramie formation, Wyoming.	1. One small tooth. 2. Numerous small teeth. 4. Teeth similar to those described by Cope.	1. Lambe, Contr. Canadian Paleontology, vol. 3, pt. 2, p. 49, 1902. t2. Cope, Acad. Nat. Sci. Philadelphia Proc., vol. 28, pp. 249, 344, 1876. 4. Hatcher, U. S. Geol. Survey Bull. 257, p. 86, 1905.	
Fort Union (Judith River) beds, Montana.	Several teeth about half the size of those of *D. explanatus*.	t. Cope, Acad. Nat. Sci. Philadelphia Proc., vol. 28, pp. 249, 344, 1876.	Hatcher (U. S. Geol. Survey Bull. 257, p. 86, 1905) says that these teeth may represent anterior teeth of *D. explanatus*.
2. Judith River beds, Montana. 4. Laramie formation.	t2. Several detached teeth from different localities. 4. Teeth similar to those described by Cope.	t2. Cope, Acad. Nat. Sci. Philadelphia Proc., vol. 28, p. 343, 1876. 4. Hatcher, U. S. Geol. Survey Bull. 257, p. 86, 1905.	2. Hatcher says that these teeth are common in the Judith River and Laramie [so-called] formations. "They appear to pertain to the anterior dentition of some of these carnivorous dinosaurs, probably of *D. horridus*."
Judith River beds, Montana.	Founded on a single tooth.	t. Cope, Acad. Nat. Sci. Philadelphia Proc., vol. 28, p. 344, 1876.	Hatcher (U. S. Geol. Survey Bull. 257, p. 86, 1905) says: "It [the tooth which constitutes the type] is distinguished by the absolutely smooth character of the anterior edge, a character of doubtful value."
Ceratops beds, Wyoming.	Founded on detached teeth similar to those of *Aublysodon mirandus*, but smaller.	t. Marsh, Am. Jour. Sci., 3d ser., vol. 44, p. 174, 1892.	Hatcher (U. S. Geol. Survey Bull. 257, p. 84, 1905) says that Marsh's *A. amplus* and *A. cristatus* from the "Ceratops beds" of Montana and Wyoming are not properly described and should be abandoned, that teeth similar to those figured by Leidy are common in both the Laramie [so-called] and Judith River formations, but that they are not sufficiently characteristic to distinguish either genera or species.
2. Judith River beds, Montana. 4. Converse County, Wyo. (?).	2. Detached teeth. 4. Teeth.	2. Cope, Acad. Nat. Sci. Philadelphia Proc., vol. 28, p. 344, 1876. t4. Marsh, Am. Jour. Sci., 3d ser., vol. 44, p. 174, 1892.	2. Hatcher (U. S. Geol. Survey Bull. 257, p. 86, 1905) says that the teeth resemble those of Troodon and possibly pertain to that genus. 4. See remarks on *D. amplus*.
Judith River beds, Montana.	Part of a third metatarsal.	t. Marsh, Am. Jour. Sci., 3d ser., vol. 39, pp. 81-86, 1890. Hatcher, U. S. Geol. Survey Bull. 257, p. 87, 1905.	Hatcher (loc. cit.) says that the genus Ornithomimus is represented by such meager material that as yet it is quite impossible to determine many of the more important characters of the genus or to compare the various species with one another satisfactorily.

TABLE 6.—*Geologic distribution of vertebrates in the Belly River, Judith River, Lance*

Species.	1 Belly River formation.	2 Judith River formation.	3 "Hell Creek beds" (Lance formation), Montana.	4 Lance formation, Wyoming.	5 "Laramie" formation, Black Buttes, Wyoming.	6 Denver and Arapahoe formations, Colorado.	Finder.	Date.
DINOSAURIA—continued.								
Ornithomimus grandis Marsh				×			Hatcher	
Ornithomimus velox Marsh				×		t×	4. Hatcher 6. Cannon.	4. 1889
Ornithomimus altus Lambe	t×		×				1. Hatcher 3. Brown.	1. 1901
Ornithomimus sedens Marsh				t×			4. Hatcher	4. 1891
Ornithomimus minutus Marsh				t×				
Tyrannosaurus rex Osborn			×	×			3. Brown 4. Brown, Sternberg.	3. 1902 4. 1900.
Palæoscincus costatus Leidy	×	t×		×			1. Lambe 2. Hayden, Hatcher. 4. Hatcher.	1. 1901
Palæoscincus sp			×	×			3. Brown 4. Williston.	
Palæoscincus asper Lambe	t×			×			1. Lambe 4. Not given.	1. 1901
Palæoscincus latus Marsh				t×			Not given	
Stereocephalus tutus Lambe	×						1. Lambe	1. 1897
Nodosaurus textilis Marsh	×(?)			t×			1. Lambe 4. Not given.	1. 1897, 1898
Ankylosaurus magniventris Brown			×				Kaisen	1906

("*Hell Creek beds*" *and* "*Ceratops beds*"), *and Denver and Arapahoe formations*—Continued.

Locality and stratigraphic position as given by the authors cited.	Material on which determination is based.	Authority and reference.	Remarks.
4. Ceratops beds, Wyoming. [See "Remarks."]	4. Femur, tibia, and fibula from one skeleton and second metatarsal from another. t. A considerable portion of a skeleton.	Marsh, Am. Jour. Sci., 3d ser., vol. 43, pp. 449–453, 1892. Hatcher, U. S. Geol. Survey Bull. 257, p. 87, 1905.	The type of this species has also been accredited to the Judith River formation, but Hatcher (loc. cit.) says that it was found in the Eagle sandstone near the mouth of Cow Creek, opposite Cow Island, Missouri River, Mont., and that "hereafter it should be referred to the Eagle formation," which is considerably older than the Judith River. 4. C. W. Gilmore says that this specimen is probably referable to Osborn's Tyrannosaurus.
4. Ceratops beds, Wyoming. 6. Denver beds, Green Mountain, near Denver, Colo.	4. Not given. 6. Bones of the limbs and feet.	4. Marsh, Am. Jour. Sci., 3d ser., vol. 43, pp. 449–453, 1892. t6. Marsh, idem, vol. 39, pp. 81–86, 1890; U. S. Geol. Survey Sixteenth Ann. Rept., pt. 1, p. 205, 1896; U. S. Geol. Survey Mon. 27, p. 518, 1896.	
1. Belly River series, below Berry Creek, Red Deer River, Canada. 3. Hell Creek beds, Montana.	1. Complete right hind limb, including the foot, the phalanges of the left foot in place, a pubic bone, and an ischium. 3. Not given.	t1. Lambe, Contr. Canadian Paleontology, vol. 3, pt. 2, p. 50, 1902. 3. Brown, Am. Mus. Nat. Hist. Bull., vol. 23, p. 842, 1907.	1. Specimens believed by Lambe to belong to this species have been found at various places by several collectors; among the specimens are a costal vertebra and phalanges from the Edmonton formation.
4. Ceratops beds, Wyoming.	4. Nearly complete pelvis with portion of the tail.	t4. Marsh, Am. Jour. Sci., 3d ser., vol. 43, pp. 451–452, 1892.	
4. Ceratops beds, Converse County, Wyo.	4. A sacrum, complete ischia, cervical, dorsal, and caudal vertebræ.	Williston, Kansas Univ. Quart., vol. 7, pp. 173–174, 1898. Marsh, Am. Jour. Sci., 3d ser., vol. 43, pp. 449–453, 1892.	
3. Canyon of Hell Creek, Mont.; Sevenmile Creek, 6 miles north of Cheyenne River, Weston County, Wyo. 4. Converse County, Wyo.	t3. The larger part of a skeleton. 4. Occiput and brain case, dermal plates, and many parts of the skeleton.	t3. Osborn, Am. Mus. Nat. Hist. Bull., vol. 21, p. 259, 1905; vol. 22, p. 281, 1906. 4. Osborn, Am. Mus. Nat. Hist. Mem., new ser., vol. 1, pt. 1, p. 4, 1912.	The specimen originally described (op. cit., vol. 21) as *Dynamosaurus imperiosus* is now included in *T. rex*.
1. Belly River series, below Berry Creek, Red Deer River, Canada. 2. Judith River beds, Cow Island, Mont. 4. Laramie formation.	1. A few teeth. t2. Founded on a single tooth discovered by Hayden. 4. Teeth of the same general pattern as that described by Leidy.	1. Lambe, Contr. Canadian Paleontology, vol. 3, pt. 2, p. 53, 1902. 2. Leidy, Am. Philos. Soc. Trans., vol. 11, p. 146, 1890. Hatcher, U. S. Geol. Survey Bull. 257, p. 88, 1905. 4. Hatcher, idem.	Hatcher (loc. cit.) says: "Teeth of the same general form and pattern as those described and figured by Leidy are common in the Judith River beds and in the Laramie. As yet they have only been found detached, so that nothing is positively known of the nature of the animals to which they belonged."
3. Hell Creek beds, Montana. 4. Ceratops beds, Converse County, Wyo.	3. Not given. 4. Not given.	3. Brown, Am. Mus. Nat. Hist. Bull., vol. 23, p. 842, 1907. 4. Williston, Science, new ser., vol. 16, pp. 952–953, 1902.	
1. Belly River series, below mouth of Berry Creek, Red Deer River, Canada. 4. Laramie Cretaceous of Converse County, Wyo.	1. One tooth. 4. Teeth.	t1. Lambe, Contr. Canadian Paleontology, vol. 3, pt. 2, p. 54, 1902. 4. Williston, Science, new ser., vol. 16, p. 953, 1902. Marsh, U. S. Geol. Survey Sixteenth Ann. Rept., pt. 1, 1896, p. 225.	1. Hatcher (U. S. Geol. Survey Bull. 257, p. 89, 1905) says that the characters on which Lambe based his determination may be due to age or to the position occupied by the tooth in the jaw rather than to specific distinction.
Ceratops beds, Wyoming.	A single tooth.	t. Marsh, Am. Jour. Sci., 3d ser., vol. 44, p. 173, 1892.	
Belly River series, Red Deer River, Canada.	1. Portion of a cranium, scutes, part of a rib, teeth, and plates of several individuals.	1. Lambe, Contr. Canadian Paleontology, vol. 3, pt. 2, p. 55, 1902.	A specimen referable to this genus has also been found by C. W. Gilmore in beds of Belly River age (Two Medicine formation) on Milk River, Mont.
1. Belly River series, Red Deer River, Canada. 4. Middle Cretaceous of Wyoming.	1. Represented by upper part of cranium and a number of dermal plates, doubtfully referred to *N. textilis*. 4. Various portions of the skeleton, but the skull not known.	1. Lambe, Ottawa Naturalist, vol. 13, pp. 68–70, 1899. t4. Marsh, Am. Jour. Sci., 3d ser., vol. 38, p. 175, 1889.	1. In a personal communication to the writer C. W. Gilmore expresses the opinion that the specimens referred by Lambe to *Nodosaurus textilis* were afterward made the type of *Stereocephalus tutus* Lambe.
Hell Creek beds, near Gilbert Creek, 120 miles northwest of Miles City, Mont.	Skull with two teeth, scapula, and coracoid, vertebræ, ribs, and dermal plates.	Brown, Am. Mus. Nat. Hist. Bull., vol. 24, pp. 197–201, 1908.	

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DINOSAURIA—continued.								
Thescelosaurus neglectus Gilmore				t×			Peterson t. Hatcher, Utterback.	1889 t. 1891.
DINOSAURIA (CERATOPSIDÆ).								
Agathaumas sylvestre Cope					t×		Meek	1872
Agathaumas milo, syn. of Hadrosaurus occidentalis.						×(?)		
Dysganus (4 species) Cope		×					Cope and Hayden	
Centrosaurus apertus Lambe	t×						Lambe	1901
Monoclonius crassus Cope		t×					Cope	1876
Monoclonius dawsoni Lambe	t×						Lambe	1901
Monoclonius sphenocerus Cope		t×					t. Sternberg	1876
Monoclonius fissus Cope		t×					Not given	
Ceratops montanus Marsh		t×				×(?)	t2. Hatcher 6. Eldridge.	2. 1888
Ceratops (Monoclonius) recurvicornis (Cope).		t×					t. Cope	t. 1876
Ceratops (Monoclonius) canadensis (Lambe).	t×						t. Lambe	

(*"Hell Creek beds" and "Ceratops beds"*), *and Denver and Arapahoe formations*—Continued.

Locality and stratigraphic position as given by the authors cited.	Material on which determination is based.	Authority and reference.	Remarks.
Lance formation, Lance Creek, Converse County, Wyo. [Peterson's specimen], and Doegie Creek, Converse County, Wyo. [type specimen].	t. A nearly complete articulated skeleton, the skull and neck being the only important parts missing.	t. Gilmore, Smithsonian Misc. Coll., vol. 61, No. 5, pp. 1-5, 1913.	Mr. Gilmore has told the writer personally that the genus at least is present in the "Hell Creek beds" (Lance formation) of Montana.
Near Black Buttes station on Union Pacific R. R., southern Wyoming, in the Bitter Creek series of coals.	Nine vertebræ, including a perfect sacrum with dorsals and caudals; both iliac and other pelvic bones, some bones of the ribs, limbs, and other parts not determined.	Hatcher, U. S. Geol. Survey Mon. 49, p. 105, 1907.	A. R. Schultz, of the United States Geological Survey, expresses the opinion that the beds in which this specimen was found are of Cretaceous age.
....	....	Cope, U. S. Geol. and Geog. Survey Terr. Seventh Ann. Rept., p. 448, 1874.	Cope says that the specimens came from Colorado, but does not give their stratigraphic position.
Judith River beds.	Teeth supposedly belonging to four species.	Hatcher, U. S. Geol. Survey Bull. 257, p. 90, 1905; U. S. Geol. Survey Mon. 49, p. 67, 1907.	Four species of this genus were described by Cope. After carefully reviewing all the literature, Hatcher says: "I am convinced that the genus was based on teeth pertaining to two or more genera, belonging in part to Trachodontidæ and in part to Ceratopsidæ. * * * In the absence of the type specimens, * * * the imperfect nature of the material, * * * the lack of any figures or sufficiently exact description, * * * I feel warranted in excluding it from the recognizable genera of the Ceratopsidæ."
Belly River series, Red Deer River, Canada.	Large posterior crest and nasal horn.	t. Lambe, Ottawa Naturalist, vol. 18, pp. 81-84, 1904.	The material on which this species is founded was first referred to *Monoclonius dawsoni* by Lambe (Contr. Canadian Paleontology), but a later study of the material convinced Lambe that two species had been included under one name.
t. Near the base of the Judith River beds, near the mouth of Birch Creek, Missouri River, Mont.	t. Teeth, caudal vertebræ, three cervicals, the fore limbs, tibia, ilium, sacrum, parietals, femur.	Hatcher, U. S. Geol. Survey Bull. 257, p. 91, 1905; U. S. Geol. Survey Mon. 49, p. 71, 1907.	
t. Belly River series, Red Deer River, below mouth of Berry Creek, Canada.	t. Part of a skull.	Hatcher, U. S. Geol. Survey Bull. 257, p. 91, 1905; U. S. Geol. Survey Mon. 49, p. 89, 1907.	
t. Near Cow Island, Missouri River, Mont.	t. Portions of premaxillary nasals and nasal horn.	Hatcher, U. S. Geol. Survey Mon. 49, p. 87, 1907.	
Not given.	t. A right pterygoid, incomplete.	Hatcher, U. S. Geol. Survey Mon. 49, p. 81, 1907.	Hatcher says that owing to the fragmentary nature of the material, the species ought to be discarded.
2. Near top of Judith River beds, on Cow Creek, Mont., 10 miles above its mouth and just below where the Cow Island-Benton road descends to the creek. 6. Arapahoe beds, near Denver, Colo.	t2. An occipital condyle and a pair of frontal horn cores.	2. Hatcher, U. S. Geol. Survey Mon. 49, p. 100, 1907. 6. Marsh, Am. Jour. Sci., 3d ser., vol. 36, pp. 477-478, 1888.	6. Marsh (op. cit., p. 478) says: "Remains of the same reptile or one nearly allied had previously been found in Colorado," by G. H. Eldridge. Lull (U. S. Geol. Survey Mon. 49, p. 183, 1907) doubts the accuracy of Marsh's determination and says: "The fragmentary nature of the fossil precludes accurate determination." Marsh also seems to have been in doubt as to the correct identification of the Colorado specimens. On page 227 of U. S. Geol. Survey Mon. 27, he includes *C. montanus* in his list of Denver and Arapahoe vertebrates, but he omits it from a list on page 527, which, but for this one omission, is a duplicate of the list on page 227. If the later list expresses Marsh's final views *C. montanus* should be excluded from the list of Denver and Arapahoe vertebrates.
t. North side of Missouri River opposite the mouth of Dog Creek.	t. Parts of the skull, including the frontal and nasal horn cores.	Hatcher, U. S. Geol. Survey Mon. 49, p. 81, 1907.	
t. Belly River beds, Red Deer River, Canada, below the mouth of Berry Creek.	t. Part of a skull and a lowe jaw.	Hatcher, U. S. Geol. Survey Mon. 49, p. 93, 1907. Lambe, Contr. Canadian Paleontology, vol. 3, pt. 2, p. 63, 1902.	

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Species.	1 Belly River formation.	2 Judith River formation.	3 "Hell Creek beds" (Lance formation), Montana.	4 Lance formation, Wyoming.	5 "Laramie" formation, Black Buttes, Wyoming.	6 Denver and Arapahoe formations, Colorado.	Finder.	Date.
DINOSAURIA (CERATOPSIDÆ)—contd.								
Ceratops (Monoclonius) belli (Lambe)	t×						t. Lambe	t. 1898
Ceratops paucidens Marsh		t×					t. Hatcher	
Polynoax mortuarius Cope						t×		
Triceratops alticornis Marsh						t×	Cannon, G. L	1887
Triceratops horridus Marsh				t×		×	t4. Guernsey, C. A. Wilson, E. B.	
Triceratops serratus Marsh			×	t×			3. Brown, G., and Lull 4. Beecher, C. E.	
Triceratops obtusus Marsh				t×			Hatcher	
Triceratops prorsus Marsh				t×			Hatcher	1889
Triceratops brevicornus Hatcher			×	t×			3. Brown 4. Utterback.	
Triceratops sulcatus Marsh				t×			Hatcher	
Triceratops (Sterrholophus) flabellatus Marsh.				t×			Hatcher	
Triceratops elatus Marsh				t×			Hatcher	

("*Hell Creek beds*" *and* "*Ceratops beds*"), *and Denver and Arapahoe formations*—Continued.

Locality and stratigraphic position as given by the authors cited.	Material on which determination is based.	Authority and reference.	Remarks.
t. Belly River series, Red Deer River, Canada.	The greater part of the coalesced parietals.	Hatcher, U. S. Geol. Survey Mon. 49, p. 96, 1907. Lambe, Contr. Canadian Paleontology, vol. 3, pt. 2, p. 66, 1902.	
t. Upper part of Judith River beds, Dog Creek, near summit of hill about 20 rods from a spring near the old freight road from Judith to Malden and about 12 miles from Judith post office.	A left maxillary and premaxillary.	Hatcher, U. S. Geol. Survey Mon. 49, p. 103, 1907.	
Colorado. [Probably from Bijou Creek 40 miles east of Denver (Cross, U. S. Geol. Survey Mon. 27, p. 244, 1896).]	t. Vertebræ and fragments of limb bones. Hatcher (U. S. Geol. Survey Mon. 49, p. 113, 1907) says that fragments supposed by Cope to pertain to the ischia are now known to be horn cores.	Hatcher, U. S. Geol. Survey Mon. 49, p. 112, 1907. Cope, U. S. Geol. and Geog. Survey Terr. Seventh Ann. Rept., pp. 447-451, 1874.	Hatcher (loc. cit.) says: "Cope's description and figures demonstrate * * * the inadequate nature of the material upon which the genus and species were based. The name should be dropped from paleontological literature."
t. Denver beds, banks of Green Mountain Creek, near Denver, Colo.	A pair of supraorbital horn cores.	t. Marsh, Am. Jour. Sci., 3d ser., vol. 34, p. 323, 1887; vol. 38, p. 174, 1889; U. S. Geol. Survey Mon. 27, pp. 512-527, 1896. Hatcher, U. S. Geol. Survey Mon. 49, pp. 104-115, 168, 170, 1907.	This species was first described as *Bison alticornis* by Marsh (1887). Later (1889) he transferred it to the genus Ceratops. Hatcher (op. cit., p. 116) says that the affinities are certainly with Triceratops rather than with Ceratops.
t4. Laramie formation, Converse County, Wyo., in a tributary of Buck Creek, near Johnson Bros.' sheep ranch. 6. Ceratops beds, near Denver, Colo.	t4. The greater part of a skull, including the horn cores and portions of the lower jaws. 6. Fragmentary remains.	t4. Marsh, Am. Jour. Sci., 3d ser., vol. 37, p. 334, 1889; vol. 38, p. 173, 1889. Hatcher, U. S. Geol. Survey Mon. 49, p. 117, 1907. 6. Marsh, U. S. Geol. Survey Mon. 27, p. 527, 1896; Am. Jour. Sci., 3d ser., vol. 37, pp. 334-335, 1889.	
3. Hell Creek beds, Hell Creek canyon, Mont., 25 miles from Missouri River. t4. Ceratops beds, Converse County, Wyo., 3 miles above mouth of Dry Creek, near Jacob Mills's sheep ranch.	3. Skull. t4. A nearly perfect skull.	3. Brown, Am. Mus. Nat. Hist. Bull., vol. 23, p. 842, 1907. Lull, Am. Mus. Nat. Hist. Bull., vol. 19, p. 685, 1903. t4. Marsh, Am. Jour. Sci., 3d ser., vol. 39, pp. 80-82, 1890. Hatcher, U. S. Geol. Survey Mon. 49, p. 122, 1907.	
Middle of Laramie, Converse County, Wyo., 1 mile east of Lance Creek and 2 miles southeast of U-L ranch.	t. A portion of the skull and jaws and vertebræ.	t. Marsh, Am. Jour. Sci., 4th ser., vol. 6, p. 92, 1898. Hatcher, U. S. Geol. Survey Mon. 49, p. 140, 1907.	
Ceratops beds, Wyoming, about 100 yards from locality for *T. serratus*.	t. A nearly perfect skull with lower jaw.	t. Marsh, Am. Jour. Sci., 3d ser., vol. 39, pp. 81-86, 1890. Hatcher, U. S. Geol. Survey Mon. 49, p. 127, 1907.	
3. Hell Creek beds, Montana. 4. Near summit of Laramie formation, Converse County, Wyo., 3 miles above the mouth and half a mile south of Lightning Creek.	3. Not given. 4. A nearly complete skull and considerable portion of the skeleton.	3. Brown, Am. Mus. Nat. Hist. Bull., vol. 23, p. 842, 1907. 4. Hatcher, U. S. Geol. Survey Mon. 49, p. 141, 1907.	
Ceratops beds, Converse County, Wyo., divide between Buck and Lance creeks.	t. Fragmentary skull, lower jaw, humerus, several vertebræ, and other parts of skeleton.	t. Marsh, Am. Jour. Sci., 3d ser., vol. 39, p. 442, 1890. Hatcher, U. S. Geol. Survey Mon. 49, p. 133, 1907.	
Ceratops beds, Converse County, Wyo., on a ridge between Buck Creek and Lance Creek.	t. A nearly complete but disarticulated skull, associated with several vertebræ, a few limb bones, etc.	t. Marsh, Am. Jour. Sci., 3d ser., vol. 38, p. 174, 1889. Hatcher, U. S. Geol. Survey Mon. 49, p. 143, 1907.	
Middle of Ceratops beds, Converse County, Wyo., one-fourth mile east of Lance Creek, opposite mouth of Lightning Creek.	t. Left side of a skull, very complete, showing all the important cranial characters; also lower jaw (detached).	t. Marsh, Am. Jour. Sci., 3d ser., p. 265, 1891. Hatcher, U. S. Geol. Survey Mon. 49, p. 134, 1907.	

TABLE 6.—*Geologic distribution of vertebrates in the Belly River, Judith River, Lance*

Species.	1 Belly River formation.	2 Judith River formation.	3 "Hell Creek beds" (Lance formation), Montana.	4 Lance formation, Wyoming.	5 "Laramie" formation, Black Buttes, Wyoming.	6 Denver and Arapahoe formations, Colorado.	Finder.	Date.
DINOSAURIA (CERATOPSIDÆ)—contd.								
Torosaurus latus Marsh				t×			Hatcher	
Torosaurus gladius Marsh				t×			Marsh	
Triceratops calicornis Marsh				t×			Hatcher	
Triceratops galeus Marsh						t×	Eldridge	
Diceratops hatcheri Lull				t×			Hatcher	
Manospondylus gigas Cope				×(?)				
Claorhynchus trihedrus Cope		×(?)						
Stegoceras validus Lambe	t×						Lambe	1898. 1901.
DINOSAURIA (TRACHODONTIDÆ).								
Trachodon mirabilis Leidy	×	t×		×			1. Lambe. 2. Hayden. 4. Hatcher, Wortman, Hill.	
Trachodon (Hadrosaurus) breviceps (Marsh).		t×						

(*"Hell Creek beds" and "Ceratops beds"*), *and Denver and Arapahoe formations*—Continued.

Locality and stratigraphic position as given by the authors cited.	Material on which determination is based.	Authority and reference.	Remarks.
Ceratops beds, about 1 mile east of U-L ranch, which is at the junction of Lance and Dry creeks, Wyo.	t. Skull with lower jaw, 11 dorsal vertebræ, several ribs, part of the pelvis, and other parts of the skeleton.	t. Marsh, Am. Jour. Sci., 4th ser., vol. 6, p. 92, 1898. Hatcher, U. S. Geol. Survey Mon. 49, p. 138, 1907.	
Arapahoe beds, near Brighton, Colo.	Nasal horn core.	Marsh, Am. Jour. Sci., 3d ser., vol. 38, p. 174, 1889. Hatcher, U. S. Geol. Survey Mon. 49, pp. 132-133.	Hatcher (op. cit., p. 132) says: "The extremely fragmentary nature of the material on which the species was based precludes the possibility of defining it adequately. * * * The species should be abandoned."
Ceratops beds, Converse County, Wyo., 35 miles southwest of the mouth of Lightning Creek.	t. A skull without the lower jaw.	Lull, U. S. Geol. Survey Mon. 49, p. 149, 1907. t. Hatcher, Am. Jour. Sci., 4th ser., vol. 20, p. 417, 1905.	
Ceratops beds, Converse County, Wyo., on the north side of Lightning Creek, about 2 miles above the mouth of the stream.	A skull without lower jaw. Posterior part of parietals, summits of horn cores, and parts of maxillaries are wanting.	t. Marsh, Am. Jour. Sci., 3d ser., vol. 42, p. 266, 1891. Hatcher, U. S. Geol. Survey Mon. 49, p. 150, 1907.	
Laramie of Converse County, Wyo., on low divide between Lightning and Cow creeks, about 1 mile distant from the mouths of these streams.	A nearly complete parietal, left squamosal, horn cores, one epijugal, the occipital condyle, and other parts of the skeleton.	t. Marsh, Am. Jour. Sci., 3d ser., vol. 42, pp. 266-267, 1891. Hatcher, U. S. Geol. Survey Mon. 49, p. 152, 1907.	
Laramie of South Dakota; probably also from the Laramie of Converse County, Wyo. t. Laramie of South Dakota.	t. Two dorsal vertebræ, of which only one can be found now.	Hatcher, U. S. Geol. Survey Mon. 49, p. 113, 1907; U. S. Geol. Survey Bull. 257, p. 96, 1905. t. Cope, Am. Naturalist, vol. 26, p. 757, 1892.	Cope's original material came from South Dakota, not from Montana. (See Hatcher, U. S. Geol. Survey Bull. 257, p. 96, 1905.) Hatcher (U. S. Geol. Survey Mon. 49, p. 114, 1907) says: "A comparison of the vertebra still preserved with others from the same region in the vertebral column but belonging to the skeleton of a carnivorous dinosaur probably pertaining to some species of Dryptosaurus, from * * * Converse County, Wyo., * * * demonstrates conclusively that the remains upon which the present genus and species were based belonged to the Theropoda rather than the Predentata, and that it was therefore not a member of the Ceratopsidæ."
Laramie. [No locality was given by Cope; Hatcher thinks it came from South Dakota, but Osborn (Contr. Canadian Paleontology, vol. 3, pt. 2, p. 15, 1902) has included it in his Montana list.]	t. A rostral and predentary, both of which are now lost.	Hatcher, U. S. Geol. Survey Mon. 49, p. 114, 1907.	This species is regarded by Hatcher (op. cit.) as belonging to the Trachodontidæ rather than to the Ceratopsidæ, but he says that in the absence of the type material the affinities can not be established with certainty.
Belly River series, Red Deer River, Canada.	Founded on two cranial fragments, probably belonging to two species.	Hatcher, U. S. Geol. Survey Mon. 49, p. 98, 1907. Lambe, Contr. Canadian Paleontology, vol. 3, pt. 2, p. 68, 1902.	Hatcher does not include this species in the Ceratopsidæ. He thinks that it belongs to a hitherto unknown reptile, and that it will probably be found to belong to another order.
1. Belly River series, near mouth of Berry Creek, Red Deer River, Canada. t2. Badlands of Judith River, Mont. 4. Converse County, Wyo.	1. Numerous maxillæ and rami, some with teeth well preserved, as well as a large number of principal bones. t2. "Specimens of teeth, generally much worn and in a fragmentary condition." 4. By Wortman and Hill, a skeleton; by Hatcher, a skeleton.	1. Lambe, Ottawa Naturalist, vol. 13, p. 69, 1899. t2. Leidy, Acad. Nat. Sci. Philadelphia Proc., vol. 8, p. 72, 1856. Hatcher, U. S. Geol. Survey Bull. 257, p. 96, 1905. 4. Hatcher, Carnegie Mus. Annals, vol. 1, pp. 382, 386, 1902; Science, new ser., vol. 12, p. 719, 1900.	1. Lambe (loc. cit.) states that remains of this species have also been collected by F. G. McConnell from the Laramie [so-called] at Scabby Butte, on Red Deer River. 2. Hatcher (loc. cit.) says: "It is scarcely possible to identify the various species of this genus or the genera of the family [Trachodontidæ] from the teeth alone." 4. In Science, vol. 12, Hatcher refers to finding a skeleton of Claosaurus of which he describes the dermal covering but does not give the specific name. In the Carnegie Mus. Annals, vol. 1, he credits Cope with having first described this covering from the same species, *Trachodon (Diclonius) mirabilis*. The assumption is therefore justified that Hatcher's Claosaurus from Converse County, Wyo., is synonymous with *T. mirabilis*.
t. Laramie [Judith River formation], Bearpaw Mountains, Mont.	Part of a right maxillary with teeth well preserved.	t. Marsh, Am. Jour. Sci., 3d ser., vol. 37, p. 335, 1889. Hatcher, U. S. Geol. Survey Bull. 257, p. 97, 1905.	Hatcher (loc. cit.) says that the teeth resemble closely those of *T. selwyni* Lambe.

TABLE 6.—*Geologic distribution of vertebrates in the Belly River, Judith River, Lance*

Species.	1 Belly River formation.	2 Judith River formation.	3 "Hell Creek beds" (Lance formation), Montana.	4 Lance formation, Wyoming.	5 "Laramie" formation, Black Buttes, Wyoming.	6 Denver and Arapahoe formations, Colorado.	Finder.	Date.
DINOSAURIA (TRACHODONTIDÆ)—cont.								
Trachodon selwyni Lambe	t×						Lambe	
Trachodon marginatus Lambe	t×						Lambe	
Trachodon altidens Lambe	t×						Lambe	
Trachodon longiceps Marsh				t×			Hatcher	
Trachodon (Hadrosaurus) paucidens Marsh.		t×(?)					Hatcher	
Trachodon (Claosaurus) annectens (Marsh).				×		×	4. Hatcher, Sternberg. 6. Not given.	4. 1891
Trachodon sp			×				Brown	
Thespesius (Hadrosaurus) occidentalis Leidy.				×		×	4. Sullins t. Hayden.	4. 1891
Pteropelyx grallipes Cope		t×					Isaacs	1876
Cionodon stenopsis Cope	t×						Dawson	
Cionodon arctatus Cope						t×	Not given	
Diclonius pentagonus Cope		t×					Not given	
Diclonius perangulatus Cope		t×					Not given	
Diclonius calamarius Cope		t×					Not given	

(*"Hell Creek beds" and "Ceratops beds"*), *and Denver and Arapahoe formations*—Continued.

Locality and stratigraphic position as given by the authors cited.	Material on which determination is based.	Authority and reference.	Remarks.
Belly River series. [Location not given.]	Founded on teeth differing from those of *T. mirabilis* by being rounded oval above instead of terminating in a point.	t. Lambe, Contr. Canadian Paleontology, vol. 3, pt. 2, p. 69, 1902. Hatcher, U. S. Geol. Survey Bull. 257, p. 97, 1905.	Hatcher (loc. cit.) says that this species may be a synonym of *T. breviceps*.
Belly River series, Red Deer River district, Canada.	Humerus, radius, ulna of left fore limb, a metatarsal and phalanges, fragments of teeth of one individual, and various parts of the skeleton found dissociated.	t. Lambe, Contr. Canadian Paleontology, vol. 3, pt. 2, p. 71, 1902. Hatcher, U. S. Geol. Survey Bull. 257, p. 97, 1905.	Hatcher (loc. cit.) says that this species is based on material pertaining to different species, genera, families, and even orders.
Belly River series, Red Deer River district, Canada.	A left maxilla with the teeth.	t. Lambe, Contr. Canadian Paleontology, vol. 3, pt. 2, p. 76, 1902. Hatcher, U. S. Geol. Survey Bull. 257, p. 98, 1905.	
Laramie of Wyoming.	A nearly perfect right dentary bone.	Marsh, Am. Jour. Sci., 3d ser., vol. 39, pp. 422–424, 1890.	
Laramie of Montana.	A left maxillary nearly complete and other portions of the skull.	t. Marsh, Am. Jour. Sci., 3d ser., vol. 37, p. 336, 1889.	The only locality given is Montana. The fossils may have come from either the Judith River or the Lance formation, as Marsh referred to both formations as the Laramie.
4. Laramie of Converse County, Wyo. 6. Ceratops beds, near Denver, Colo.	4. By Hatcher—a nearly complete skeleton. By Sternberg—a nearly complete skeleton. Not given.	4. Marsh, Am. Jour. Sci., 3d ser., vol. 43, pp. 449–453, 1892. Osborn, Science, new ser., vol. 29, p. 793, 1909. 6. Marsh, U. S. Geol. Survey Mon. 27, p. 227, 1896.	
Hell Creek beds, Montana.	Not given.	Brown, Am. Mus. Nat. Hist. Bull., vol. 23, p. 842, 1907.	
4. Laramie of Wyoming. 6. Ceratops near Denver, Colo. t. Grand River, Nebr. (N. Dak.)	4. A nearly complete skull and skeleton. 6. Not given.	4. Marsh, Am. Jour. Sci., 3d ser., vol. 43, pp. 449–453, 1892. Hatcher, Am. Jour. Sci., 3d ser., vol. 45, p. 143, 1893. 6. Cope, U. S. Geol. and Geog. Survey Terr. Seventh Ann. Rept., pp. 432–466, 1874. Marsh, U. S. Geol. Survey Mon. 27, p. 527, 1896. t. Leidy, Acad. Nat. Sci. Philadelphia Proc., vol. 8, p. 311, 1856.	4. Marsh described the Wyoming and Colorado specimens as *Claosaurus annectens*.
t. Judith River beds, near Cow Island, Mont.	A considerable portion of a skeleton without skull or teeth.	t. Cope, Am. Naturalist, vol. 23, p. 904, 1889. Hatcher, U. S. Geol. Survey Bull. 257, p. 98, 1905.	
t. Fort Union (?) beds, near Milk River near latitude 49° and between longitudes 112° and 113°.	t. Maxillary and teeth.	Cope, Acad. Nat. Sci. Philadelphia Proc., vol. 28, p. 9, 1876. t. Dawson, British North America Boundary Comm. Rept., p. 130, 1875. Hatcher, U. S. Geol. Survey Bull. 257, p. 99, 1905.	Eugene Stebinger, of the United States Geological Survey, who has recently mapped this area, says that the formation is undoubtedly of Belly River age.
Colorado.	A tooth, two dorsal vertebræ, distal end of a femur with the condyles well preserved.	t. Cope, U. S. Geol. Survey Terr. Rept., vol. 2, pp. 57–62, 1875. Hatcher, Carnegie Mus. Annals, vol. 1, p. 381, 1902.	
Fort Union beds [Judith River formation], Montana.	Detached teeth.	t. Cope, Acad. Nat. Sci. Philadelphia Proc., vol. 28, p. 253, 1876. Hatcher, U. S. Geol. Survey Bull. 257, p. 99, 1905.	Concerning this and the next two species, Hatcher (loc. cit.) says the genus is generally considered as a synonym of Trachodon. In the absence of any figures it is doubtful if any of the species are identifiable without access to the types; and as these are no longer determinable in the Cope collection, it would not be amiss to drop the specific names referred to this genus.
Fort Union beds [Judith River formation], Montana.	Detached teeth.	t. Cope, Acad. Nat. Sci. Philadelphia Proc., vol. 28, p. 254, 1876. Hatcher, U. S. Geol. Survey Bull. 257, p. 99, 1905.	
Fort Union beds [Judith River formation], Montana.	Detached teeth.	t. Cope, Acad. Nat. Sci. Philadelphia Proc., vol. 28, p. 255, 1876. Hatcher, U. S. Geol. Survey Bull. 257, p. 99, 1905.	

TABLE 6.—*Geologic distribution of vertebrates in the Belly River, Judith River, Lance*

Species.	1 Belly River formation.	2 Judith River formation.	3 "Hell Creek beds" (Lance formation), Montana.	4 Lance formation, Wyoming.	5 "Laramie" formation, Black Buttes, Wyoming.	6 Denver and Arapahoe formations, Colorado.	Finder.	Date.
AVES.								
Cimolopteryx rarus Marsh				t×			Hatcher	
Cimolopteryx retusus Marsh				t×			Hatcher	
MAMMALIA.								
Ptilodus primævus Lambe	t×						Lambe	1901
Ptilodus sp			×				Brown	
Meniscoessus conquistus Cope			×	×			3. Brown. 4. Hatcher. t. Wortman.	t. 1882.
Boreodon matutinus Lambe	t×						Lambe, Hatcher	
Cimolomys gracilis Marsh				×			Hatcher	
Cimolomys bellus Marsh				×			Hatcher	
Cimolodon nitidus Marsh				×			Hatcher	
Nanomys minutus Marsh				×			Hatcher	
Dipriodon robustus Marsh				×			Hatcher	
Dipriodon lunatus Marsh				×			Hatcher	
Tripriodon cœlatus Marsh				×			Hatcher	
Tripriodon caperatus Marsh				×			Hatcher	
Selenacodon fragilis Marsh				×			Hatcher	
Halodon sculptus Marsh				×			Hatcher	
Halodon serratus Marsh				×			Hatcher	
Camptomus amplus Marsh				×			Hatcher	
Dryolestes tenax Marsh				×			Hatcher	
Didelphops (Didelphodon) vorax Marsh				×			Hatcher	
Didelphops (Didelphodon) ferox Marsh				×			Hatcher	
Didelphops (Didelphodon) comptus Marsh.				×			Hatcher	

(*"Hell Creek beds" and "Ceratops beds"*), *and Denver and Arapahoe formations*—Continued.

Locality and stratigraphic position as given by the authors cited.	Material on which determination is based.	Authority and reference.	Remarks.
Laramie of Wyoming.	A coracoid bone.	t. Marsh, Am. Jour. Sci., 3d ser., vol. 38, p. 83 (footnote), 1889; vol. 44, p. 175, 1892.	
Laramie of Wyoming.	A left coracoid.	t. Marsh, Am. Jour. Sci., 3d ser., vol. 44, p. 175, 1892.	
Belly River series, Red Deer River, Canada.	An imperfect right mandible and ramus with fourth premolar and first molar attached.	Lambe, Contr. Canadian Paleontology, vol. 3, pt. 2, p. 79, 1902.	
Hell Creek beds, Montana.	Not given.	Brown, Am. Mus. Nat. Hist. Bull., vol. 23, p. 842, 1907.	
3. Hell Creek beds, Montana. 4. Laramie formation. Locality not given. t. Laramie of South Dakota.	3. Not given. t. Two molars and a distal extremity of a humerus.	3. Brown, Am. Mus. Nat. Hist. Bull., vol. 23, p. 842, 1907. 4. Cope, Am. Naturalist, vol. 16, p. 830, 1882.	
Belly River series, Red Deer River, Canada.	By Lambe, a single tooth. By Hatcher, a jaw.	Lambe, Contr. Canadian Paleontology, vol. 3, pt. 2, p. 79, 1902.	
Laramie of Wyoming.	An upper molar.	Marsh, Am. Jour. Sci., 3d ser., vol. 38, pp. 81-90, 1889.	In Science, new ser., vol. 12, p. 719, 1900, Hatcher says that all the mammals obtained by him under the direction of Marsh came from Converse County, Wyo. Hence all the succeeding species are from that general locality. The 17 genera and 28 species whose names are printed in italic in the list (taken from Marsh) have, according to Osborn (Am. Naturalist, vol. 25, p. 609, 1891), been reduced to "four or five genera, one of which can now be well defined (Meniscoessus), while the remainder are probably distinct genera, which we may be able to define by the acquisition of more material (Cimolomys, Didelphops, and Cimolestes). There is no question that the majority of the remaining generic names are synonyms, although it is quite possible that some of the types described, such as Oracodon and Pediomys, may be found to represent distinct or new genera." The remaining species of the list have been reviewed by the same writer (Am. Mus. Nat. Hist. Bull., vol. 5, pp. 311-330, 1893), with a considerable reduction in the number of genera. From Osborn's reviews, cited above, it appears that many of Marsh's species are synonyms or are established on inadequate material, and that the list should be greatly reduced. In a personal communication to the writer J. W. Gidley refers 12 of these species to Ptilodus and 7 to Meniscoessus and states that 7 are uncertain, leaving 9 species as probably determined correctly by Marsh.
Laramie of Wyoming.	An upper molar.	Marsh, Am. Jour. Sci., 3d ser., vol. 38, pp. 81-90, 1889.	
Laramie of Wyoming.	An upper molar.	Marsh, Am. Jour. Sci., 3d ser., vol. 38, pp. 81-90, 1889.	
Laramie of Wyoming.	A number of very minute teeth, of which a single tooth is taken as a type.	Marsh, Am. Jour. Sci., 3d ser., vol. 38, pp. 81-90, 1889.	
Laramie of Wyoming.	A left upper molar.	Marsh, Am. Jour. Sci., 3d ser., vol. 38, pp. 81-90, 1889.	
Laramie of Wyoming.	A first or second molar.	Marsh, Am. Jour. Sci., 3d ser., vol. 38, pp. 81-90, 1889.	
Laramie of Wyoming.	An upper molar. Several lower molars were found with the type, but the association may be accidental.	Marsh, Am. Jour. Sci., 3d ser., vol. 38, pp. 81-90, 1889.	
Laramie of Wyoming.	A lower incisor, associated with other incisors and other teeth in various states of preservation.	Marsh, Am. Jour. Sci., 3d ser., vol. 38, pp. 81-90, 1889.	
Laramie of Wyoming.	An upper fragmentary molar.	Marsh, Am. Jour. Sci., 3d ser., vol. 38, pp. 81-90, 1889.	
Laramie of Wyoming.	Fourth premolar of the lower jaw. Two incisors, probably from the same species, are also represented.	Marsh, Am. Jour. Sci., 3d ser., vol. 38, pp. 81-90, 1889.	
Laramie of Wyoming.	A lower molar.	Marsh, Am. Jour. Sci., 3d ser., vol. 38, pp. 81-90, 1889.	
Laramie of Wyoming.	A scapula, with which are associated several parts of a skeleton and fragments of teeth.	Marsh, Am. Jour. Sci., 3d ser., vol. 38, pp. 81-90, 1889.	
Laramie of Wyoming.	A lower jaw which does not show the number or form of the teeth.	Marsh, Am. Jour. Sci., 3d ser., vol. 38, pp. 81-90, 1889.	
Laramie of Wyoming.	Several teeth and parts of the skeleton.	Marsh, Am. Jour. Sci., 3d ser., vol. 38, pp. 81-90, 1889.	
Laramie of Wyoming.	A number of teeth, of which the lower molar is taken as the type.	Marsh, Am. Jour. Sci., 3d ser., vol. 38, pp. 81-90, 1889.	
Laramie of Wyoming.	Several teeth, of which the lower molar is taken as the type.	Marsh, Am. Jour. Sci., 3d ser., vol. 38, pp. 81-90, 1889.	

TABLE 6.—*Geologic distribution of vertebrates in the Belly River, Judith River, Lance*

Species.	1 Belly River formation.	2 Judith River formation.	3 "Hell Creek beds" (Lance formation), Montana.	4 Lance formation, Wyoming.	5 "Laramie" formation, Black Buttes, Wyoming.	6 Denver and Arapahoe formations, Colorado.	Finder.	Date.
MAMMALIA—continued.								
Cimolestes incisus Marsh				×			Hatcher	
Cimolestes curtus Marsh				×			Hatcher	
Pediomys elegans Marsh				×			Hatcher	
Cimolomys digona Marsh				×			Hatcher	
Selenacodon brevis Marsh				×			Hatcher	
Stagodon tumidus Marsh				×			Hatcher	
Stagodon nitor Marsh				×			Hatcher	
Stagodon validus Marsh				×			Hatcher	
Oracodon anceps Marsh				×			Hatcher	
Oracodon conulus Marsh				×			Hatcher	
Allacodon lentus Marsh				×			Hatcher	
Allacodon fortis Marsh				×			Hatcher	
Allacodon pumilus Marsh				×			Hatcher	
Allacodon rarus Marsh				×			Hatcher	
Halodon formosus Marsh				×			Hatcher	
Cimolodon parvus Marsh				×			Hatcher	
Cimolodon agilis Marsh				×			Hatcher	
Telacodon præstans Marsh				×			Hatcher	
Telacodon lævis Marsh				×			Hatcher	
Batodon tenuis Marsh				×			Hatcher	

("*Hell Creek beds*" *and* "*Ceratops beds*"); *and Denver and Araphoe formations*—Continued.

Locality and stratigraphic position as given by the authors cited.	Material on which determination is based.	Authority and reference.	Remarks.
Laramie of Wyoming.	Several teeth in a good state of preservation, of which the lower molar is taken as the type.	Marsh, Am. Jour. Sci., 3d ser., vol. 38, pp. 81-90, 1889.	
Laramie of Wyoming.	A molar with several other teeth.	Marsh, Am. Jour. Sci., 3d ser., vol. 38, pp. 81-90, 1889.	
Laramie of Wyoming.	An upper molar and other teeth.	Marsh, Am. Jour. Sci., 3d ser., vol. 38, pp. 81-90, 1889.	
Laramie of Wyoming.	A number of remains, of which an upper molar is most characteristic and is taken as the type.	Marsh, Am. Jour. Sci., 3d ser., vol. 38, pp. 177-180, 1889.	
Laramie of Wyoming.	An upper molar with other teeth.	Marsh, Am. Jour. Sci., 3d ser., vol. 38, pp. 177-180, 1889.	
Laramie of Wyoming.	A premolar attached to a portion of the maxillary.	Marsh, Am. Jour. Sci., 3d ser., vol. 38, pp. 177-180, 1889.	
Laramie of Wyoming.	Several molars and premolars.	Marsh, Am. Jour. Sci., 3d ser., vol. 38, pp. 177-180, 1889.	
Laramie of Wyoming.	Anterior part of right lower jaw.	Marsh, Am. Jour. Sci., 3d ser., vol. 43, pp. 249-261, 1892.	
Laramie of Wyoming.	A number of premolars.	Marsh, Am. Jour. Sci., 3d ser., vol. 38, pp. 177-180, 1889.	
Laramie of Wyoming.	A single tooth.	Marsh, Am. Jour. Sci., 3d ser., vol. 43, pp. 249-261, 1892.	
Laramie of Wyoming.	An upper molar and other teeth, several of which were found together.	Marsh, Am. Jour. Sci., 3d ser., vol. 38, pp. 177-180, 1889.	
Laramie of Wyoming.	Entire upper series of molars and premolars.	Marsh, Am. Jour. Sci., 3d ser., vol. 43, pp. 249-261, 1892.	
Laramie of Wyoming.	Several teeth.	Marsh, Am. Jour. Sci., 3d ser., vol. 38, pp. 177-180, 1889.	
Laramie of Wyoming.	A few isolated molar teeth.	Marsh, Am. Jour. Sci., 3d ser., vol. 43, pp. 249-261, 1892.	
Laramie of Wyoming.	A fourth premolar.	Marsh, Am. Jour. Sci., 3d ser., vol. 38, pp. 177-180, 1889.	
Laramie of Wyoming.	Isolated remains, including the anterior portion of a lower jaw with incisors in place.	Marsh, Am. Jour. Sci., 3d ser., vol. 43, pp. 249-261, 1892.	
Laramie of Wyoming.	Left lower jaw with one molar in place.	Marsh, Am. Jour. Sci., 3d ser., vol. 43, pp. 249-261, 1892.	
Laramie of Wyoming.	A lower jaw, also a lower molar with other specimens.	Marsh, Am. Jour. Sci., 3d ser., vol. 43, pp. 249-261, 1892.	
Laramie of Wyoming.	A right lower jaw, containing three molars in place; a detached upper molar and premolar also referred to this form.	Marsh, Am. Jour. Sci., 3d ser., vol. 43, pp. 249-261, 1892.	
Laramie of Wyoming.	A lower jaw with canine in place and several other specimens.	Marsh, Am. Jour. Sci., 3d ser., vol. 43, pp. 249-261, 1892.	

Exclusive of the mammals 135 species are described. In Table 7 are brought together for convenience of comparison all the forms given in Table 6 which have been reported to occur in more than one of the formations involved (the "Hell Creek beds," Lance of Wyoming, and Denver and Arapahoe being considered collectively as "Ceratops beds"). Table 7 therefore shows at a glance the forms common to the Judith River and Belly River, to the Judith River and "Ceratops beds," to the Belly River and "Ceratops beds," and to all three of these formations. It also indicates forms whose specific identification for certain of the formations is in doubt.

TABLE 7.—*Species common to two or more of the formations represented in Table 6.*

[Specific names in italic indicate doubt as to specific identity of the form from that particular formation. For basis of doubt see Table 6, columns "Material" and "Remarks."]

Belly River formation.	Judith River formation.	"Ceratops beds."[a]
Pisces (total species 9):		
Acipenser albertensis	*Acipenser albertensis*	*Acipenser albertensis.*
Ceratodus eruciferus	*Ceratodus eruciferus*	
Diphyodus longirostris	*Diphyodus longirostris*	*Diphyodus longirostris.*
Lepisosteus (Lepidotus) occidentalis	*Lepisosteus (Lepidotus) occidentalis*	Lepisosteus (Lepidotus) occidentalis.
Myledaphus bipartitus	*Myledaphus bipartitus*	*Myledaphus bipartitus.*
Amphibia (total species 5):		
Scapherpeton tectum	Scapherpeton tectum	Scapherpeton tectum.
Plesiosauria (total species 3):		
	Ischyrosaurus antiquum	Ischyrosaurus antiquum.
Chelonia (total species 29):		
Adocus lineolatus	*Adocus lineolatus*	Adocus lineolatus.
Basilemys variolosus	Basilemys variolosus	
	Aspideretes beecheri	Aspideretes beecheri.
Trionyx foveatus	Trionyx foveatus	*Trionyx foveatus.*
Rhynchocephalia (total species 6):		
Champsosaurus annectens	Champsosaurus annectens	
Crocodilia (total species 6):		
	Crocodilus humilis	*Crocodilus humilis.*
Dinosauria (total species 74):		
Troodon formosus	*Troodon formosus*	*Troodon formosus.*
Deinodon horridus	Deinodon horridus	
	Deinodon hazenianus	*Deinodon hazenianus.*
	Aublysodon mirandus	Aublysodon mirandus.
	Zapsalis abradens	*Zapsalis abradens.*
Deinodon incrassatus	*Deinodon incrassatus*	
Deinodon explanatus	Deinodon explanatus	Deinodon explanatus.
	Deinodon cristatus	*Deinodon cristatus.*
Ornithomimus altus		Ornithomimus altus.
Palæoscincus costatus	Palæoscincus costatus	Palæoscincus costatus.
Palæoscincus asper		Palæoscincus asper.
Nodosaurus textilis		Nodosaurus textilis.
Trachodon mirabilis	Trachodon mirabilis	Trachodon mirabilis.
	Ceratops montanus	*Ceratops montanus.*

[a] The term "Ceratops beds" is here used to include "Hell Creek beds," Lance formation of Wyoming, and Denver and Arapahoe formation of Table 6.

The forms reported to be common to the "Ceratops beds" and one or both of the other formations are classified as follows:

Pisces	4
Amphibia	1
Plesiosauria	1
Chelonia	3
Dinosauria (only one of which is a ceratopsian)	12
Crocodilia	1

The distribution of these species according to geologic formations is as follows:

Pisces.—Out of 9 species described 5 are common to the Belly River and Judith River, and 4 of these are also common to the "Ceratops beds."

Amphibia.—Of 5 species described there is but 1 that occurs in more than one of the formations, and that 1 is common to the three formations.

Plesiosauria.—Out of 3 species described there are none common to the Belly River and either of the other formations and only 1 common to the Judith River formation and "Ceratops beds."

Chelonia.—Out of 29 species described 3 are common to the Judith River and Belly River, 2 of which are also common to the Lance, and only 1 is common to the Judith River and Lance and not found in the Belly River.

Rhynchocephalia.—Out of 6 species described 1 is common to the Belly River and Judith River, and none are common to either of these formations and the Lance.

Squamata.—No species in common.

Crocodilia.—Of 6 species described 1 is common to the Judith River and the Lance, and none are common to either of these formations and the Belly River.

Dinosauria.—Of 74 species described 6 are common to the Belly River and Judith River, 7 are common to the Belly River and Lance, and 9 are common to the Judith River and Lance.

Table 8 is introduced for the purpose of showing in a concise way those forms whose specific identification for the localities indicated is doubtful.

TABLE 8.—*Species whose identification, from certain formations, is based on inadequate material.*

[The type of the species may or may not, however, be based on adequate material.]

Species.	Belly River formation.	Judith River formation.	"Hell Creek beds."	Lance formation, Converse County, Wyo.	Denver and Arapahoe formations.	Material. (See also "Remarks," Table 6.)
Pisces:						
Acipenser albertensis	×	×		×		Dermal shield.
Ceratodus cruciferus	×	×				Fragments of cranial bones and a dentigerous lamina.
Ceratodus hieroglyphus		×				A dentigerous plate.
Diphyodus longirostris	×	×		×		A jaw with teeth scars.
Hedronchus sternbergii		×				The crown of a young tooth.
Lepisosteus haydeni		×				A single scale.
Lepisosteus (Lepidotus) occidentalis	×	×				A few scales, which Hatcher says are insufficient and of little value for correlation.
Myledaphus bipartitus	×	×		×		A few simple isolated and detached teeth, which Hatcher says are too simple to identify either genera or species.
Plesiosauria:						
Cimoliasaurus magnus	×					Several vertebræ, which Hatcher says may pertain to another genus and species; in some respects they resemble *Ischyrosaurus antiquum*.
Ischyrosaurus antiquum		×				Vertebral centra, which Hatcher says may belong to another genus; the material is too incomplete for accurate determination.
Chelonia:						
Adocus lineolatus	×	×				Imperfect fragments of costals, regarded by Hay as inadequate for identification.
Basilemys imbricaria	×					Three fragments, probably costals, regarded as very unsatisfactory and inadequate by Hay.
Aspideretes beecheri		×				Two carapaces, of which Hay says no characters are observed which distinguish them from *A. beecheri;* it is not improbable, however, that they belong to a distinct species.
Aspideretes (Trionyx) foveatus			×		×	The Denver specimen may belong to *A. beecheri.* The "Hell Creek" specimens consist of 3 neurals and portions of costals, of which Hay says: "Had they been found in the Judith River deposits, they would without hesitation be referred to *A. foveatus.* Perhaps only the finding of a complete shell of this 'Laramie' form will settle the question involved."
Rhynchocephalia:						
Champsosaurus brevicollis		×				A single vertebra of an immature individual. Barnum Brown says the species is invalid.
Crocodilia:						
Crocodilus humilis				×	×	Type from Judith River was founded on the crowns of teeth, which Hatcher says furnish no characters for positive identification of other material.
Dinosauria:						
Troodon formosus	×	×		×		The type from Judith River is founded on a single tooth. Hatcher regards the material as insufficient.
Zapsalis abradens				×		Small teeth, which Hatcher says can not be certainly identified with the type.
Deinodon incrassatus		×				Two teeth, which Hatcher says probably belong to *D. horridus.*
Deinodon falculus		×				Detached teeth, which Hatcher says may be anterior teeth of *D. explanatus.*
Deinodon hazenianus		×		×		Detached teeth, which Hatcher says may be anterior teeth of *D. explanatus.*
Deinodon lævifrons		×				A single tooth, regarded as of doubtful value by Hatcher.
Deinodon amplus				×		Founded on teeth which Hatcher says do not afford characters for either generic or specific distinction.
Deinodon cristatus		×		×		Detached teeth, which Hatcher says do not afford characters for either generic or specific distinction.
Palæoscincus asper	×					Type, a single tooth, of which Hatcher remarks that the characters assigned to it may be due to age and not to specific differences.
Nodosaurus textilis	×					Part of cranium, at first doubtfully referred by Lambe to this species, but later to *Stereocephalus tutus.*
Dysganus (Ceratopsidæ)		×				Genus and four species founded on teeth pertaining in part to Ceratopsidæ and in part to Trachodontidæ. Hatcher regards the genus as unrecognizable.
Monoclonius fissus		×				A right pterygoid, so fragmentary that Hatcher says the species should be discarded.
Ceratops montanus					×	Lull regards the determination as a case of mistaken identity. Marsh, to whom the determination is attributed, does not include it in his last list of vertebrates from the Denver Basin. (See "Remarks," Table 6.)

TABLE 8.—*Species whose identification, from certain formations, is based on inadequate material*—Continued.

Species.	Belly River formation.	Judith River formation.	"Hell Creek beds."	Lance formation, Converse County, Wyo.	Denver and Arapahoe formations.	Material. (See also "Remarks," Table 6.)
Dinosauria—Continued.						
Polynoax mortuarius					×	Hatcher says the name should be dropped from paleontologic literature.
Triceratops galeus					×	Nasal horn core; material so fragmentary that Hatcher says the species should be abandoned.
Trachodon marginatus	×					Based on material which Hatcher says pertains to different species, genera, families, and even orders.
Diclonius pentagonus		×				Detached teeth, no longer determinable in the Cope collection. Hatcher says it is doubtful if any of the species are identifiable and that the specific names should be dropped.
Diclonius perangulatus		×				
Diclonius calamarius		×				
Mammalia. (See "Remarks," Table 6.)						

By combining part of the data in Tables 7 and 8, the number of species reported to be common to the several formations and also the number of these forms whose specific identification for either of the formations is doubtful are brought out in Table 9.

TABLE 9.—*Number of probably valid and doubtful forms common to the formations represented in Tables 7 and 8.*

		Pisces.	Amphibia.	Plesiosauria.	Chelonia.	Rhynchocephalia.	Squamata.	Crocodilia.	Dinosauria.	Total.
Species common to the Judith River and Belly River formations.	Total	5	1	0	3	1	0	0	6	16
	Probably valid	0	1	0	2	1	0	0	4	8
	Doubtful	5	0	0	1	0	0	0	2	8
Species common to the Belly River and Lance formations.	Total	4	1	0	2	0	0	0	7	14
	Probably valid	1	1	0	0	0	0	0	4	6
	Doubtful	3	0	0	2	0	0	0	3	8
Species common to the Judith River and Lance formations.	Total	4	1	1	3	0	0	1	9	19
	Probably valid	1	1	0	0	0	0	0	4	6
	Doubtful	3	0	1	3	0	0	1	5	13

Table 10 gives a list of the species in Table 6 which are based on inadequate material and regarded as of doubtful validity, and Table 11 gives the forms that are probably synonyms.

TABLE 10.—*Species whose types are of doubtful validity.*

[For basis of doubt, see Table 6, columns "Material" and "Remarks."]

Pisces:
- Acipenser albertensis.
- Ceratodus eruciferus.
- Ceratodus hieroglyphus.
- Diphyodus longirostris.
- Hedronchus sternbergii.
- Lepisosteus occidentalis.

Plesiosauria:
- Cimoliasaurus magnus.

Chelonia:
- Basilemys imbricaria.

Rhynchocephalia:
- Champsosaurus brevicollis.

Crocodilia:
- Crocodilus humilis.

Ceratopsidæ:
- Dysganus (genera and species).
- Monoclonius fissus.
- Polynoax mortuarius.
- Triceratops galeus.

Trachodontidæ:
- Trachodon mirabilis.
- Trachodon marginatus.
- Diclonius pentagonus.
- Diclonius perangulatus.
- Diclonius calamarius.

All other Dinosauria:
- Troodon formosus.
- Deinodon falculus.
- Deinodon hazenianus.
- Deinodon lævifrons.
- Deinodon amplus.
- Deinodon cristatus.
- Deinodon incrassatus.
- Palæoscincus costatus.
- Palæoscincus asper.

TABLE 11.—*Forms which are probably synonyms.*

[See "Remarks," Table 6.]

	Belly River formation.	Judith River formation.	"Hell Creek beds."	Lance formation, Converse County, Wyo.	Denver and Arapahoe formations.	Authority.
Pisces:						
Lepisosteus occidentalis.						
L. haydeni		×				Hatcher.
Chelonia:						
Basilemys variolosus.						
B. ogmius	×					Hay.
Dinosauria:						
Deinodon horridus.						
Aublysodon mirandus		×		×		Osborn, Lambe.
Paronychodon lacustris		×				Hatcher.
Trachodon breviceps.						
T. selwyni	×					Hatcher.
Thespesius (Hadrosaurus) occidentalis.						
Agathaumas milo						Cope.

The preceding tables show that there are in all, as identified, 16 species, 8 of which are probably valid, common to the Belly River and Judith River; 14 species, 6 of which are probably valid, common to the Belly River and Lance; and 19 species, only 6 of which are probably valid, common to the Judith River and Lance.

So far as the number of species identified as common to the various formations goes, the vertebrates furnish no more basis for correlating the Judith River and the Lance than for correlating the Belly River and the Lance, but they do show a slight preponderance of evidence in favor of the correlation of the Judith River with the Belly River. On the other hand, a study of the generic and specific relationships of the vertebrate faunas from the three formations shows a closer relation between the faunas of the Judith River and the Belly River than between either of these and that of the Lance. This is especially true of the Ceratopsidæ, which form so important an element in the faunas of these three formations and which in the present state of knowledge furnish the most reliable and conclusive evidence of all the vertebrates.

With regard to the Ceratopsidæ, the preceding tables show that with one doubtful exception (*Ceratops montanus*) there are no species or even genera which are reported as common to the faunas of the Judith River and Belly River on the one hand and the Lance formation on the other; and that there are two genera of the Ceratopsidæ (Ceratops and Monoclonius) which are reported to occur in the Judith River and Belly River formations but not in the Lance, and two genera (Triceratops and Torosaurus) which are reported to occur in the Lance but not in the Judith River or Belly River.

The remarks in Table 6 on *Ceratops montanus*, which occurs in the Judith River formation and has been reported as occurring in the Denver formation (supposed to be approximately the equivalent of the Lance), show that there is doubt regarding Marsh's identification of the specimen from the Denver formation. *Ceratops montanus* is therefore not certainly known to occur except in the Judith River formation. With this exception there is not a single instance reported in which Ceratops or Monoclonius has yet been found in the Lance formation, although these genera occur in the Judith River and Belly River formations. Similarly, not a single specimen of Triceratops or Torosaurus has yet been reported from either the Judith River or the Belly River formation, although these genera are abundant in the Lance formation.

It therefore appears that the Ceratopsidæ, which, as stated above, form an important element in the fauna of the Belly River, Judith River, and Lance formations, show a closer generic relationship between the Belly River and Judith River faunas than between either of these faunas and that of the Lance formation. It may be profitable now to consider briefly the genetic relationship of the faunas of the Belly River, Judith River, and Lance formations.

Most if not all paleontologists who are familiar with the faunas of these formations agree that there is a closer genetic relationship between the faunas of the Judith River and Belly River than between the fauna of either of these formations and that of the Lance; also that the Belly River and Judith River forms are more primitive than those occurring in the Lance. These conclusions are adequately expressed in the following quotations from Osborn and Hatcher. Osborn[1] says:

It soon appeared to the writer, in the study of the fine collection made by Mr. Lambe, that the Belly River vertebrates of the Northwest Territory were of decidedly different and apparently of older type than those from the Laramie beds of Converse County, Wyo., described by Marsh, and were rather to be compared with those described by Leidy, Cope, and Marsh, from Montana, chiefly from the Judith River beds, a region by no means distant geographically. * * *

There is thus very little in common between the Belly River fauna and the Laramie fauna of Wyoming and Colorado, so far as described, except the dinosaur Ornithomimus and the very persistent chelonian Baena. Most of the dinosaurs will probably be found to be separated generically.

On the other hand, so far as known, the Montana fauna has much in common with the Belly River, especially the Testudinata, Iguanodontia, and Ceratopsia.

Hatcher's conclusions[2] are in part as follows:

When considered in its entirety, the vertebrate fauna of these beds [Judith River] is remarkably similar to though distinctly more primitive than that of the Laramie. * * *

It is in the Ceratopsidæ more than in any other group that we are at present able to contrast the Judith River and Laramie forms. * * * The primitive nature of the Judith River Ceratopsidæ, as compared with the Laramie, is especially seen in the smaller size of the individuals, the less perfectly developed armature of the skull, and the imperfectly developed parietal crest. * * *

Briefly, the Judith River fauna, it is clear, is descended from the Jurassic and is the direct ancestor of the Laramie. Its relations with the former are not close, and several groups are absent in the one which are present in the other. Its relations with the Laramie are much closer, as should be expected, considering the stratigraphic position. With one or two possible exceptions, all the families represented in either of these two later deposits are present also in the other. Although several genera and species now appear to be common to both these formations, it is probable that when more perfect material is available they will be found, in most instances, to be quite distinct, though some pertaining to more persistent types may prove to be identical. In every case where any group of the fauna has been studied from sufficient material it has been found to be represented by distinctly older and more primitive types than the related forms from the Laramie.[3]

In a personal communication to the writer C. W. Gilmore, of the United States National Museum, says:

The more we come to know these faunas the more evidence there is that the Belly River and Judith River species are distinct from those of the Lance formation. If the fauna of the Belly River and Judith River were known from more adequate material, instead of the fragmentary material now at our disposal, the apparent conflicting evidence would no doubt largely, if not entirely, disappear.

A study of the lists of vertebrates reported from the formations under discussion renders one of two conclusions inevitable. Either the vertebrates are of little value for close time correlation or the identification of the stratigraphic horizon or of the material is at fault. As shown in the "Remarks" column of Table 6, many of the identifications have been made on inadequate and insufficient material, and in this connection the comments of so eminent an authority as W. D. Matthew,[4] which have appeared in print since the tables of this paper were prepared, are of special significance. Matthew says:

Deinodon Leidy is determinable as to family but is not determinable generically, as the genera of carnivorous dinosaurs are now distinguished. The same is true of a whole series of genera and species described by Leidy and Cope from the Judith River. The treatment of types and referred specimens of these genera by paleontologists as specifically distinguishable or identical has sadly misled Dr. Peale in his recent discussion of the vertebrate evidence as to the age of the Judith River beds, leading him to present as conclusive evidence of identity in age a correspondence in fauna, which to those who know the nature of the specimens on which the lists are based is no evidence at all.

It is also possible that there was a confusion of stratigraphic horizons, especially in the assignment of the earlier collections, and until the type area of the Judith River formation (from which most of the vertebrate remains ascribed to that formation have been collected) is mapped in detail on an adequate base of large scale it can not be asserted that all the species

[1] Osborn, H. F., Distinctive characters of the mid-Cretaceous fauna: Contr. Canadian Paleontology, vol. 3, pt. 3, pp. 7, 10, 1902.

[2] U. S. Geol. Survey Bull. 257, pp. 101-103, 1905.

[3] Osborn and Hatcher here used the term "Laramie" for the formation which the United States Geological Survey now calls the Lance.—C. F. B.

[4] Matthew, W. D., The laws of nomenclature in paleontology: Science, new ser., vol. 37, pp. 788-792, May 23, 1913.

attributed to the formation really belong there. The extensive faulting that has disturbed the strata along Missouri River renders it possible, though it is not extremely probable, that blocks of the Lance formation may be faulted down among the beds of Judith River age and that some of the vertebrates collected by Hayden and others "from the badlands of the Judith" may have been obtained from the Lance formation instead of the Judith River formation, as they supposed.

SUMMARY AND CONCLUSION.

The stratigraphic and paleontologic evidence as to the position and age of the Judith River formation has been presented in the foregoing pages. It is shown in the discussion of the stratigraphy that the Judith River formation has been traced from areas where its position beneath the Bearpaw shale is undisputed into the western part of the type area (namely, at the mouth of Judith River) and has been found to be identical with the Judith River at that locality. It has also been shown that at some localities along Missouri River, especially on Cow Creek, Stanton and Hatcher found the Judith River formation overlain normally and in flat-lying attitude by the Bearpaw shale, though over most of the area along Missouri River the Bearpaw has been completely eroded. Similar stratigraphic relations between the Judith River and Bearpaw have been observed by the writer between Missouri and Milk rivers in the area lying east of the Bearpaw Mountains.

The paleontologic evidence shows (1) that the marine sandstone of the Claggett formation immediately underlying the Judith River formation at the mouth of Judith River is no more closely allied to the Fox Hills proper than to the underlying Eagle sandstone, and therefore the argument that the Judith River formation overlies the Fox Hills is unfounded; (2) that the flora of the Judith River formation, so far as it has been determined, is of Montana age; (3) that the invertebrates of the Judith River formation are more closely allied to the Belly River than to the Lance; (4) that almost all the vertebrates that are common to the Judith River and Lance are also common to the Belly River and Lance, and hence, if the Judith River is to be made the equivalent of the Lance on the basis of the similarity of the vertebrate fauna, the Belly River must on the same evidence also be made the equivalent of the Lance formation; (5) that the Ceratopsidæ, which form so important an element of the Lance fauna, are generically and specifically unlike the representatives of that family in the Belly River and Judith River faunas.

The evidence of the vertebrate fauna, so far as in the present state of knowledge it has any weight, and the evidence of the fresh and brackish water invertebrates, so far as it is decisive for accurate time determination, indicate a closer relationship between the Belly River and Judith River than between either of these formations and the Lance. This is in accord with the stratigraphic evidence, which shows conclusively that both the Judith River and Belly River formations are separated from the Lance by a marine formation which is of undoubted Cretaceous age.

THE CRETACEOUS-EOCENE CONTACT IN THE ATLANTIC AND GULF COASTAL PLAIN.

By LLOYD WILLIAM STEPHENSON.

INTRODUCTION.

The Cretaceous deposits of the Atlantic and Gulf Coastal Plain are separated from the overlying Eocene and younger formations by an unconformity of regional extent. Several authors, including Harris,[1] Dall,[2] Vaughan,[3] and Hill and Vaughan,[4] have briefly described this unconformity and have stated some of the important facts in regard to the differences exhibited by the faunas on the two sides of the contact. The magnitude of these differences, however, has not been sufficiently appreciated by geologists, notwithstanding the published statements of the authors cited. Eighteen years ago Harris wrote with reference to the Gulf region:

> Between the basal Eocene deposits and the uppermost Cretaceous there is in this section of the country a decided break both stratigraphic and faunal, so that not one species is known certainly to have crossed from one formation to the other. At or immediately above this line an entirely new fauna makes its appearance upon the scene.

Fourteen years ago (1900) Vaughan stated in regard to the unconformity along Frio River, Tex., that—

> These data prove absolutely that there must have been a break in the sequence of sedimentation long enough to permit a complete faunal revolution.

In 1909 Stanton [5] said:

> The succeeding Tertiary faunas, whether on the Pacific coast, the Gulf border, or the Atlantic Coastal Plain, show a very striking change from the Cretaceous faunas that immediately precede them. The specific types are practically all different.

The object of this paper is to present additional data bearing on the contact and especially to emphasize its importance in the geologic history of the Atlantic and Gulf Coastal Plain.

TREND OF THE OUTCROP AND NATURE OF THE CONTACT.

With certain interruptions the unconformity is traceable from New Jersey to the Rio Grande and, according to Dumble,[6] thence far southward into Mexico. In some places the contact is overlapped and concealed by Miocene or younger formations, and in others it is obscured by weathering and the similarity of the materials immediately below and above the unconformity. But for the greater part of the distance, where the contact is not concealed by transgressing formations, it is sharp and easily recognizable. The sea in which the basal Eocene strata were formed advanced across a land surface which had reached an old or nearly base-leveled stage of erosion, as is shown by the almost horizontal or broadly uneven attitude of the contact, which, however, presents numerous minor irregularities. Throughout much

[1] Harris, G. D., The Midway stage: Bull. Am. Paleontology, vol. 1, p. 119, 1896.
[2] Dall, W. H., A table of North American Tertiary horizons: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 2, pp. 332-335, 1898.
[3] Vaughan, T. W., Reconnaissance in the Rio Grande coal fields of Texas: U. S. Geol. Survey Bull. 164, pp. 35, 36, 1900; U. S. Geol. Survey Geol. Atlas, Uvalde folio (No. 64), pp. 2, 3, 1900.
[4] Hill, R. T., and Vaughan, T. W., U. S. Geol. Survey Geol. Atlas, Austin folio (No. 76), p. 6, 1902.
[5] Stanton, T. W., Succession and distribution of later Mesozoic invertebrate faunas in North America: Jour. Geology, vol. 17, p. 422, 1909.
[6] Dumble, E. T., Tertiary deposits of northeastern Mexico: Science, new ser., vol. 33, pp. 232-234, 1911.

of the linear extent of the Coastal Plain clays, sands, or limestones carrying marine invertebrates of Eocene age rest upon sands, clays, or marls carrying Upper Cretaceous invertebrates. The conglomeratic material at the base of the Eocene is everywhere relatively thin and usually consists of a few inches to a few feet of coarse sand or small pebbles with an intermixture of rolled chunks from the underlying formation, phosphatic nodules, casts of shells, shark teeth, and other fossil remains. Because of the marine origin of the beds below and above the contact the conditions are favorable for determining the faunal relationships of the formations. In east-central Georgia, northern Virginia, and the Potomac River region in Maryland the Eocene rests upon Lower Cretaceous deposits.

The approximate trend of the outcrop of the Cretaceous-Eocene contact and its geographic position with reference to the fall line and to transgressing formations younger than Eocene are indicated on the map forming Plate XI.

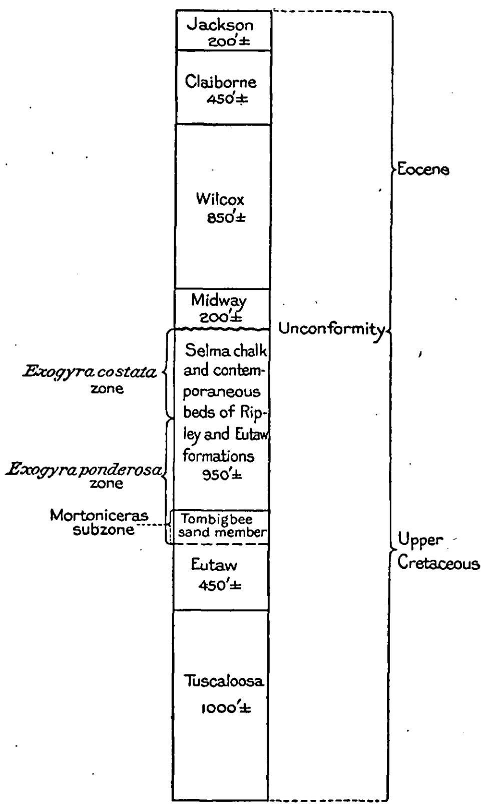


FIGURE 13.—Generalized section of the Upper Cretaceous and Eocene series and their major subdivisions in west-central Alabama and east-central Mississippi.

GENERALIZED SECTION IN THE CENTRAL PART OF THE EASTERN GULF REGION.

A generalized section of the Upper Cretaceous and Eocene strata in the central portion of the eastern Gulf region is given in figure 13. In the Cretaceous section are the Tuscaloosa, Eutaw, and Selma formations, named in ascending order.

The Tuscaloosa is a plant-bearing formation composed of sands and clays of shallow-water origin. The lower part of the formation is correlated by E. W. Berry with the Dakota sandstone of the western interior region.

The Eutaw formation is composed of sands, in part calcareous and glauconitic, and clays, all of marine origin. The upper or Tombigbee sand member of the formation (also known as the Mortoniceras subzone) carries a purely marine fauna which includes 70 or more species. Several lines of evidence seem to show with a fair degree of certainty that the Mortoniceras subzone is approximately synchronous with the Niobrara formation of the western interior region.

The Selma chalk has its fullest development in west-central Alabama and east-central Mississippi, and here the formation as a whole may be roughly correlated with the Montana group of the western interior region. This chalk formation merges to the east in Alabama and Georgia into nonchalky marine sands and clays referred to the Ripley formation, which carries an abundant marine invertebrate fauna, and to the northwest and north in Mississippi and Tennessee into similar sands and clays referred in part to the Ripley formation and in part to the Eutaw formation.

Two major faunal zones have been distinguished in the Upper Cretaceous deposits. The *Exogyra ponderosa* zone includes the Tombigbee sand and approximately the lower half of the Selma chalk; the *Exogyra costata* zone includes the upper part of the Selma chalk. These two zones are traceable through practically the entire linear extent of the Atlantic and Gulf Coastal Plain. In west-central Alabama and east-central Mississippi the Selma is unconformably overlain by the Midway, an invertebrate-bearing group of marine origin, and in ascending order the Midway is succeeded by the Wilcox, Claiborne, and Jackson groups.

MAP SHOWING APPROXIMATE TREND OF THE CRETACEOUS-EOCENE CONTACT IN THE ATLANTIC AND GULF COASTAL PLAIN

AND ITS GEOGRAPHIC RELATION TO THE PALEOZOIC AND CRYSTALLINE ROCK BOUNDARY, AND TO TRANSGRESSING FORMATIONS YOUNGER THAN EOCENE

Scale $\frac{1}{7,000,000}$

100 50 25 0 50 100 200 300 STAT. MILES

1914

FORMATIONS IN CONTACT ELSEWHERE IN THE ATLANTIC AND GULF COASTAL PLAIN.

From a point near Houston, Chickasaw County, Miss., to Tennessee the Midway rests upon the Ripley formation; farther north, in Tennessee, Kentucky, and southern Illinois, the deposits immediately below and immediately above the Cretaceous-Eocene contact are of shallow-water origin and so far as known are barren of invertebrates. From central Alabama eastward to central Georgia the Midway rests upon the Ripley formation, in part upon typical marine beds and in part upon shallow-water deposits which have been designated the Providence sand member of the Ripley formation.

In east-central Georgia and southwest-central South Carolina the Claiborne group of the Eocene transgresses northwestward across both the older Eocene and the Upper Cretaceous and rests upon the Lower Cretaceous. The Upper Cretaceous reappears in eastern South Carolina, and at Wilmington, N. C., the Peedee sand, of the Upper Cretaceous series, is overlain by the stratigraphic equivalent of the Jackson, the youngest Eocene division. A little farther north deposits correlated with the Claiborne overlie the Peedee sand. In northeastern North Carolina and southeastern Virginia the Eocene and Cretaceous are entirely transgressed by the Miocene, which extends westward to the fall line. Farther north in Virginia the Lower Cretaceous and Eocene reappear from beneath the Miocene, and in Maryland the Upper Cretaceous reappears from beneath the Eocene. In Maryland the Aquia formation, of the Eocene, which is correlated with the lower part of the Wilcox of the Gulf region, rests unconformably in part upon the Matawan formation and in part upon the Monmouth formation, of the Upper Cretaceous. The Monmouth, the younger of the two formations last named, corresponds approximately to the *Exogyra costata* zone of the Gulf region. In New Jersey the Miocene again transgresses upon the Upper Cretaceous, although the Shark River marl, of the Eocene, which is probably about contemporaneous with the Claiborne, appears in Monmouth County, where it rests upon the Manasquan formation, of the Upper Cretaceous.

From the vicinity of Arkadelphia, Ark., southwestward to the Rio Grande, Upper Cretaceous deposits bearing marine invertebrates and roughly corresponding in age to the *Exogyra costata* zone of the eastern Gulf region are overlain almost continuously by marine Eocene strata which Harris has correlated with the Midway. The writer's work in southwestern Texas has resulted in the discovery of the contact at two localities and its approximate determination at several other localities along the Rio Grande and in its approximate determination at several places in Uvalde and Medina counties. In at least one area in southwestern Texas the Midway is transgressed by younger Eocene strata.

CRETACEOUS AND EOCENE FAUNAS COMPARED.

At no known place between Maryland and the Rio Grande are the Upper Cretaceous deposits immediately below the Eocene contact markedly younger than the upper part of the *Exogyra costata* zone of the eastern Gulf region, nor are the Eocene deposits immediately above the contact older than the Midway. In this connection it should be stated that the Rancocas and Manasquan formations of New Jersey, which carry only a meager fauna, are thought to be somewhat younger than the *Exogyra costata* zone, and the upper part of the Escondido formation of southwestern Texas may be a little younger than that zone, although its fauna is composed of strictly Mesozoic types, of which the genus Sphenodiscus is the most striking example. The time represented by the unconformity at other places throughout the Coastal Plain is therefore approximately equal to or greater than the time represented by the unconformity in the eastern Gulf region. As the faunas above and below the contact are best known in the Gulf region the available data relating to that region form the chief basis for the statements which follow.

During the time represented by the unconformity separating the Cretaceous and Eocene strata of the eastern Gulf region some very important changes took place in the molluscan life of the region. A preliminary study of the faunas has shown that 168 or more species belonging to the subkingdom Mollusca existed in the zone of *Exogyra costata* of the Upper

Cretaceous. Of these not a single species is known with certainty to have been found in the basal Eocene or Midway formation. Several species of Cretaceous mollusks have been reported from basal Eocene beds at different places in the Atlantic and Gulf Coastal Plain, but when the records are critically examined more or less uncertainty is found in each record, either as to the correctness of the identifications or as to the authenticity of the localities at which they were reported to have been found.

The 168 species of mollusks in the zone of *Exogyra costata* represent 89 genera. At least 20 of the more common of these genera became extinct before the Midway formation began to be deposited, and these are enumerated in the list which follows. One whole order, the Ammonoidea, which included five or more genera, entirely disappeared.

Genera common in the zone of Exogyra costata (Upper Cretaceous), which became extinct before the deposition of the Midway formation (Eocene).

Breviarca.	Cyprimeria.	Belemnitella.
Nemodon.	Legumen.	Order Ammonoidea:
Gervilliopsis.	Ænona.	Baculites.
Inoceramus.	Linearia.	Scaphites.
Exogyra.	Leptosolen.	Sphenodiscus.
Paranomia.	Perissolax.	Hamites.
Liopistha.	Pugnellus.	Turrilites.

The genus Trigonia, which is common in the zone of *Exogyra costata*, does not appear in the Eocene of the Atlantic and Gulf Coastal Plain but occurs rarely in the post-Cretaceous in other parts of the world. One genus, Hamulus, belonging to the subkingdom Vermes, or worms, became extinct. Some of the smaller forms of life, such as Foraminifera, Bryozoa, and Ostracoda, have not been studied critically, and it is not known what changes may have taken place among them. However, R. S. Bassler has found that a bryozoan fauna which occurs in the Rancocas, the youngest but one of the Upper Cretaceous formations of New Jersey, reappears in part with certain varietal changes in the Aquia formation (Eocene) in Maryland.

Although practically all the species of mollusks in the Midway formation are different from those found in the underlying Cretaceous, the number of genera that make their first appearance in the Midway is probably less than the number of Upper Cretaceous genera that became extinct in the interval represented by the unconformity. However, using Harris's paper, already cited,[1] as principal authority, the writer has been able to note at least seven common genera in the Midway that are not found stratigraphically below that level in the eastern Gulf region; these are Chama, Venericardia, Meretrix, Mazzalina, Calyptraphorus, Mesalia, and Enclimatoceras. Some of these genera are known in the Upper Cretaceous in other parts of the world.

MAGNITUDE OF THE FAUNAL CHANGES.

The following comparisons will give some idea of the magnitude of the faunal changes that took place during the time represented by the unconformity. The Mortoniceras subzone of the Eutaw formation, which is thought to correspond approximately in age to the Niobrara of the western interior region, has yielded about 70 species of mollusks representing about 43 genera. Of these, 40 species and all but two or three of the genera range upward to the top of the Cretaceous. During the time required for the deposition of the beds carrying the Mortoniceras fauna and the overlying strata composing the Selma chalk and its nonchalky representatives, and probably during the time represented by the entire Upper Cretaceous section of the Chattahoochee region, the faunal changes were not nearly so great as those which occurred during the time that elapsed between the deposition of the uppermost Cretaceous strata and that of the lowermost Eocene strata of the area—that is, during the time represented by the hiatus—for at the close of the period of deposition 40 out of 70 species and all but two or three of the 43 genera survived, while at the close of the

[1] Harris, G. D., The Midway stage: Bull. Am. Paleontology, vol. 1, 156 pp., 15 pls., 1898.

period of erosion, out of 168 species representing 89 genera, few if any species survived, and 20 or more common genera, including one whole order, became extinct.

T. W. Vaughan, who has a wide acquaintance with the Tertiary and Quaternary faunas of the eastern United States, is authority for the almost startling statement that "the changes that took place in the marine animal life of the Atlantic and Gulf Coastal Plain during the time represented by the unconformity separating the Cretaceous and Eocene of this area are more striking than the changes that have taken place between earliest Midway time and the present day, for no great orders comparable to the Ammonoidea that lived during Midway time have become extinct."

CRETACEOUS AND EOCENE FLORAS COMPARED.

The evidence afforded by the Cretaceous and Eocene floras is in substantial agreement with that supplied by the invertebrates. The following is quoted from a letter received from Mr. E. W. Berry, of Johns Hopkins University:

> With regard to the Upper Cretaceous and Eocene floras of the eastern Gulf region, their differences are profound, and I believe the unconformity at the base of the Midway represents a very long interval. The last extensive Cretaceous floras in the Gulf region are, of course, a good way from the end of the Cretaceous, but they are totally different from the plants collected near Earle, Tex., in beds believed to belong to the Midway formation. Even when comparisons are made between these Midway (?) plants and the Wilcox flora of the Gulf and the late Cretaceous of the Rocky Mountain province, the contrast is just as marked, unless you are prepared to call the Denver formation Cretaceous. There are a number of Denver plants in the Gulf Eocene, but I do not recall a single Laramie plant.

INTERPRETATION OF THE HIATUS.

In an attempt to explain the differences exhibited by the faunas found in the beds below and above the Cretaceous-Eocene contact several factors are to be considered, including time, the physical changes that may have caused the extinction or the more rapid evolution of the forms of marine life, and the migration of new forms into the area. The unconformity that separates these deposits, extending throughout the length of the Atlantic and Gulf Coastal Plain of the United States and far into Mexico is, in itself, an evidence both of a considerable lapse of time and of great diastrophic movements. The area which was submerged during Upper Cretaceous time was elevated and the shore line retreated far to the east and south, probably a considerable distance beyond the present shore line and perhaps nearly to the edge of the continental shelf. The faunas were thus forced into new environments, which doubtless contributed in part to the extinction of old genera and species and to the development of new species. There is, however, little, if any, evidence of marked changes in climate or in the temperature of the marine waters.

There is evidence that after the close of the Cretaceous period as recorded and before the beginning of the earliest recorded Eocene deposition some new forms came into the Atlantic and Gulf Coastal Plain province from an outside province or provinces. But the number of genera thus introduced is probably relatively small compared with the number of genera that survived from the Cretaceous of the same province, though represented by new species. The faunal changes are therefore believed to be more largely due to evolutionary development from forms that previously existed in the same province than to new elements introduced from outside provinces.

It is pretty generally conceded by paleontologists that evolutionary changes have proceeded more rapidly at certain times during the earth's history than at other times; but if this quickening of development is admitted the hiatus, in order to produce the observed changes, must have been of great duration even when measured in terms of geologic time. How much of that time should be classed with the Cretaceous and how much with the Tertiary can not be determined with the available data. It is reasonable to conclude, however, that Cretaceous time did not end with the deposition of the uppermost Cretaceous strata now preserved, nor did Tertiary time begin with the deposition of the lowermost Eocene strata. The line separating the two periods probably lies somewhere toward the middle of the hiatus.

UNPUBLISHED DETAILS RELATING TO THE CONTACT.

During the last eight years the writer has had occasion to examine the Cretaceous-Eocene contact at many places between Virginia and the Rio Grande in Texas, and some of his observations have already been published. Many of the localities had been previously visited by geologists and the results of their studies put on record. Perhaps the majority of the published sections are essentially correct, so that for the present purpose their description would be an unnecessary duplication. Several sections in Alabama and Mississippi in which the contact is exposed have been incorrectly interpreted, and a restatement of the age and structural relations is necessary. New data in regard to the contact in Alabama, Mississippi, and Texas are also given on succeeding pages.

EASTERN GULF REGION.

VICINITY OF CLAYTON, ALA.

Langdon[1] mentioned an outcrop of Midway limestone in a cut on the Central of Georgia Railway east of Clayton, Barbour County, Ala., as follows: "Two miles east of Clayton this rock may be seen cropping out in a cut on the Clayton & Eufaula Railroad [now Central of Georgia Railway]."

Harris studied this section and in 1896 published a description of it,[2] which is in essential agreement with the one here given. Although he recognized the unconformity between layers 1 and 2 of the section given below, he did not interpret it to be the contact between the Cretaceous and Eocene. In 1910 the writer carefully examined this cut and other exposures along the railroad immediately to the east and found what he regarded as the Cretaceous-Eocene contact.

Section in cut of Central of Georgia Railway 1½ miles east of Clayton, Ala.

	Feet.
Eocene (Midway group):	
6. Deep-red ferruginous sand, grading downward into light-colored, rather fine sand	10–12
5. Dark to black laminated clay	3–4
4. Hard fossiliferous limestone (Clayton limestone) in which were recognized *Ostrea crenulimarginata* Gabb, Ostrea sp., *Turritella mortoni* Conrad, Turritella sp., and Venericardia sp.; the limestone appears to pass into sand toward the east	5
3. Fine yellow, slightly micaceous massive sand with small oysters in the upper part	5–6
(A few rods east of the end of the cut and 1 or 2 feet lower than the base of layer No. 3 the section is continued as follows:)	
2. Strongly ferruginous sand and sandy clay, partly indurated, with small particles of lignite and some pyrite or marcasite	1–2
Sharp, unconformable contact presenting minor irregularities.	
Upper Cretaceous (Providence sand member of Ripley formation):	
1. Greenish-gray compact coarse sand	3+

The base of this section is estimated to be approximately 70 feet lower than the railroad track at Clayton station.

In gullies and cuts within half a mile east of the section just described are exposures of coarse, irregularly bedded sands and clays resembling the Providence sand member of the Ripley formation, which is typically developed east of Chattahoochee River in Georgia. The sands are in part arkosic, are very coarse, and contain pebbles having a maximum length of half an inch or more; they also contain clay balls and some clay bowlders which attain a maximum observed diameter of 1 foot. Interbedded with the sands are lenses of drab sandy massive clay, in places mottled and blotched with yellow and purple. Local unconformities are common between the layers and lenses of sand and clay. A thickness of 40 or 50 feet of these materials was noted, but the base of the member did not appear in the exposures examined.

[1] Langdon, D. W., jr., The Tertiary and Cretaceous formations east of Alabama River (in Smith, Johnson, and Langdon, On the geology of the Coastal Plain of Alabama, Alabama Geol. Survey), p. 418, 1894.

[2] Harris, G. D., The Midway stage: Bull. Am. Paleontology, vol. 1, No. 4, pp. 149, 150, 1896.

TROY, ALA.

The contact between the Cretaceous and Eocene outcrops north of Troy in the northward-facing slope of the Conecuh River valley. Figure 14 is a generalized section from the town northward to the river, a distance of about 3 miles, showing the relation between the Cretaceous and Eocene strata. The details and approximate thicknesses of the beds are as follows:

Section from Troy, Ala., to Conecuh River.

	Feet.
Eocene (Midway group):	
f. Deep-red weathered massive sands, forming the surface materials at Troy, grading downward into less weathered massive sands	80
e. Gray glauconitic sand	20
d. Limestone in which the following Eocene mollusks were recognized: *Ostrea crenulimarginata* Gabb, Venericardia sp., *Turritella mortoni* Conrad (Clayton limestone)	15
c. Light-gray massive argillaceous sand	30
Probable unconformity. The exact contact between the Cretaceous and Eocene was not seen clearly exposed in the vicinity of Troy, but the general relation of the deposits as observed in numerous exposures justifies the belief that the contact lies immediately above layer *b* at the point indicated in figure 14.	
Upper Cretaceous (Ripley formation):	
b. Drab to yellowish and reddish fine to coarse sands with interbedded subordinate lenses and layers of massive clay, lenses of laminated clay, white clay films and grains, and some clay balls (Providence sand member)	100
a. Dark-gray to black argillaceous, very micaceous sand or sandy clay, containing fossils in the form of soft casts; *Crassatellites pteropsis* Conrad and Breviarca sp. recognized	30

Layers *a* and *b* of the section are exposed along the road leading northward from Troy to Orion; layers *d* to *f* are exposed in deep gullies at the headwaters of a small branch just north of Troy.

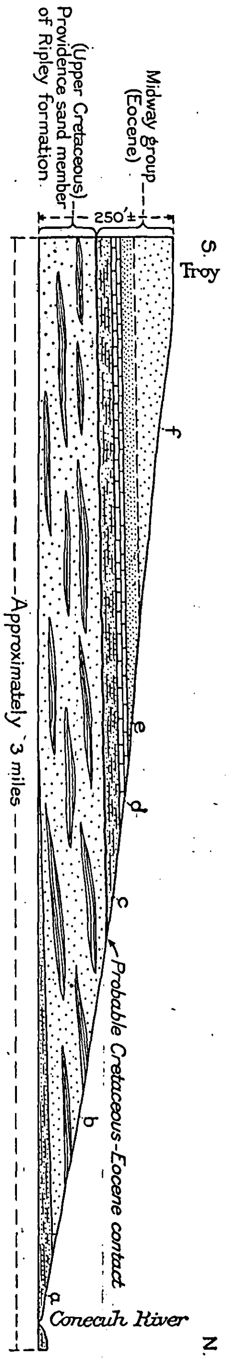


FIGURE 14.—Generalized section from Troy, Ala., northward to Conecuh River, showing the relation between the Cretaceous and overlying Eocene deposits. For details of section see text.

BRIDGEPORT LANDING, ALABAMA RIVER, ALA.

Smith and Johnson[1] in 1887 described in detail the section exposed in the bluff at Bridgeport Landing, Alabama River, Wilcox County, Ala. With the exception of 10 feet of terrace materials at the top of the bluff, the whole section embracing a thickness of about 50 feet of strata was assigned by them to the Ripley formation (Upper Cretaceous).

In 1910 the writer, in company with Dr. Smith, visited this landing and found in an indurated layer 10 feet above water level the Eocene fossil *Enclimatoceras ulrichi* White, and a few feet higher Venericardia sp. It was at once agreed that the strata belonged to the Midway group and that no Cretaceous beds appeared above water level.

[1] Smith, E. A., and Johnson, L. C., Tertiary and Cretaceous strata of the Tuscaloosa, Tombigbee, and Alabama rivers: U. S. Geol. Survey Bull. 43, p. 74, Pl. XIX, fig. 3, 1887. See also Smith, E. A., Johnson, L. C., and Langdon, D. W., jr., On the geology of the Coastal Plain of Alabama, Alabama Geol. Survey, p. 262, Pl. XVI, 1894.

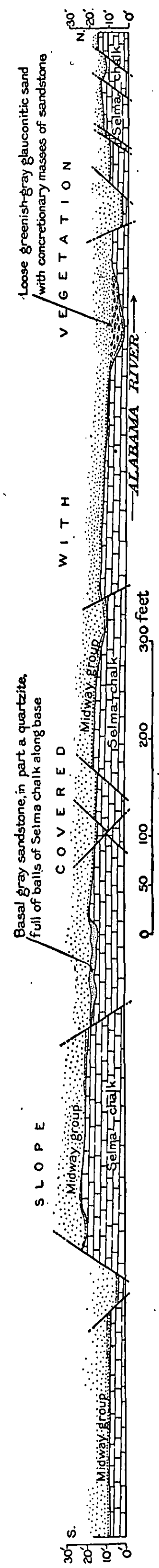


FIGURE 15.—Sketch showing position of Cretaceous-Eocene contact and faulting at Old Canton Landing, Alabama River, Ala.

OLD CANTON LANDING, ALABAMA RIVER, ALA.

The Cretaceous-Eocene contact is clearly exposed in a bluff on Alabama River below Old Canton Landing, Wilcox County, Ala. This section was described in 1887 by Smith and Johnson,[1] but the contact was not recognized and that portion of the section which belongs to the Midway was referred to the Ripley formation of the Upper Cretaceous. The locality was visited by the writer in 1909 and the results expressed in the section given below were obtained. In 1910 he again went to the locality, in company with Dr. Smith, who concurred in this interpretation.

Section at Old Canton Landing, Alabama River, Ala.

	Feet.
Pleistocene (terrace deposit): Red ferruginous pebbly sand with gravel in the lower portion (poorly exposed toward base)	25–30
Unconformity.	
Eocene (Midway group): The steep slope is largely covered with vegetation, but in the road leading down to the landing nodular layers of calcareous sandstone are poorly exposed, and along the bluff below the landing, immediately above the contact, is 10 to 20 feet of greenish-gray, more or less glauconitic calcareous sandstone, underlain in depressions in the Selma chalk by loose glauconitic gray sand with rows of indurated concretionary masses (see Pl. XII), and in places rolled lumps of Selma chalk and reworked Cretaceous fossils. Along the immediate base of the Midway is a gray quartzite-like rock varying in thickness from a film to 1 foot. In the calcareous sandstone the following Eocene fossils, identified by C. Wythe Cooke, were obtained: A coral, Terebratulina? sp., *Cucullæa saffordi* (Gabb), *Ostrea pulaskensis* Harris, Turritella sp., *Levifusus trabeatus* (Conrad) var.? (U. S. G. S. collection 5480); in addition to these the writer recognized Venericardia sp. and *Enclimatoceras ulrichi* White	90–105
Unconformity.	
Upper Cretaceous (Selma chalk): Light-gray chalky limestone, typical in upper part, somewhat sandy below; contains 30 or more characteristic species of the *Exogyra costata* zone of the Upper Cretaceous	3–20

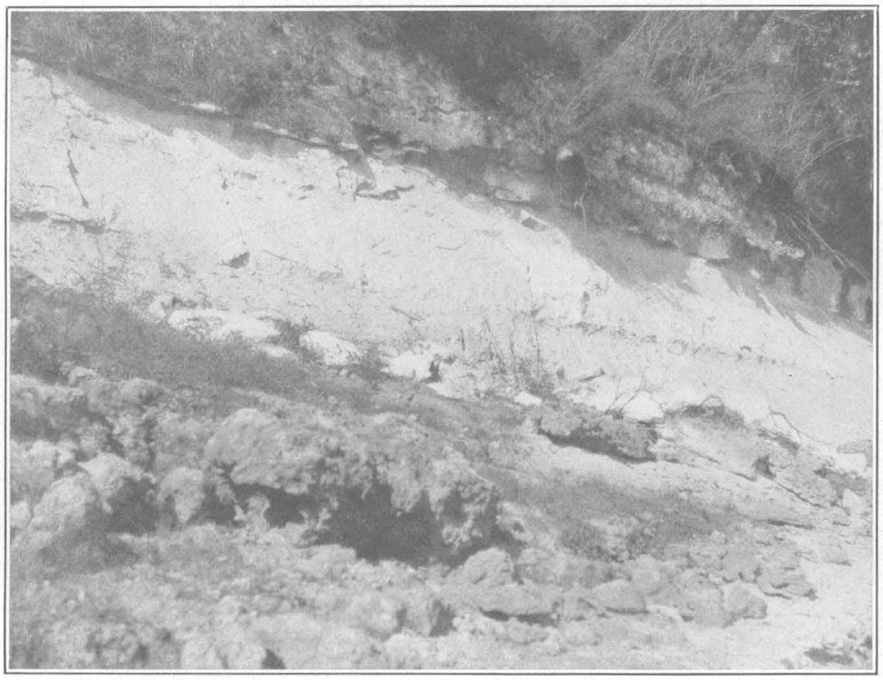
The strata exposed in the lower 25 or 30 feet of the bluff exhibit numerous minor faults involving both the Cretaceous and Eocene. Figure 15 is a rough sketch of the structural features exhibited by the rocks exposed along the face of the bluff. (See also Pl. XIII, *A*.)

MOSCOW LANDING, TOMBIGBEE RIVER, ALA.

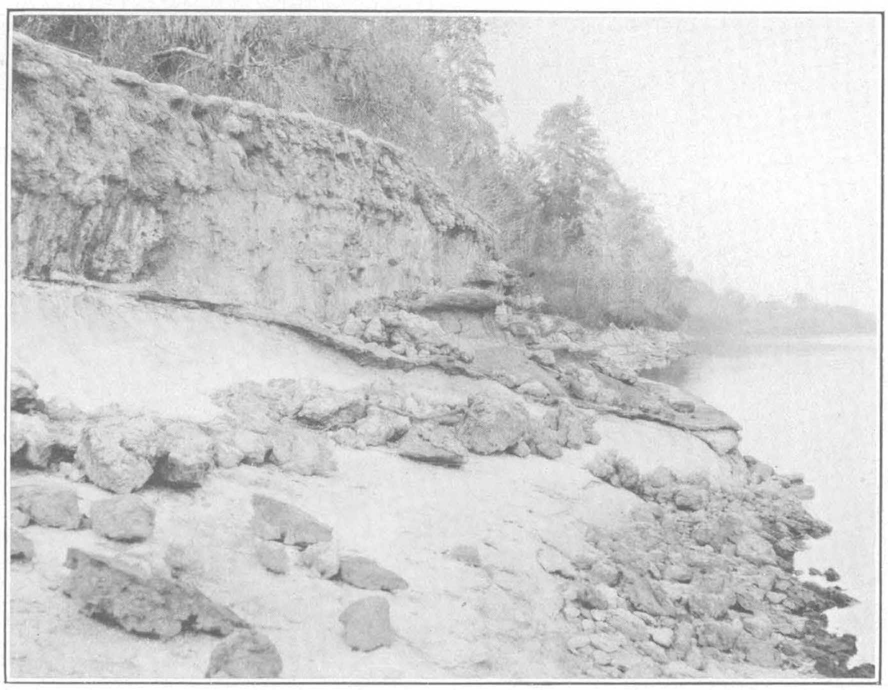
The Cretaceous-Eocene contact is well exposed at Moscow Landing, on Tombigbee River about 14 miles below Demopolis, Ala. In 1887 the beds above the contact were referred by Smith and Johnson[2] to the Ripley formation (Upper Cretaceous), but in 1910 this mistaken correlation was partly corrected by Smith.[3] This exposure has been examined by T. W. Vaughan, E. W. Berry, and the writer, and all agree that the sandstone and conglomeratic lenses occupying depressions in the Selma chalk and overlain by strata of undoubted Midway age are basal Eocene deposits, and not Cretaceous deposits, as interpreted by Smith.

The Eocene sea advancing across an uneven surface planed off the tops of the elevations and rapidly filled the depressions. After the hollows were completely filled, and while the sea was still shallow, the waves continued for

[1] Op. cit., pp. 74–75, Pl. XIX, fig. 4. See also Smith, Johnson, and Langdon, op. cit., pp. 262–264, Pl. XVI.
[2] Op. cit., pp. 80–81, 133, Pl. X. See also Smith, Johnson, and Langdon, op. cit., pp. 270–272, 358, 359, Pl. XVIII.
[3] Smith, E. A., The Cretaceous-Eocene contact: Jour. Geology, vol. 18, pp. 430–434, 1910.



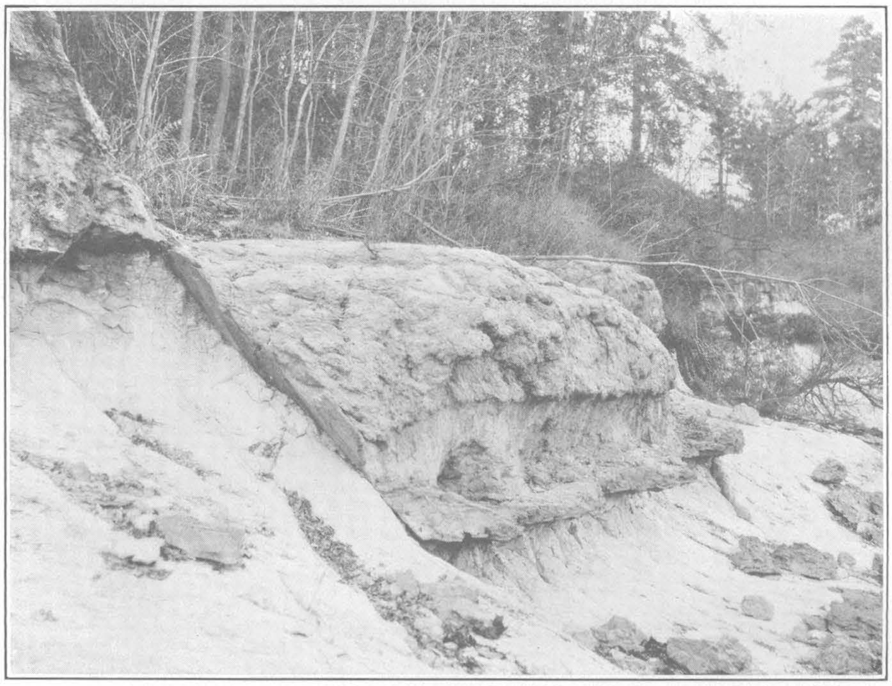
A.



B.

CONTACT BETWEEN THE SELMA CHALK (UPPER CRETACEOUS) AND MIDWAY GROUP (EOCENE) AT OLD CANTON LANDING, ALABAMA RIVER, ALA.

The thin layer of quartzite at the base of the vegetation in *A*, and projecting conspicuously in *B*, marks the base of the Eocene.



A. FAULT INVOLVING THE CRETACEOUS-EOCENE CONTACT AT OLD CANTON LANDING, ALABAMA RIVER, ALA.

B. EXPOSURE EXHIBITING THE CRETACEOUS-EOCENE CONTACT ON MACON-DEKALB ROAD 7½ MILES SOUTH OF MACON, ALA.

Half a mile north of the crossing of Running Water Creek. On account of the similarity of the materials composing the uppermost Cretaceous (Selma) and the lowermost Eocene (Midway), the contact was determined only by the aid of the contained fossils. The basal Midway is here composed of reworked Selma chalk. The camera case rests on the contact.

a short time to plane off the sea bottom and slightly cut down the fillings in the depressions. Soon, however, as the land continued to sink, the deposition of regular massive strata began, covering both the truncated elevations of the Selma and the planed-off fillings in the depressions and producing the appearance of unconformity between the coarse fillings and the regularly bedded deposits above. The Cretaceous fossils found in these basal, lenslike sands and conglomerates were derived by mechanical mixture from the underlying Selma chalk.

The following fossils collected from the Midway at Moscow Landing by T. W. Vaughan and the writer were identified by C. Wythe Cooke:

Fossils from the Midway group at Moscow Landing, Tombigbee River, Ala.

	Collection of L. W. Stephenson (U. S. G. S. 5585).	Collection of T. W. Vaughan (U. S. G. S. 5658).		Collection of L. W. Stephenson (U. S. G. S. 5585).	Collection of T. W. Vaughan (U. S. G. S. 5658).
Trochocyathus hyatti Vaughan	×		Crassatellites sp	×	
Terebratula (Chlidonophora) sp		×	Venericardia sp	×	
Terebratulina sp		×	Turritella humerosa Conrad var.?	×	
Discinisca? sp	×		Turritella mortoni Conrad		×
Cucullaea saffordi (Gabb)	×		Vermetus sp	×	×
Ostrea pulaskensis Harris	×	×	Enclimatoceras ulrichi White	×	×
Crassatellites gabbi (Safford)?	×				

VICINITY OF LIVINGSTON, ALA.

Southwest of Livingston, Sumter County, Ala., the Midway (Eocene) rests unconformably upon the Selma chalk (Upper Cretaceous). Here, as at Moscow Landing, Old Canton Landing, and elsewhere in west-central Alabama, strata of the Midway group were mistaken for the Ripley formation by Smith[1] and his assistants. The section represented by figure 16 expresses the writer's interpretation of an exposure on the Curls station road, half a mile southwest of the courthouse and just west of Sucarnochee Creek. In one of his trips to the locality (in 1910) the writer was accompanied by Dr. Smith, who concurred in this interpretation so far as it relates to the beds immediately below and above the contact. The details of the section are as follows:

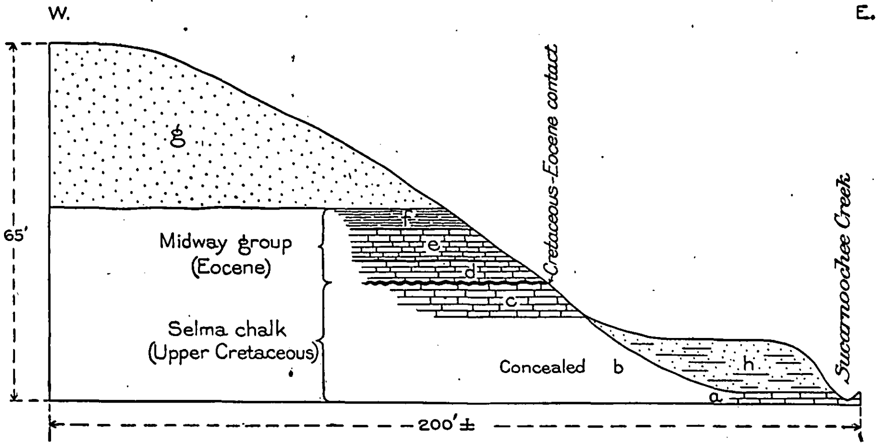


FIGURE 16.—Section showing Cretaceous-Eocene contact on Curls station road half a mile southwest of the courthouse at Livingston, Ala. For details of section see text.

Section on Curls station road southwest of Livingston, Ala.

	Feet.
Pleistocene (terrace deposit):	
h. Alluvial sand and clay	10
Unconformity.	
Pleistocene or Eocene:	
g. Poorly exposed red ferruginous sand, grading down into coarse grayish sand (weathered phase of Midway or Pleistocene terrace deposit)	30

[1] Smith, E. A., Johnson, L. C., and Langdon, D. W., jr., Geologic map of Alabama, Alabama Geol. Survey, 1894.

	Feet.
Eocene (Midway group):	
f. Dark shaly calcareous clay	4
e. White massive limestone, apparently a chalk; contains Foraminifera. Weathers in conchoidal fragments	6
d. Massive argillaceous sandy limestone; contains the Midway Eocene fossils Arca sp. and *Ostrea pulaskensis* Harris, the latter becoming numerous toward the base. In the basal portion occur phosphatic nodules and phosphatic casts and some shells of Upper Cretaceous fossils, present as a mechanical mixture, as follows: *Exogyra costata* Say, Gyrodes sp., Pyropsis sp., Baculites sp., Hamites sp	4
Contact obscure, owing to similarity of materials above and below the unconformity.	
Upper Cretaceous (Selma chalk):	
c. Massive argillaceous chalky limestone	6
b. Concealed	14
a. Chalky limestone similar to layer *c;* contains *Exogyra costata* Say	1

In company with Dr. Smith the writer made a trip by way of the Ramsey road from Livingston to Sumterville, a small village situated about 10 miles west of north of Livingston. After crossing Sucarnochee Creek within half a mile of the courthouse greenish clays—the Sucarnochee clay of the Midway group—were observed at intervals in road exposures for a distance of 4 or 5 miles. At a crossing of Sucarnochee Creek about 5 miles from Livingston the Cretaceous-Eocene contact was observed where the stream had cut through the Eocene into the underlying Selma chalk. Figure 17 and the subjoined section show the relations of the deposits as observed. The thicknesses given in the section are approximate.

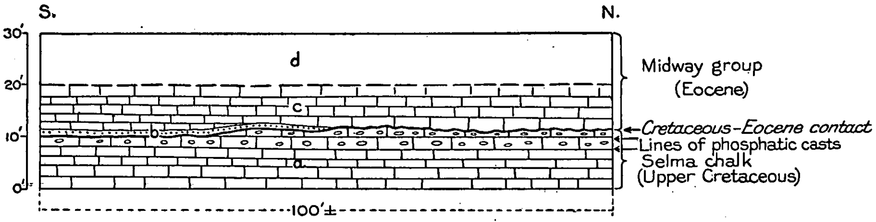


FIGURE 17.—Section showing Cretaceous-Eocene contact on Sucarnochee Creek 5 miles northwest of Livingston, Ala.

Section on Sucarnochee Creek 5 miles northwest of Livingston, Ala.

	Feet.
d. Concealed by vegetation	10
Eocene (Midway group):	
c. Sandy limestone	8–10
b. Coarse phosphatic sand with Cretaceous fossils, principally casts, mechanically derived from the underlying Selma chalk	1½
Sharp undulating contact.	
Upper Cretaceous (Selma chalk):	
a. Massive chalky limestone. A line of phosphatic casts of Cretaceous fossils is cut off in places by the unconformity, and a similar line of casts occurs a little lower in the section	10–12

The Cretaceous-Eocene contact was observed at several places within 2 or 3 miles northwest of this locality, and at one place phosphatic casts of Cretaceous fossils mechanically included in the base of greenish clays (Sucarnochee clay) were noted. Sucarnochee clay was observed overlying the chalk to a point within 2 or 3 miles of Sumterville, the base of the clay gradually rising to the north and the clay finally feathering out south of Sumterville. These observations show that northwest of Livingston the Sucarnochee clay of the Midway group transgresses the older sandy and calcareous beds of the Midway, and south of Sumterville these beds are entirely overlapped and the clay rests directly upon the Selma chalk.

VICINITY OF SCOOBA AND WAHALAK, MISS.

The town of Scooba, Kemper County, Miss., is underlain by the Sucarnochee clay of the Midway group of the Eocene. Several poor exposures of greenish clays were observed in the streets and along the roads in the vicinity of the town, and a poor exposure of similar clay was noted along the Mobile & Ohio Railroad, 1 mile north of town. Clays of the same character overlain by 5 to 10 feet of sand of undetermined age (probably Eocene) were observed at intervals along the Giles road for a distance of 2½ miles east of Scooba.

Three miles east of Scooba, where the road descends into a small valley, 6 feet of compact gray limestone belonging to the Selma chalk (Upper Cretaceous) appears in the roadbed and is overlain by 6 feet of residual sandy clay (Sucarnochee). From the chalk were obtained *Exogyra costata* Say, Gryphæa sp., *Pecten venustus* Morton, Plicatula sp. nov., and Lima sp. From this point to a place within half a mile of Giles, a small village about 6 miles east of Scooba, greenish clays overlain by a few feet of yellow sands, probably of Midway age, are exposed at intervals. Half a mile west of Giles the section represented in figure 18 was examined and found to contain the following beds:

Section half a mile west of Giles, Miss.

	Feet.
Eocene (Midway group):	
b. Yellow sand, grading down into greenish-gray sandy sticky clay (Sucarnochee clay)...	5
Unconformity.	
Upper Cretaceous (Selma chalk):	
a. Gray argillaceous chalky limestone, containing *Ostrea plumosa* Morton................	10

A few feet of sand corresponding to layer *b* in this section appears in the public road to a point about 3½ miles east of Giles. In places this sand is underlain by 10 feet or more of greenish clays. A mile and a quarter east of Giles the Selma chalk appears in a bald spot and is overlain by the greenish clays. The chalk yielded *Ostrea larva* Lamarck and Gryphæa sp. The Selma is also exposed in a bald spot in the road about 3½ miles east of Giles, and

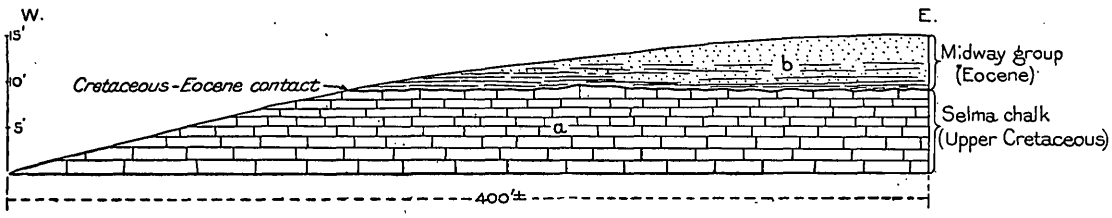


FIGURE 18.—Section showing Cretaceous-Eocene contact half a mile west of Giles, 5½ miles east of Scooba, Kemper County, Miss.

here were found *Ostrea larva* Lamarck and *Ostrea plumosa* Morton. Beyond this point to the east the Midway covering thins out and disappears and the surface materials consist of residual clays derived from the Selma chalk. About 10 feet of typical massive limestone of the Selma chalk is well exposed in the banks of a dry branch a short distance west of Ivy, Sumter County, Ala.

A trip was made from Scooba northward along a road which joins the Wahalak-Binnsville road in the Wahalak Creek valley about 6 miles from Scooba. Numerous exposures of greenish clay (Sucarnochee clay) of the Midway group were observed to the crest of the steep slope overlooking the Wahalak Creek valley. In the road leading down the slope the following section is revealed:

Section in public road about 6 miles north of Scooba, Kemper County, Miss.

	Feet.
Eocene (Midway group):	
3. Greenish weathered clay (Sucarnochee clay)..	10
Unconformity.	
Upper Cretaceous (Selma chalk):	
2. Massive chalky limestone, containing phosphatic casts of characteristic Upper Cretaceous fossils (*Exogyra costata* zone) in the upper 10 feet...........................	60
1. Very sandy limestone, constituting an arenaceous phase of the Selma chalk............	50

The Minnie Portis Spring is a quarter of a mile north of the post office at Wahalak, Kemper County, Miss., in a small branch which has cut its valley 25 or 30 feet below the upland level. The surface materials at the spring and in the immediate vicinity are the greenish clays belonging to the Sucarnochee clay, of the Midway group. This clay is closely underlain by fossil-bearing calcareous sandy clays, also belonging to the Midway, as shown by the following log of a shallow dug well in a small branch valley a few hundred yards east of the spring. The log is based in part on an examination of the materials thrown from the well and in part on oral statements by Mr. D. W. Portis.

Log of well near the Minnie Portis Spring, Wahalak, Miss.

[Fossils identified by C. Wythe Cooke.]

	Thickness.	Depth.
Midway group (Eocene):	*Feet.*	*Feet.*
3. Yellowish clay	5	5
2. Light greenish-gray, very calcareous sandy clay, containing *Ostrea pulaskensis* Harris (U. S. G. S. collection 6571)	10	15
1. Bluish-gray, very calcareous clay, less weathered than the preceding, containing *Ostrea pulaskensis* Harris (U. S. G. S. collection 6571)	6	21

The fact that *Hamulus onyx* Morton, a Cretaceous fossil, was found associated with *Ostrea pulaskensis* Harris in layer 1 of the section doubtless shows that the Selma chalk closely underlies the Eocene and that this Cretaceous fossil was mechanically intermingled with the Eocene oysters.

Crider [1] has noted the occurrence of Selma chalk along the bed of Wahalak Creek in the vicinity of Wahalak. He says:

Three miles north of Scooba the western border of the Selma chalk outcrop is seen in a series of hills forming the south bank of Wahalak Creek. The bottom of the creek here is about 1½ miles wide, with the steeper slope on the south side. The creek has channeled its bed into the white Selma chalk, which outcrops continuously throughout its course. The limestone occurs in the bed of the creek to a point 6½ or 7 miles northwest of Wahalak, but the overlying Porters Creek clay is present on the higher land on both sides of the creek.

On the low range of hills south of Wahalak Creek, beginning near the Mobile & Ohio Railroad track and extending eastward, is a bed of sand rock 10 feet thick capping the tops of the hills. It is a coarse-grained sandstone cemented with lime carbonate and contains numerous little bivalve shells. It is similar to sandstone found 7 miles east of Sucarnoochee and doubtless represents the lowest beds of the Ripley formation.

Although the writer has not seen the calcareous sandstone mentioned in the second paragraph quoted, Crider's statement that it contains numerous small bivalve shells suggests that the rock is the basal calcareous portion of the Midway group, which in western Alabama carries large numbers of *Ostrea pulaskensis* Harris, doubtless the fossil he noted.

On the geologic map accompanying Crider's report the Ripley formation (Upper Cretaceous) is represented as outcropping in a narrow area southwest of a northwesterly line passing through Scooba. The Selma chalk is represented as outcropping northeast of the same line. The observations just recorded show that the Ripley is absent in this area and that the Midway group (Eocene)—probably the Sucarnochee clay—transgresses the Selma chalk for 5 to 10 miles to the northeast and east of Scooba.

Although on the map Crider represents Scooba as situated in the Cretaceous area, in his text [2] he states that the town is in the Flatwoods area, which is underlain by the Midway group. This and other statements in Crider's text show that with the exception of his reference of the relatively thin calcareous and sandy basal beds of the Midway to the Ripley formation his interpretation of the stratigraphy of the area was correct.

VICINITY OF SHUQUALAK, MISS.

The Flatwoods, which are underlain by the Sucarnochee clay of the Midway group, are well developed immediately west of Shuqualak, Noxubee County, Miss. North of the town several poor exposures of Selma chalk (Upper Cretaceous) were observed in the Macon road, and in a field west of the road 1 mile north of town the Selma chalk is fairly well exposed in several bald spots; here were found the characteristic Upper Cretaceous fossils *Ostrea plumosa*

[1] Crider, A. F., Geology and mineral resources of Mississippi: U. S. Geol. Survey Bull. 283, pp. 18, 79, 1906.

[2] Idem, p. 78.

Morton, *Gryphæa vomer* Morton, and *Pecten venustus* Morton. The town of Shuqualak is therefore situated about on the boundary between the Cretaceous and Eocene.

The Cretaceous-Eocene contact was found in the Macon-De Kalb road about half a mile north of the crossing of Running Water Creek and about 4 miles northwest of Shuqualak. The exposure is a bald spot on the southward-facing slope of a small branch and reveals the following section:

Section in Macon-De Kalb road about 7½ miles south of Macon, Miss., and half a mile north of the crossing of Running Water Creek.

[Midway fossils identified by C. Wythe Cooke.]

	Feet.
Eocene (Midway group):	
3. Dark, greenish-gray compact calcareous clay containing Foraminifera and in the lower 3 to 5 feet large numbers of *Ostrea pulaskensis* Harris (U. S. G. S. collection 6582)	8
2. Moderately hard bluish-gray, somewhat sandy and argillaceous limestone. The upper 2 feet is a little harder than the lower portion and contains the following Eocene (Midway) species: *Cucullæa saffordi* Gabb?, *Venericardia alticostata* Conrad, *Turritella mortoni* Conrad (U. S. G. S. collection 6581). The basal portion weathers soft and a little shaly and contains *Gryphæa vomer* Morton?, probably a Cretaceous fossil derived mechanically from the underlying Selma chalk	6
Unconformity indicated by some reworking of layer 1 in layer 2 and by borings in layer 1 filled by the darker materials of layer 2.	
Upper Cretaceous (Selma chalk):	
1. Gray, very hard, slightly sandy and argillaceous massive chalky limestone. Baculites sp. was found loose on the surface near the upper part of this bed	4

Owing to the close lithologic resemblance between layers 1 and 2 of the section the contact is inconspicuous and requires close scrutiny to discover it. A view of the exposure is given in Plate XIII, *B*.

NORTHWEST OF MACON, MISS.

The position of the Cretaceous-Eocene contact was approximately determined in an exposure on Horse Creek, a quarter of a mile north of Benjamin Taylor's store and 12 or 13 miles northwest of Macon, Noxubee County, Miss. The creek bank reveals 20 feet of massive, compact argillaceous, slightly siliceous chalky limestone belonging to the Selma chalk. The upper 2 feet of the rock is perforated with borings filled with gray calcareous clay. Weathered out in the soil on the slope just above the exposed beds of the Selma were found the following Eocene (Midway) fossils (identified by C. Wythe Cooke): A coral, *Cucullæa saffordi* Gabb?, *Ostrea pulaskensis* Harris, Turritella sp., Natica (2 species), Xenophora sp., Cylicna? (cast), and Pleuratoma? (cast) (U. S. G. S. collection 6572). The perforated portion of the chalk was doubtless immediately below the contact with the overlying Midway.

STARKVILLE, MISS.

The Selma chalk is exposed in gullies on the campus of the Agricultural and Mechanical College, near Starkville, Oktibbeha County, Miss., and these exposures have yielded 37 or more species of characteristic Upper Cretaceous fossils (from the *Exogyra costata* zone). A short distance north of the campus, in the Mayhew road about 1¾ miles east of Starkville, the following section is exposed:

Section in Mayhew road 1¾ miles east of Starkville, Miss.

	Feet.
Upper Cretaceous:	
Selma chalk:	
3. Moderately sandy and argillaceous chalky limestone, with many fossils	26
Ripley formation:	
2. Gray, finely micaceous, somewhat calcareous sand, with a few slightly indurated ledges	20
1. Moderately sandy, very calcareous clay	4

The writer[1] has shown that the chalky limestone revealed in gullies on the campus is a northward-extending tongue of the Selma and is stratigraphically higher than a long tongue of the Ripley formation which extends southward from Chickasaw County and apparently pinches out in Noxubee County. W. N. Logan[2] correctly referred layer 2 of the Mayhew road section to the Ripley formation, but he regarded the sand as overlying the limestone (layer 3) and as constituting an outlier of the Ripley.

Starkville is located on the Cretaceous-Eocene contact, which is exposed in cuts of the Illinois Central Railroad southwest of the station. The following succession of strata appears in a cut a quarter of a mile southwest of the station:

Section in cut of Illinois Central Railroad a quarter of a mile southwest of the station at Starkville, Miss.

	Feet.
Eocene (Midway group):	
4. Weathered brown, finely micaceous sandy clay	5
3. Thinly stratified fine gray micaceous sand with yellow and brown streaks	7
2. Concealed	2
1. Greenish-gray to olive-green tough clay	1

The beds described in the section were referred by Logan[3] to the Lafayette formation, but the writer does not hesitate to correlate them with the Midway group of the Eocene. They constitute the eastward feather edge of the Midway, the main outcrop of which begins within less than 1½ miles southwest of Starkville along this railroad.

From the cut southwestward the railroad track descends a rather steep grade, and half a mile from the station 6 feet of massive chalky limestone (Selma chalk) overlain by 2 feet of yellow residual clay is exposed in a shallow cut. A cut 1½ miles southwest of the station reveals 4 or 5 feet of grayish to greenish-gray hard sandy residual clay, probably a weathered phase of the Sucarnochee clay of the Midway group (Eocene). The actual contact between the Cretaceous and Eocene was not observed in this vicinity.

VICINITY OF HOUSTON, MISS.

A cut of the Mobile & Ohio Railroad (Houston branch) at Houston, Miss., reveals the following section:

Section in cut of Mobile & Ohio Railroad at Houston, Miss.

	Feet.
Eocene (Midway group?):	
4. Residual yellow sandy ferruginous clay	7
3. Gray massive, compact calcareous glauconitic, somewhat argillaceous, finely micaceous sand	5
2. Yellow loose ferruginous sand with scattered white grains of arkose?, poorly exposed	4
Sharp contact.	
Upper Cretaceous (Selma chalk):	
1. Gray massive, very calcareous glauconitic, finely sandy clay resembling an impure phase of the Selma chalk	2

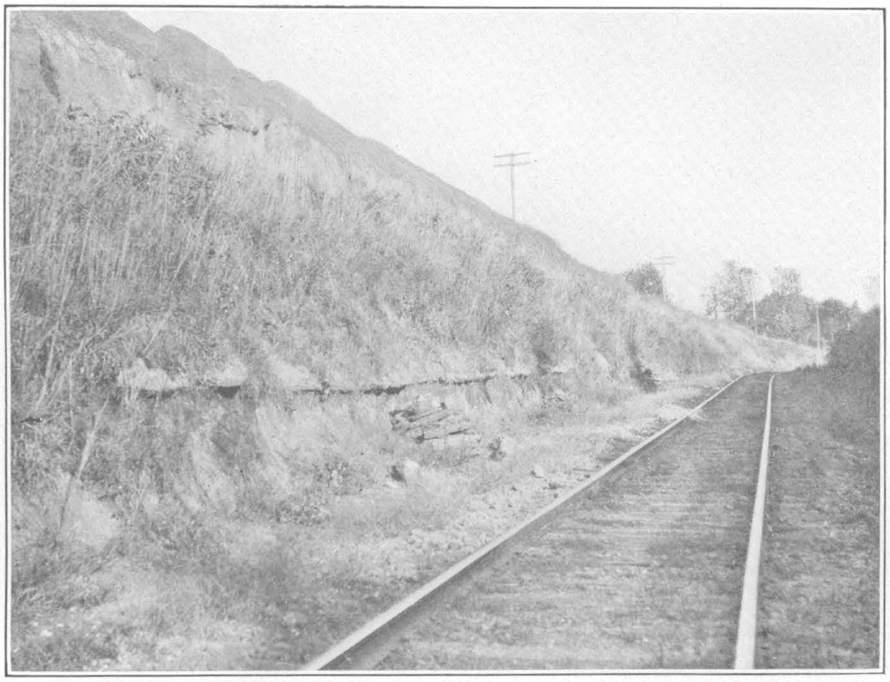
Baculites sp., probably derived from layer 1 of the section, was found on the dump at the end of the cut.

The Cretaceous-Eocene contact is exposed on the old Houlka road 1½ miles north of Houlka, as described in the following section:

Section in the old Houlka road 1½ miles north of Houston, Miss.

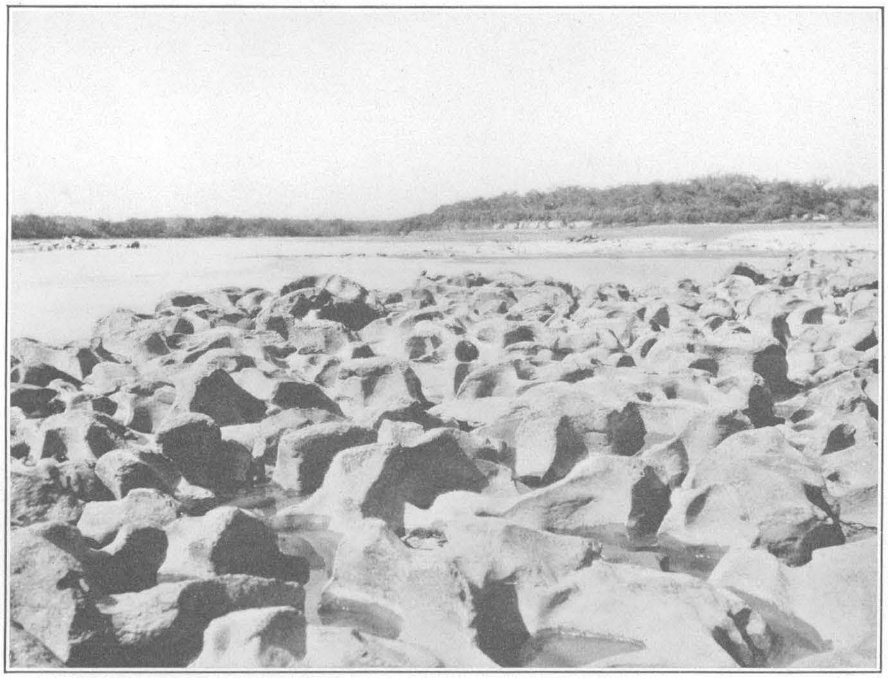
	Feet.
Eocene (Midway group):	
7. Yellowish hard calcareous glauconitic sandstone	7
6. Dark-gray argillaceous glauconitic compact calcareous sand, containing *Ostrea pulaskensis* Harris	3
5. Greenish-gray calcareous sandstone	½
4. Compact red and yellow fine micaceous sand	1
3. Reddish, rather coarse sandstone	¼
2. Yellow, rather fine stratified mealy sand	1
Sharp contact.	
Upper Cretaceous (Selma chalk):	
1. Compact gray argillaceous limestone	2

[1] U. S. Geol. Survey Prof. Paper 81, p. 17, Pl. IX, 1914. [2] Mississippi Agr. and Mech. Coll. Bull., vol. 1, No. 2, p. 30, 1904. [3] Idem, p. 35.



A. CRETACEOUS-EOCENE CONTACT IN CUT OF ST. LOUIS & SAN FRANCISCO RAILROAD 1 MILE EAST OF NEW ALBANY, MISS.

The contact is beneath the indurated layer.



B. POTHOLES IN BASAL LIMESTONE OF THE MIDWAY FORMATION ON THE RIO GRANDE 1 MILE BELOW WHITE BLUFF, MAVERICK COUNTY, TEX.

About 4 miles above the Webb County line.

A cut of the New Orleans, Mobile & Chicago Railroad 3 miles north of Houston reveals about 8 feet of light-greenish to yellowish nodular limestone containing large numbers of *Ostrea pulaskensis* Harris (U. S. G. S. collection 5587; identified by C. Wythe Cooke) in the upper 4 feet, overlain by 8 feet of tough yellowish and greenish clay, probably residual from the limestone; this rock belongs to the Midway group of the Eocene.

In the main public road 1 to 1½ miles south of Houston reddish and yellowish ferruginous sands and clays, probably belonging to the Midway group of the Eocene, were observed overlying with a sharp unconformity the massive argillaceous chalky limestone of the Selma chalk, which in places contains numerous characteristic Upper Cretaceous fossils (*Exogyra costata* zone).

The weathered representatives of the sands and clays of the Midway at Houston extend eastward above the Selma, capping the tops of the hills for a distance of at least 2 miles.

VICINITY OF PONTOTOC, MISS.

A deep cut of the New Orleans, Mobile & Chicago Railroad about half a mile south of the station at Pontotoc, Miss., reveals nearly 50 feet of reddish, yellowish-brown, and grayish glauconitic sands belonging to the Ripley formation (Upper Cretaceous). In a stratum of massive coarse yellowish-brown glauconitic sand, 15 to 20 feet below the top of the section, the following poorly preserved characteristic Upper Cretaceous fossils (*Exogyra costata* zone) were recognized: *Exogyra costata* Say, *Veniella conradi* (Morton), *Cardium tippanum* Conrad. About 30 feet of similar sands are exposed in a ballast pit along the same railroad about 2½ miles northwest of Pontotoc.

From a point a short distance west of the old right of way of the New Orleans, Mobile & Chicago Railroad, which lies a mile or more west of the present right of way, southwestward for several miles the public road passes over light-yellowish clays which are probably weathered residual materials derived from the Sucarnochee clay of the Midway group.

The Cretaceous-Eocene contact was not found well exposed in the vicinity of Pontotoc, but the data just given indicate that the boundary lies about a mile west of the railroad station.

VICINITY OF NEW ALBANY, MISS.

The town of New Albany, Union County, Miss., lies about a mile west of the outcrop of the Cretaceous-Eocene contact. The relations of the two series are well exhibited in a cut of the St. Louis & San Francisco Railroad 1 mile east of New Albany. (See Pl. XIV, *A*.)

Section in cut of St. Louis & San Francisco Railroad 1 mile east of New Albany, Miss.

	Feet.
Eocene (Midway group):	
6. Weathered red ferruginous argillaceous sand	12
5. Yellowish-brown ferruginous sand with masses of small irregular to roundish iron concretions, apparently arranged in lenses	7
4. Weathered yellowish-brown ferruginous sand	9
3. Yellow massive, somewhat sandy limestone, containing the Midway species Venericardia sp. and *Turritella mortoni* Conrad (U. S. G. S. collection 6573; identified by C. Wythe Cooke). Mechanically included in the base of the limestone were found the following Upper Cretaceous fossils: *Pecten argillensis* Conrad, Crassatellites sp., and *Cardium tippanum* Conrad	6
2. Yellow, very calcareous sand	½–1
Upper Cretaceous (Ripley formation):	
1. Dark-gray massive, very compact argillaceous sand with a few poorly preserved specimens of *Exogyra costata* Say, *Pecten argillensis* Conrad, and Baculites sp	5

SOUTHWESTERN TEXAS.

MAVERICK COUNTY.

Roemer[1] in 1848 discussed the geographic position of the Cretaceous-Eocene contact in Texas as follows:

An ideal line drawn from Presidio de Rio Grande on the Rio Grande in a northeast direction, and crossing the San Antonio River at the town of the same name, the Guadalupe at New Braunfels (the German settlement), the Colorado

[1] Roemer, Ferdinand, Contributions to the geology of Texas: Am. Jour. Sci., 2d ser., vol. 6, p. 21, 1848.

at Austin, the Brazos at the falls of this river, the Trinity below its forks, and reaching from there to the Red River in the same northeast direction, divides the Tertiary strata and the diluvial and alluvial deposits (of the level and "rolling" part of the country) from the Cretaceous and older formations (of the hilly and mountainous sections).

In 1889 Penrose[1] stated, with reference to the Cretaceous along the Rio Grande:

It may be said, however, that Cretaceous fossils have been found at Eagle Pass, and from there down the river to the Webb County line are found great quantities of ammonites and other fauna of that epoch. In fact, it is not until we reach a point 3 miles below the northwest corner of Webb County that true Tertiary (or Laramie) forms are found. Supposing the Cretaceous and Tertiary parting to cross the river at this point, we would do away with the much mooted question of the westerly extension to Las Moras Creek, above Eagle Pass, as drawn by Loughridge, Conrad, and others, and the slight deflection to the west could easily be accounted for by the supposition of an embayment on the Rio Grande at the time of the deposition of these strata, similar to that which existed at the same time on the Mississippi. Roemer makes the line of parting across the Rio Grande at Presidio de Rio Grande, 10 miles above Laredo, while Schott refers to all the country from the mouth of the Pecos to the Gulf of Mexico as the "Cretaceous basin of the Rio Bravo" (Rio Grande). It seems probable now, so far as can be judged without a further study of the fossils, that Roemer was nearer right than the others, and that, as has been pointed out by Hill, the line as drawn by Conrad was based on certain Tertiary fossils which had been misplaced in the collection.

* * * * * * *

At a point 5 miles below Las Cuevas Creek are the Angostora Rapids. These are caused by a reef of oyster shells, of the same kind as mentioned above, which run across the river and are covered on either bank by the same gray or buff sandstones. For 16 miles below here, by river, we find almost uninterrupted outcrops of similar deposits of desiccated and indurated sands and clays, containing many ammonites and other forms similar to those found at the Cretaceous exposure in Anderson County. At this point we come to what is known as Las Isletas. The river is a half mile wide and very shallow. It is full of small islands, consisting of sand bars and covered by mesquite and cane. The bottom of the river is rocky and causes almost continuous rapids for 5 miles.

For 12 miles below Las Isletas, and to a point 3 miles below the north line of Webb County, we see many outcrops of a formation similar to those already described and with similar fossils. But here the fauna changes and the character of the strata becomes more glauconiferous.

Dumble[2] in 1892 discussed the same section as follows:

From this point [10 miles below Eagle Pass] to the falls of the Rio Grande, just above the Webb County line, the exposures are but repetitions one of another—brown, buff, blue, or green clays, with sandstones, sometimes friable and sometimes so indurated as to be semiquartzites. Abundant fossils, consisting of ammonites (Placenticeras), oysters, and gastropods, are found. The rapids (or falls of the Rio Grande), which continue almost to the line between the two counties, are formed by the edges of some of these ammonite-bearing beds as they pass below water level. From this point to Webb Bluff, a distance of 3 miles, no fossils were found; but there was no change in the lithologic character of the rock materials, nor could the clays at the base of the Webb Bluff section be distinguished in any way from those observed at the rapids above.

Webb Bluff section.

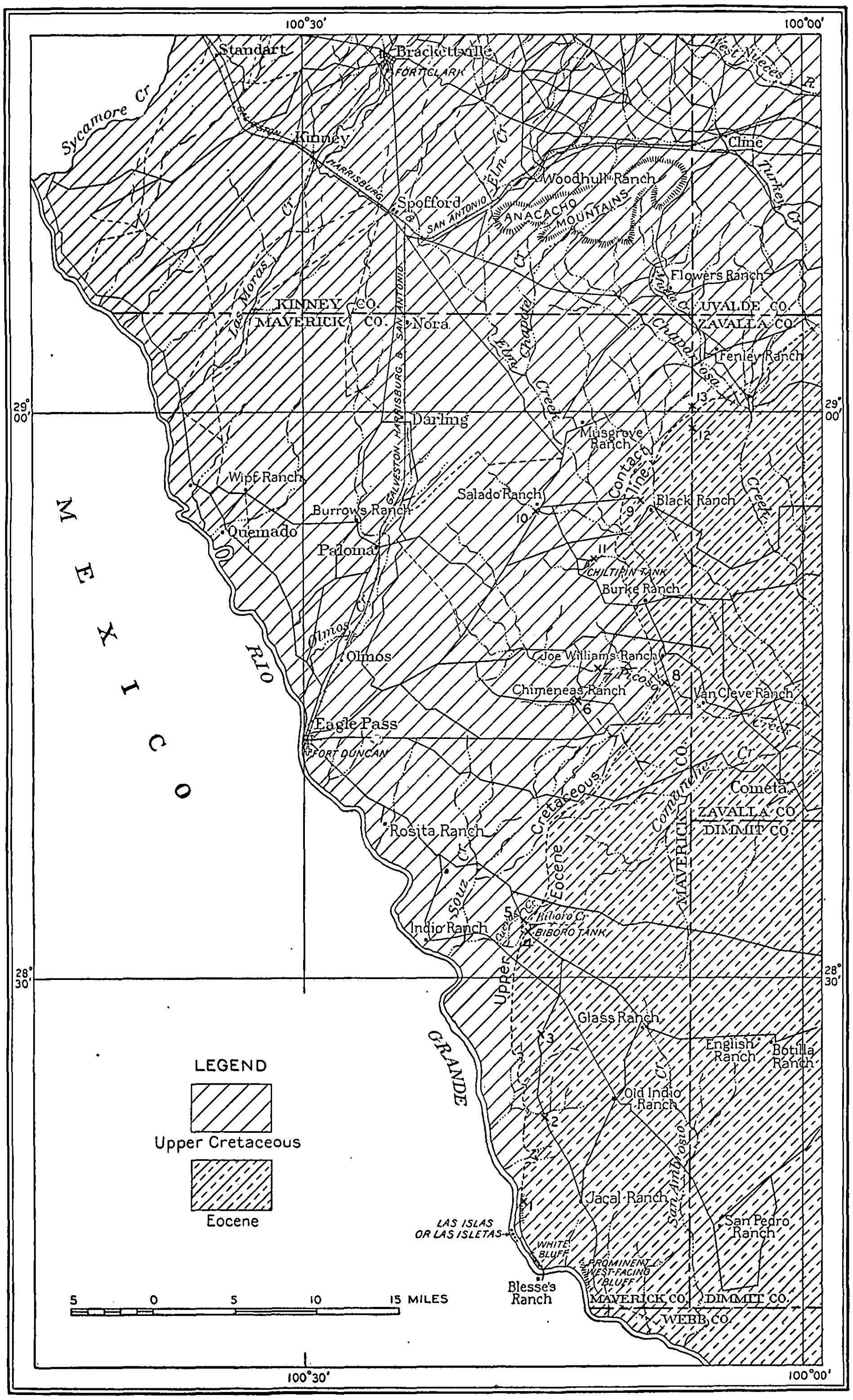
	Feet.
Gravel.	
Sandstone, white and glistening, with mica and some little iron; calcareous sandstones; clay, with cannon-ball concretions; and small seam of grahamite	30
Greensand marls with many Tertiary fossils; nodules of carbonate of lime; specks of glauconite	7–8
Stiff, plastic dark-greenish or blue clay, jointed	10

We have, therefore, only 3 miles in which there can be any room for deposits intermediate between strata containing fossils of recognized and decisively marine Cretaceous forms and those containing marine Eocene forms. The average dip does not exceed 100 feet per mile, and we saw nothing in any of the exposures on either bank of the river in this space to indicate a change until we reached Webb Bluff itself. The entire appearance of the upper portion of this bluff was so different from that of the materials we had been examining for the three previous days that it was remarked even before we landed.

Vaughan[3] in 1900 said, with reference to the location of the contact in Maverick County, Tex.:

It is at about the point where the foregoing section was made [4½ miles above mouth of San Ambrosia Creek] that the southern fence of the India ranch pasture is reached. This fence is, according to the statements of a colored cowboy, between three-fourths of a mile and a mile above the Webb-Maverick county line. Just beyond this fence, within the India ranch pasture, hematitic concretions containing *Venericardia alticostata* Conrad and a species of Glycymeris (Pectunculus) of the type of *G. staminea* (Conrad) were found in the clays. A little farther up the river was a large mass of sandstone resting on the clays and containing beautiful specimens of *Turritella mortoni*. The sandstone was so hard that no attempt was made to get the shells out.

[1] Penrose, R. A. F., jr., Geol. Survey Texas First Ann. Rept., pp. 38–41, 1889.
[2] Dumble, E. T., Geol. Soc. America Bull., vol. 3, pp. 228, 229, 1892.
[3] Vaughan, T. W., Reconnaissance in the Rio Grande coal fields of Texas: U. S. Geol. Survey Bull. 164, pp. 38–39, 53, 1900.



MAP OF MAVERICK COUNTY, TEX., SHOWING THE APPROXIMATE TREND OF THE CRETACEOUS-EOCENE CONTACT FROM THE RIO GRANDE NORTHWARD THROUGH THE COUNTY.

From 1½ to 2 miles above the fence referred to the thinly bedded sands and clays are seen to be underlain by thinly bedded sands, passing downward into thin ledges of soft sandstone.

This has carried the Eocene to a point at least 2 to 3 miles above the Webb-Maverick county line. The horizon of the Eocene is Midwayan. The following five species of fossils were collected [list revised by Mr. Vaughan]:

- Turritella mortoni Conrad.
- Ostrea crenulimarginata Gabb.
- Glycymeris (Pectunculus) sp. indet.
- Venericardia planicosta Lamarck (var.).
- Venericardia perantiqua Conrad?.

Harris has identified from the Dumble-Penrose collection made 3 miles below the Webb-Maverick county line fossils that are probably Midwayan, lower Eocene, but the writer has been unable to obtain a list of the species found there. Harris[1] says: "We should note the peculiar fauna, Midway, in part at least, found by Dr. White 18 miles southeast of Eagle Pass. It consists of *Cucullæa macrodonta* (perhaps *saffordi*), Pectunculus, and Venericardia. The shelly matter of these species is completely crystallized. The matrix was evidently a calcareous light sand or sandstone."

* * * * * * *

From the foregoing discussion of the Eocene-Cretaceous contact and from the sections of the Eocene it has already been made evident that there is not yet sufficient data to trace accurately the boundary between the Cretaceous and the Eocene. This boundary crosses the Rio Grande some miles, at least 4 or 5, above the north line of Webb County; it runs northeastward 1 or 2 miles northwest of India ranch, and passes some 16 miles west of Carrizo Springs. From here the boundary continues northeastward and crosses the Nueces River about the north line of Zavalla County. It continues north of east to the Frio River, crossing that stream 2 miles below the Engelmann ranch, and 5 miles, in a straight line, north of the south line of Uvalde County. The last-mentioned point is the only absolutely determined contact. The others are supposed or inferred from the data at hand.

In 1903 Dumble[2] took exception to Vaughan's statement in regard to the exact geographic position of the exposures from which he (Vaughan) obtained certain Eocene fossils and endeavored to show that these exposures were probably close to Webb Bluff.

Additional statements with reference to the Cretaceous-Eocene contact along the Rio Grande were made by Dumble[3] in 1911 as follows:

Major Emory, in the first part of the Boundary Survey report, on page 68, gives a description of Las Isletas and the falls of the Rio Grande, with a full-page illustration opposite. This description would indicate that the falls of the Rio Grande and Las Isletas were the same. The truth is that Las Isletas is located about the mouth of Castano Creek, while the falls are some 4 miles lower down the river, just below the mouth of Caballero Creek.

It will thus be seen that our collections were made from localities directly on the line of travel of the Boundary Survey party, and it seems highly probable that the original specimens described by Conrad were in reality obtained from these same beds.

The horizon is the uppermost portion of our Escondido beds. The fossils are among the latest Cretaceous forms of which we have any present knowledge in this region.

The Cretaceous-Eocene contact is well shown 3 miles below Toro Colorado, just above the falls of the Rio Grande and on Caballero Creek.

The only other records I can find of any of these forms are as follows:

Prof. G. D. Harris, in "The Tertiary geology of southern Arkansas," gives a list of fossils collected by Dr. C. A. White, in 1887, at his camp 18 miles southeast of Eagle Pass, Tex., which were supposed to be basal Tertiary. Among these there is a Cardium which Mr. Harris figures both in this paper and later with his Midway fauna, "Bulletin of American Paleontology, No. 4," without giving it a specific name.

This camp was probably at the Eagle Pass-Laredo road crossing near the junction of Cuevas and Pena creeks, and on or near the Cretaceous-Tertiary contact. The Cardium is unquestionably the *Cardium congestum* of Conrad, while the other forms named by Prof. Harris are from the overlying Midway.

The fossils obtained by White 18 miles southeast of Eagle Pass, as determined by Harris,[1] are *Cucullæa macrodonta* (Whitfield), Pectunculus sp., Venericardia sp., and Cardium sp.

Dumble, in the paper published in Science just cited, does not state the position of the fossil localities described with reference to the Webb County line, but Las Isletas (or Las Islas), which he says is located about the mouth of Castano Creek, is in Maverick County, approximately 7 miles by the river above the Webb County line; according to his further statement, this would place the intersection of the Cretaceous-Eocene contact with the Rio Grande about 3 miles above instead of 3 miles below the county line.

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[1] Harris, G. D., The Midway stage: Bull. Am. Paleontology, vol. 1, pp. 127-128, 1896.
[2] Dumble, E. T., Geology of southwestern Texas: Am. Inst. Min. Eng. Trans., vol. 33, pp. 931, 932, 1903.
[3] Dumble, E. T., Rediscovery of some Conrad forms: Science, new ser., vol. 33, p. 971, 1911.

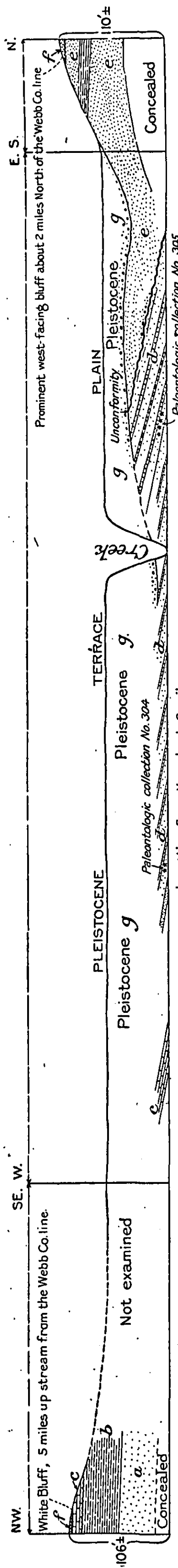


FIGURE 19.—Profile section along the left bank of the Rio Grande from White Bluff, Maverick County, Tex., about 5 miles above the Webb County line, downstream to the prominent westward-facing bluff 2 miles above the county line. For details see text.

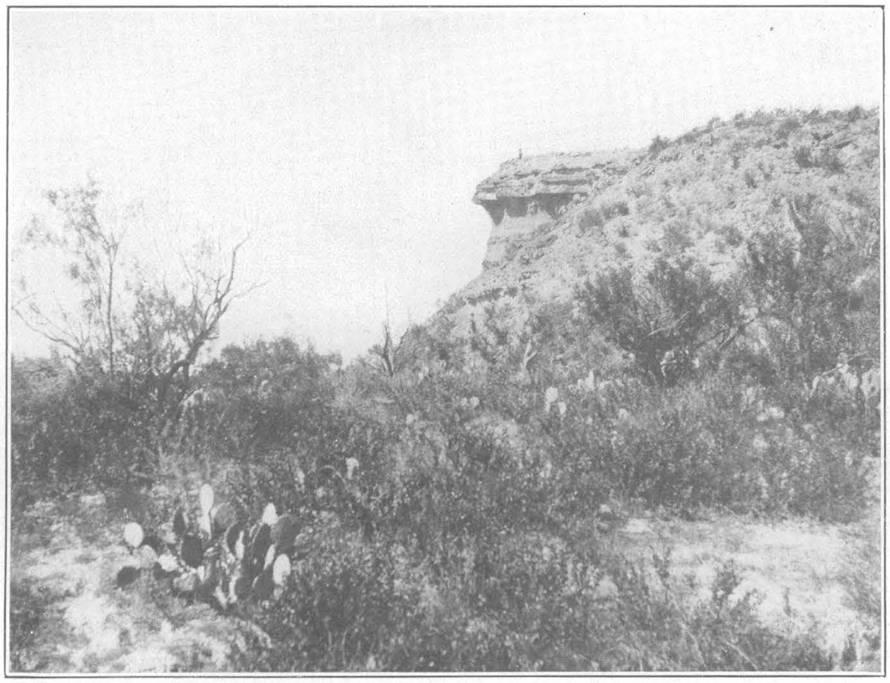
In the autumn of 1912 the writer made investigations in Maverick County which resulted in the exact determination of the Cretaceous-Eocene contact along the river and the approximate determination of the outcrop of the contact northward through the county. (See Pl. XV.)

The accompanying profile section (fig. 19) shows roughly the structure and stratigraphic relations of the beds exposed between White Bluff, 5 miles above the Webb County line, and a prominent westward-facing bluff about 2 miles above the county line. The succession is as follows:

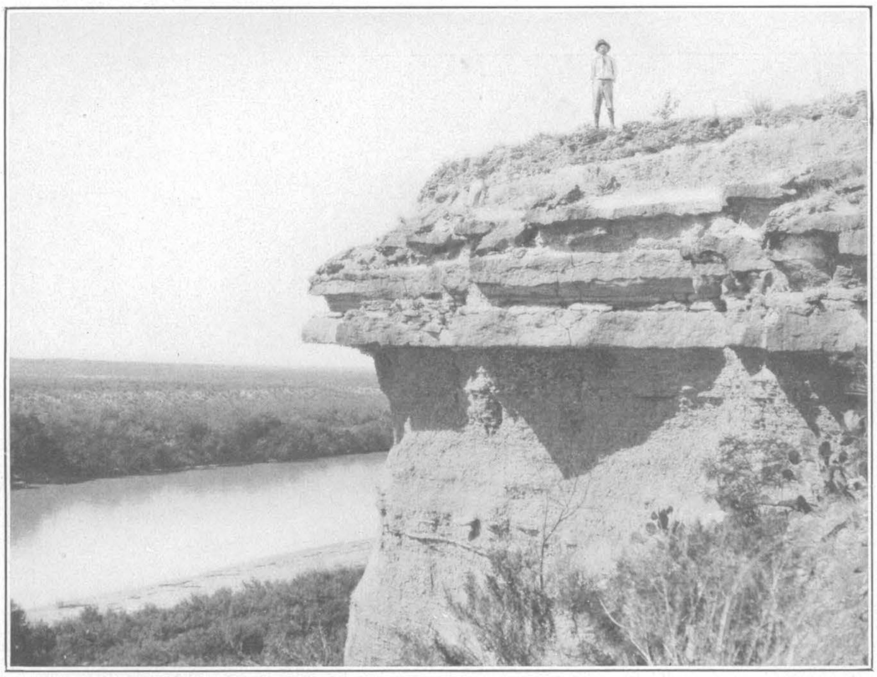
Section on Rio Grande below White Bluff, Maverick County, Tex.

	Feet.
Pleistocene (terrace deposit):	
g. Gray massive loamy sand, with a band of pebbles along the base in places	20–50
Unconformity.	
Pliocene or Pleistocene (Uvalde formation):	
f. Thin surficial covering of gravel, in places cemented with a white spongy matrix of lime	3–4
Unconformity.	
Eocene:	
Sandstone of Midway or Wilcox age:	
e. Irregularly bedded medium to coarse grained sandstone, with subordinate thin laminated layers of gray clay; includes some thick, relatively short massive lenses of sandstone, but in the main the rocks are cross-bedded. Vegetable particles and small pieces of lignite are common. At one place there is a basal conglomerate 2 or 3 feet thick composed chiefly of pebbles of iron carbonate derived from the concretions in the underlying strata (*d*)	150±
Unconformity; sharp contact, undulating slightly.	
Midway formation:	
d. Massive dark-gray (light gray or greenish gray where weathered), more or less argillaceous and glauconitic, slightly indurated sand, with harder ledges at intervals of 5 to 15 feet. Subordinate layers of shaly clay were noted. Concretions of iron carbonate are common in the upper 50 feet and in places occur in layers. Fossils were found at the points indicated (field Nos. 304 and 305; see lists on p. 173)	150–200
c. Gray fossiliferous limestone in layers 1 to 1½ feet thick, interbedded with greenish-gray sand in layers 1 to 2 feet thick; becomes sandy and glauconitic in the basal portion, which also contains some balls and fragments of clay derived from the underlying Cretaceous strata. Fossils obtained from the limestone are enumerated on page 173	12
Unconformity; contact sharp and undulates slightly.	
Upper Cretaceous (Escondido formation):	
b. Greenish-gray shaly clay with crystals of gypsum; contains a few interbedded lenses of fine greenish-gray sandstone; grades downward into next layer	38
a. Greenish-gray glauconitic sand, partly indurated to nodular layers; contains numerous Upper Cretaceous fossils (see list on p. 173)	40

At White Bluff (see map, Pl. XV), at the upstream end of the profile section, the Cretaceous-Eocene contact is clearly exposed for a distance of several rods (see Pl. XVI) and lies 90 or 95 feet above the river. At the upstream end of the prominent part of the bluff the base of the Eocene limestone is faulted down 25 or 30 feet below the position shown in the photograph. The section is as follows:



A.



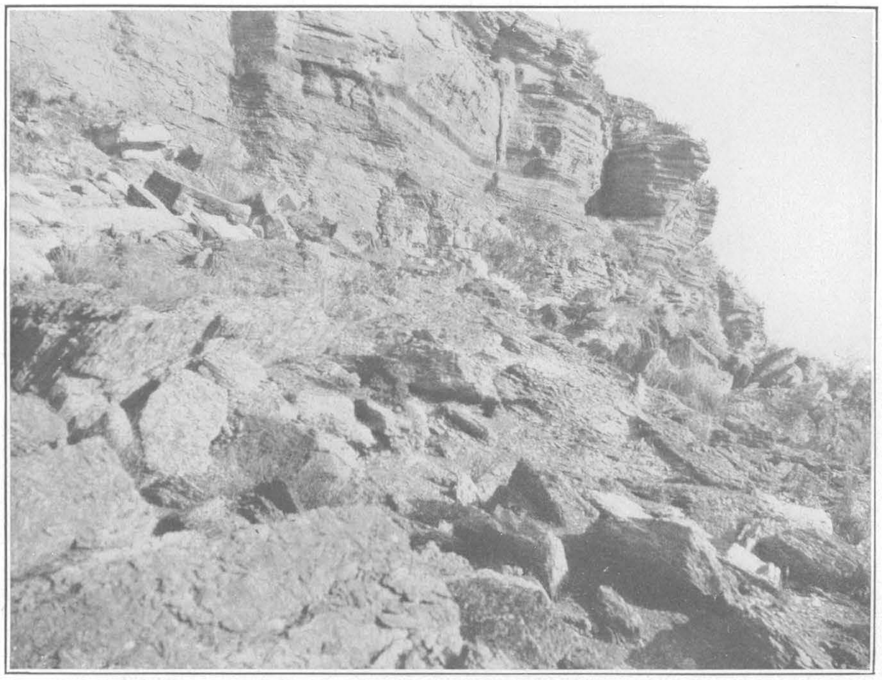
B.

CRETACEOUS-EOCENE CONTACT ON THE RIO GRANDE AT WHITE BLUFF, MAVERICK COUNTY, TEX.

About 5 miles above the Webb County line. The contact lies at the base of the projecting ledge of rock.

A. CONTACT BETWEEN THE MIDWAY FORMATION AND OVERLYING SANDSTONE OF MIDWAY OR WILCOX AGE ON THE RIO GRANDE IN MAVERICK COUNTY, TEX.

About 2½ miles above the Webb County line.



B. SANDSTONE OF MIDWAY OR WILCOX AGE IN A PROMINENT WESTWARD-FACING BLUFF ON THE RIO GRANDE IN MAVERICK COUNTY, TEX.

About 2 miles above the Webb County line.

Section at White Bluff, Maverick County, Tex.

	Feet.
Pliocene or Pleistocene (Uvalde formation):	
5. Gravel cemented with a white spongy matrix of lime	1
Unconformity.	
Eocene (Midway formation):	
4. Gray fossiliferous limestone in layers 1 to 2½ feet thick, interbedded with greenish-gray sand in layers 1 to 2 feet thick. The immediate base of the limestone is sandy and in places strongly glauconitic and contains balls and fragments of the underlying Cretaceous clay, present as a mechanical mixture. The limestone contains the following Eocene fossils (field No. 301), identified by T. W. Vaughan: Leda sp., *Cucullæa macrodonta* Whitfield, *Cytherea ripleyana* Gabb, *Venericardia smithii* Aldrich, and *Venericardia perantiqua* Conrad (U. S. G. S. collection 6575). A costate Anomia (field No. 302), probably derived from the underlying Cretaceous, is present as a mechanical mixture in the immediate base of the limestone	12
Unconformity; contact sharp and undulates slightly.	
Upper Cretaceous (Escondido formation):	
3. Greenish-gray shaly clay with crystals of gypsum. Contains a few interbedded lenses of fine greenish-gray sandstone. Grades downward into next layer	38
2. Greenish-gray glauconitic sand, partly indurated to nodular layers. Contains numerous Upper Cretaceous fossils, including *Ostrea cortex* Conrad, Cardium sp., numerous poorly preserved gastropods, and *Sphenodiscus pleurisepta* Conrad (field No. 303)	40
1. Concealed to water's edge	15

According to Mr. Vaughan, the fossils in layer No. 4 indicate the Midway age of the stratum.

The next place examined on the river was at a point about 1 mile below White Bluff and a quarter to half a mile below the Blesse ranch house, which is on the Mexican side. (See map, Pl. XV, and profile section, fig. 19.) Here the basal Eocene limestone, which is so prominently exposed near the top of White Bluff, dips below water level in the river bed. The rock is well exposed on the Texas side of the channel and extends for a considerable distance out into the river, which has cut a relatively narrow channel through the rock parallel to and near the south bank.

The writer was not able positively to identify the "falls of the Rio Grande" described by Dumble and others, but at this point a rise of the river a few feet above the ordinary low-water stage would result in more conspicuous rapids at the outcrop of this Eocene limestone than would be produced by other ledges of Cretaceous and Eocene rock which appear at many places in the bed of the river at low water, both above and below this point. It therefore seems likely that this is the so-called falls.

The base of the limestone is not exposed, but the thickness was estimated to be 10 or 15 feet. The inference is probably justified that here, as at White Bluff, the Cretaceous-Eocene contact lies immediately below the limestone, and the contact would therefore cross the river directly above the outcrop of the rock in the river bed. The limestone contains Venericardia sp. and other Eocene forms. The surface of the rock in the river bed has been strongly potholed and presents a rough, jagged appearance. (See Pl. XIV, *B*.)

A nearly continuous series of exposures appears along the left bank of the river from this point downstream to the prominent westward-facing bluff indicated on the map, a distance of about 2 miles. The beds overlying the limestone (division *d* of profile section, fig. 19) dip downstream at the rate of at least 100 feet to the mile. In dark greenish-gray glauconitic sand, estimated to be 30 or 40 feet above the base of this division, a few black casts of gastropods and Venericardia sp. were collected (U. S. G. S. collection 6576; field No. 304), and about 35 feet below the top of the division black casts of Venericardia sp. (U. S. G. S. collection 6577; field No. 305) were obtained. The beds of this division are of purely marine origin, as shown by the fossils and the glauconite.

The marine division is overlain unconformably (see Pl. XVII, *A*) by irregularly bedded sandstones (division *e*, fig. 19), which form the major part of the prominent westward-facing bluff at the downstream end of the section. (See Pl. XVII, *B*.) This bluff rises 100 or 110 feet above water level (aneroid reading), but only the upper 60 or 70 feet is well exposed. Interbedded with the coarse sandstones in this section is a band of gypsiferous shale 10 to 15 feet thick, the top of which is about 20 feet below the top of the sandstone. The gypsum occurs in seams and separate crystals. The relation of these irregularly bedded sandstones to the typical Carrizo sandstone of Owen[1] has not been determined, but they probably occupy a lower stratigraphic position, being equivalent in age either to a portion of the typical Midway group of Alabama or to the lower part of the overlying Wilcox group. The highest part of the bluff is capped by 3 or 4 feet of surficial gravel of the Uvalde formation.

Mr. Vaughan has informed the writer that the fossils enumerated in United States Geological Survey Bulletin 164, page 38, were found in beds below the typical Carrizo sandstone of Owen, and they may have come from the strata represented by division *d* of the profile section (fig. 19). According to Mr. Vaughan, the fossils indicate the Midway age of the containing beds. No fossils were found in division *e* of the section, and therefore no additional evidence regarding its age can be presented.

The next exposure examined on the Rio Grande was a prominent westward-facing bluff 4 miles nearly due west or perhaps a little south of west of the Jacal ranch house and about 9 miles above the Maverick-Webb county line. The section is as follows:

Section at westward-facing bluff on Rio Grande about 9 miles above the Maverick-Webb county line.

[Station 1 on the map, Pl. XV.]

	Feet.
Pliocene or Pleistocene (Uvalde formation):	
6. Gravel	10
Unconformity.	
Eocene (Midway formation):	
5. Greenish sandy clay, with indurated layers a few feet apart, weathered and poorly exposed.	20
4. Hard gray limestone in layers 1 to 2 feet thick, with interbedded thinner layers of greenish fine, slightly indurated sand. The limestone is replete with Venericardia sp., Cucullæa sp., and other Eocene fossils (field No. 306a). A costate Anomia derived mechanically from the underlying Cretaceous strata occurs in the base of the limestone	13
Exact contact not clearly exposed.	
Upper Cretaceous (Escondido formation):	
3. Greenish-gray shaly gypsiferous clay, with subordinate interbedded thin layers and some thicker layers of fine hard gray sandstone weathering greenish gray	35
2. Greenish-gray massive marine sand, slightly indurated, some layers more indurated than others, and forming slightly projecting ledges. Fossils are numerous and the following were recognized: Breviarca sp., *Ostrea cortex* Conrad, Anomia sp. (with costæ), Mactra sp.? and Sphenodiscus sp. (field No. 306)	50
1. Concealed by talus and Recent alluvium	35

The Cretaceous-Eocene contact is here about 120 feet above the water level of the river. The description given applies particularly to the upper end of the bluff, where a good exposure is afforded by the northwestward-facing side of a short gully. Good exposures of the fossiliferous beds of the Escondido formation (layer 2 of the section) extend southward for half a mile or more along the bluff.

A wire fence extends from the Jacal ranch house in a direct line west of south to White Bluff (see Pl. XV), and about 3 miles from the ranch house crosses a low peak, the top of which is nearly as high as the general level of the upland in the vicinity of the ranch house (200 feet or more above the river). The sandstone of Midway or Wilcox age is fairly well exposed in the upper 40 feet of this peak and consists of rather soft medium to coarse gray shaly sandstone with several more massive layers forming ledges. A few indistinct impressions of small pelecypods were noted.

Near the same fence, on the crest of a gravel-covered ridge, about 1½ miles from the Jacal ranch house, poorly preserved prints of Venericardia sp. were found in a partly exposed ledge of hard calcareous ferruginous sandstone.

A number of observations having an important bearing on the location of the Cretaceous-Eocene contact in Maverick County were made along the road leading from the Jacal ranch

[1] Owen, J., Texas Geol. Survey First Rept. Progress, pp. 70–73, 1889.

house to Eagle Pass by way of the Biboro tank. (See map, Pl. XV.) About 6 miles from the ranch house (station 2, Pl. XV) a poor exposure of gray sandstone corresponding to the sandstone of Midway or Wilcox age shown in division *e*, figure 19, was observed in a small branch near the road, and associated with it were fragments of rock exhibiting cone in cone structure. Fragments of similar sandstone were noted along the same road for the next 3 miles toward Eagle Pass. From about the tenth to the eleventh mile from the ranch house the road where it cuts through the surficial loams and gravels of the Uvalde formation reveals greenish to yellowish clays, locally ferruginous and containing concretions of iron carbonate in different stages of oxidation. In ferruginous material, about 11 miles from the ranch house (station 3, Pl. XV), prints of Venericardia sp. (U. S. G. S. collection 6578; field No. 307), identified by C. W. Cooke, were obtained.

The next important exposure studied was at the crossing of Biboro Creek just below Biboro tank (station 4, Pl. V), which is estimated to be about 18 miles by the wagon road from Eagle Pass. The bed of the creek at the road crossing is about 20 feet below the general level of the surrounding upland. Ledges of hard gray fossiliferous limestone and greenish-gray calcareous sandstone crop out below the dam of the tank. From the limestone fossils were collected and identified by T. W. Vaughan and C. W. Cooke as follows: *Cucullæa macrodonta* Whitfield, Lucina sp., *Cytherea ripleyana* Gabb, *Venericardia perantiqua* Conrad var. *smithii* Aldrich?, and Enclimatoceras sp. nov. (U. S. G. S. collection 6583; field No. 308).

The rock corresponds exactly in its lithologic and faunal character to the basal Eocene limestone exposed along the Rio Grande south and west of the Jacal ranch house (division *c* of the profile section, fig. 19). The exact base of the limestone was not discovered. According to Messrs. Vaughan and Cooke the fossils indicate the Midway age of the containing bed.

Within less than half a mile of Biboro Creek in the direction of Eagle Pass (station 5, Pl. XV), fragments of fine greenish-gray sandstone belonging to the Escondido formation of the Upper Cretaceous were noted along the road. In descending the northwestward-facing slope of Cuevas Creek, about 1½ miles from Biboro tank, the roadbed reveals greenish-gray, more or less argillaceous, slightly indurated sand, in which some layers are more indurated than others and form ledges. The rock is fossiliferous and the following poorly preserved forms were collected: Breviarca sp., *Ostrea cortex* Conrad, Anomia sp., Cardium sp., Mactra sp.?, and *Sphenodiscus pleurisepta* Conrad (field No. 309). These are characteristic species of the Escondido formation. Similar beds are exposed in the bed of Cuevas Creek at the road crossing, and here a few well-preserved specimens of Sphenodiscus sp. were collected (field No. 310).

Although the base of the Eocene limestone was not seen in the vicinity of Biboro tank, the appearance of Cretaceous strata within less than half a mile to the northwest shows that the contact between the two systems lies a short distance west of the tank, and it must intersect Biboro Creek below the road crossing, possibly within a few rods. Between Cuevas Creek and Eagle Pass the only strata exposed, except the surficial gravels and loams of the Uvalde formation, belong to the Upper Cretaceous.

The next place north of Biboro tank at which data bearing on the geographic position of the contact were obtained was in the valley of Picoso Creek between the Chimeneas ranch house and the Joe Williams ranch house. (See map, Pl. XV.) Aside from the surficial loams and gravels of the Uvalde formation, the only rocks observed along the road from Eagle Pass to the Chimeneas ranch house belonged to the Upper Cretaceous. A few hundred yards east of this ranch house (station 6, Pl. XV) a layer of hard nodular fossiliferous limestone crops out in the bed of a small creek and along the gentle bordering slopes and yielded specimens of *Exogyra costata* Say and *Cardium spillmani* Conrad? (field No. 314). The rock therefore belongs to the Escondido formation of the Upper Cretaceous. Similar rock was observed in the bed of the same creek about a mile east of the ranch house, and also in the bed of Picoso Creek at a road crossing about 2½ miles northeast of the ranch house (station 7, Pl. XV), where poorly preserved specimens of *Exogyra costata* Say were noted.

From the crossing of Picoso Creek along the road northward for 2 or 2½ miles and then eastward toward the Joe Williams ranch house (see Pl. XV), poor exposures of sandstone of the Escondido formation were noted here and there to a point within about 1 mile west of the ranch house, beyond which the road was heavy with sand. In the immediate vicinity of the ranch house several small exposures of gray, rather coarse sandstone having the characteristics of the sandstone unconformably overlying the marine Midway on the Rio Grande (division *e*, fig. 19), were observed. From the Joe Williams ranch house southward to Picoso Creek, a distance of 2 or 2½ miles, several small outcrops of this sandstone appear along the road. A fairly good exposure of the same formation was found in the bed of a small branch, perhaps 2 miles south of the ranch house (station 8, Pl. XV). Here the rock consists of soft medium to coarse grained irregularly bedded massive to thin-bedded sandstone, containing numerous grains, films, and small balls of white clay, and on weathering the surface is mottled with red.

These observations indicate that the Cretaceous-Eocene contact lies about 1 mile west of the Joe Williams ranch house. The intersection of the contact with Picoso Creek is probably a little west of south of the ranch house.

A few small outcrops of the gray sandstone corresponding to division *e* of figure 19 appear along the road leading west of north from the Joe Williams ranch house to the Burke ranch house, a distance of 3 or 4 miles. The same sandstones were noted in small, inconspicuous exposures at numerous places along an abandoned roadway which leads in a general northerly direction from Burke's ranch house across Chacon Creek to Black's ranch house, an air-line distance of 5 or 6 miles. They were seen also about 1 mile northwest of Black's ranch house (station 9, Pl. XV) in several small exposures in and near the road leading toward the Salado ranch. No significant exposures were found beyond these outcrops, but specimens of Sphenodiscus sp. were observed loose in the bed of a small creek about 1½ miles a little north of east of the Salado ranch house.

At an abandoned tank on Salado Creek just south of the Salado ranch house along the Eagle Pass-Uvalde road (station 10, Pl. XV) typical sandstones of the Escondido formation were examined. The rock is a gray hard, more or less calcareous sandstone and contains fossils among which were recognized Breviarca sp., *Ostrea cortex* Conrad, Gyrodes sp., and two species of Sphenodiscus (field No. 315).

From the Salado ranch house along the road running 4 or 4½ miles in a southeasterly direction to Chiltipin tank, which is situated in a small valley draining eastward (station 11, Pl. XV) characteristic sandstones of the Escondido formation were observed in many small outcrops. Along the sides of the valley below the tank are large masses of hard gray sandstone, weathering brown, belonging to the Escondido formation. Some lenses are very fossiliferous, but the fossils are not easily separated from the matrix. The following forms were recognized: Breviarca sp., *Ostrea cortex* Conrad, Anomia sp., unidentified gastropods, and Sphenodiscus sp.

The data above presented show that the outcrop of the Cretaceous-Eocene contact probably lies within 1 or 2 miles west of the Joe Williams ranch house, and that north of this place the possible outcrop is limited to an area a few miles wide which lies west of the Burke and Black ranch houses and east of Chiltipin tank and the Salado ranch house.

As no marine invertebrate-bearing beds corresponding to the strata of the Midway formation (Eocene), which outcrop along the Rio Grande, were seen in this area, it appears that the gray sandstones unconformably overlying the marine Midway deposits on the Rio Grande have here transgressed westward, concealing the marine Midway strata and resting upon the Escondido formation (Upper Cretaceous).

ZAVALLA AND UVALDE COUNTIES.

Vaughan[1] has approximately determined the Cretaceous-Eocene contact in the northwestern part of Zavalla County and the southern part of Uvalde County as far east as Frio River and exactly at one locality on Frio River. The only additional data resulting from the

[1] Vaughan, T. W., Reconnaissance in the Rio Grande coal fields of Texas: U. S. Geol. Survey Bull. 164, pp. 53, 54, Pl. I, 1900; U. S. Geol. Survey Geol. Atlas, Uvalde folio (No. 64), pp. 2; 3, 1900; idem, Brackett folio (in preparation).

writer's field studies west of Frio River relate to certain outcrops west of south of the old Fenley ranch house. About 4½ miles south of the Eagle Pass and Uvalde road, near the Zavalla-Maverick county line, about a quarter of a mile south of a new ranch house (station 12, Pl. XV), is a small exposure of hard gray quartzite-like rock showing faint stratification lines and having the characteristics of the gray Eocene sandstones on the Rio Grande shown in figure 19, *e*. About 1¾ miles north of this point, near the road leading northward to the Uvalde and Eagle Pass road (station 13), are several small outcrops of rock typical of the Escondido formation of the Upper Cretaceous ("Pulliam" formation of Vaughan), consisting of hard greenish-gray fine-grained calcareous sandstone. These data limit the possible outcrop of the contact to a belt less than 2 miles wide.

The writer has examined some of the fossils which were obtained by Vaughan from his Myrick formation just above the Cretaceous-Eocene contact on Frio River in the southeastern part of Uvalde County, 2 miles below Engelmann's ranch, and which he states indicate the Midway age of the strata in which they were found. The matrix is a weathered glauconitic phase of the basal Eocene (Midway) limestone, division *c* of the profile section given in figure 19. The Myrick formation, which Vaughan estimates to be 800 feet thick, must therefore include strata belonging to the Midway formation and to overlying undifferentiated Eocene formations. The fossils collected and identified by Vaughan from the basal stratum of the Eocene at this locality are the following (U. S. G. S. collection 3181):

Cucullæa saffordi (Gabb).	Venericardia sp.	Turritella humerosa Conrad.
Ostrea crenulimarginata Gabb?	Lucina sp.	Turritella mortoni Conrad.
Ostrea pulaskensis Harris.	Cytherea sp.	Levifusus trabeatus (Conrad) var.?
Venericardia perantiqua Conrad.	Natica sp.	Nautilus sp. nov.

In the eastern part of Uvalde County the Cretaceous-Eocene contact was determined by the writer to be in the northwestward-facing slope of Elm Creek near the Schuddemagen ranch house, which is just north of the junction of the creek with Sabinal River. (See map, fig. 20.) With the exception of a prominent limestone ledge (layer 4 of the section below; see also Pl. XVIII, *A*) the strata forming the hill are not well exposed, but by a close inspection of small outcrops along the slope the following section was determined:

Section in northwestward-facing slope of Elm Creek near the Schuddemagen ranch house, 11 miles south of Sabinal, Tex.

[Station 14, fig. 20.]

	Feet.
Pliocene or Pleistocene (Uvalde formation):	
6. Gravel, not well exposed	20
Eocene (Midway formation):	
5. Fine greenish-gray, slightly calcareous sand with numerous interbedded thin layers of sandstone, the whole poorly exposed. At one place the basal 2 or 3 feet is replete with Ostrea sp. (apparently new) (U. S. G. S. collection 6278; field No. 247*d*)	50
4. Massive sandy limestone with poorly preserved fossils, prominently exposed along the hill slope. Messrs. Vaughan and Cooke have identified the following species from this limestone: Glycymeris sp., Ostrea sp., *Venericardia perantiqua* Conrad var. *smithii* Aldrich, *Cytherea ripleyana* Gabb, Natica sp., *Turritella mortoni* Conrad, Turritella sp., *Calyptraphorus velatus* Conrad var., Pseudoliva cf. *P. unilineata* Aldrich, Phos? sp., Pleurotoma sp. (U. S. G. S. collection 6279; field No. 247*c*)	10
Exact Cretaceous-Eocene contact was not observed, but it probably lies at the top of layer 3.	
Upper Cretaceous (Escondido formation = "Pulliam" formation of Vaughan):	
3. Fine greenish-gray calcareous sand, poorly exposed	45
2. Soft greenish-gray fine calcareous sandstone from which were obtained Ostrea sp., Anomia sp., and Sphenodiscus sp. (field No. 247*a*); poorly exposed	3
1. Greenish-gray fine calcareous sand, poorly exposed	18

Layer 4 of the section (Pl. XVIII, *A*) corresponds in lithologic character to the basal Eocene limestone exposed along the Rio Grande in the southern part of Maverick County (division *c* of the profile section, fig. 19, p. 172), and Messrs. Vaughan and Cooke state that the fossils indicate the Midway age of the stratum.

Small outcrops of Cretaceous rock were noted at several places between the Schuddemagen ranch house and Sabinal.

MEDINA COUNTY.

The position of the Cretaceous-Eocene contact was determined approximately along the road leading from D'Hanis, Medina County, Tex., a little east of south to Yancey. At a point 7½ miles from D'Hanis, near the crest of a northeastward-facing slope (station 15, fig. 20), about 15 feet of hard white limestone is moderately well exposed. Among fossils collected from this limestone C. W. Cooke identified *Cucullæa macrodonta* Whitfield?, *Ostrea crenulimarginata* Gabb, *Venericardia perantiqua* Conrad, Lucina sp., and unidentified gastropod fragments (U. S. G. S. collection 6584; field No. 340). In its lithologic character the rock corresponds to the basal Eocene limestone in Maverick County (division *c* of the profile section, fig. 19), and according to Mr. Cooke the fossils indicate the Midway age of the bed.

The exact base of the limestone was not observed, but along the road about a quarter of a mile north of the outcrop and not more than 10 or 15 feet lower than the lowest exposed portion of the limestone the Cretaceous fossils *Ostrea cortex* Conrad and Anomia sp. were found in an impure yellow limestone. The contact is therefore determined within a horizontal distance of less than a quarter of a mile. No direct aneroid reading was made, but the base of the limestone of Midway age is estimated to be at least 160 feet higher than the bed of Seco Creek west of this locality.

Between the locality just described and D'Hanis, aside from surficial loams and gravels, only Cretaceous strata were observed.

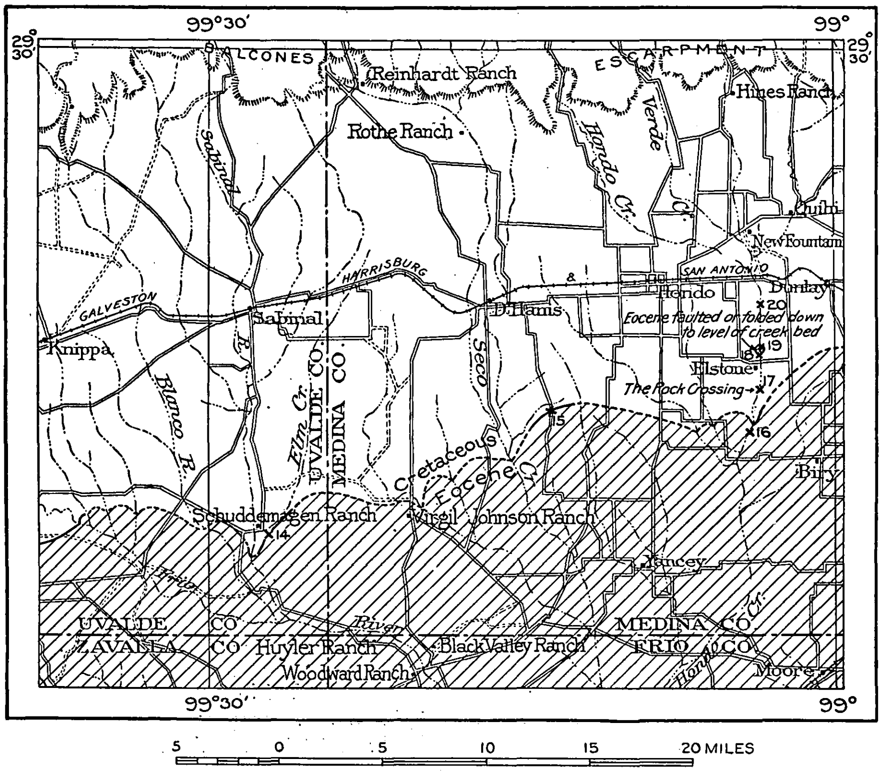
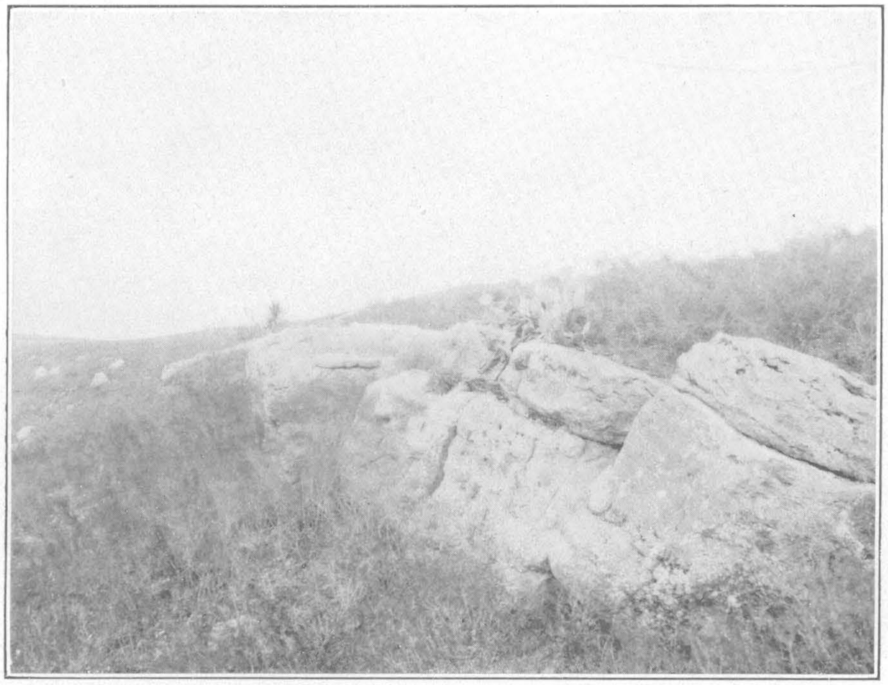


FIGURE 20.—Sketch map showing outcrop of Cretaceous-Eocene contact in portions of Uvalde and Medina counties, Tex. The full line indicates places where the contact has been determined with a fair degree of accuracy; the dashed line indicates the approximate or inferred position of the outcrop.

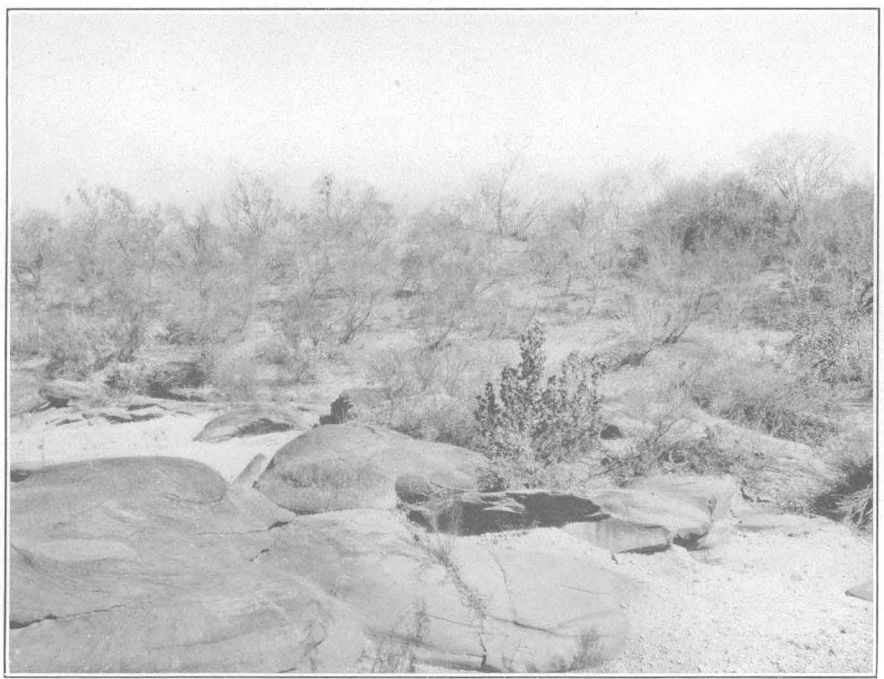
On Hondo Creek 3½ miles south of Elstone, half a mile south of the Lon Moore crossing (station 16, fig. 20), masses of gray to brown, strongly cross-bedded medium to fine, slightly calcareous sandstone with interbedded thin layers showing cone in cone structure are prominently exposed in the bed of the creek and along the left bank for several hundred yards. (See Pl. XVIII, *B*.) Although no fossils were found, this rock has the lithologic aspect of some phases of the sandstone (division *e*, fig. 19) unconformably overlying the marine Midway on the Rio Grande. Similar sandstones appear in the creek bed for the next mile below this point, and other outcrops of sands, sandstones, and clays, probably Eocene, were observed still farther down the creek within 6½ miles below Elstone.

At a locality on Hondo Creek known as Rock Crossing (station 17, fig. 20), which is about 1¼ miles below the crossing of the road leading due east from Elstone and one-half to three-quarters of a mile above the Blue Water Hole (on the Elstone-Biry road crossing), fossiliferous strata of Cretaceous age are well exposed. (See Pl. XIX, *A*.) The section is as follows:



A. BASAL LIMESTONE OF MIDWAY FORMATION ON SOUTHEAST SIDE OF ELM CREEK 11 MILES SOUTH OF SABINAL, TEX.

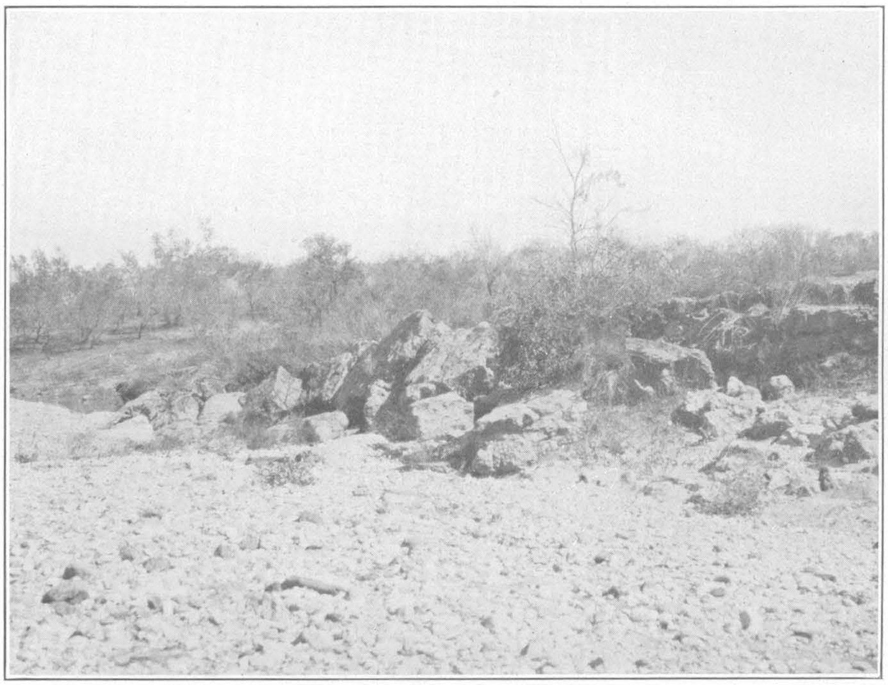
Near Schuddemagen ranch house.



B. EOCENE SANDSTONE IN BED OF HONDO CREEK 3½ MILES SOUTH OF ELSTONE, TEX.

A. ESCONDIDO FORMATION IN BED OF HONDO CREEK AT ROCK CROSSING, MEDINA COUNTY, TEX.

About 1¼ miles below the crossing of the road leading east from Elstone. Sphenodiscus (several varieties) occurs abundantly in these strata.



B. BASAL LIMESTONE OF MIDWAY FORMATION ON LEFT BANK OF HONDO CREEK IN MEDINA COUNTY, TEX.

About a quarter of a mile above the crossing of the road leading east from Elstone.

Section at Rock Crossing on Hondo Creek, Medina County, Tex.

	Feet.
Pleistocene (terrace deposit):	
7. Heavy bed of gravel with a few feet of loam at the top	15
Unconformity.	
Upper Cretaceous (Escondido formation="Pulliam" formation of Vaughan):	
6. Layer of brown fine-grained slaty sandstone with thin lenses of coquina in the lower part; contains poorly preserved fossils	½-1½
5. Fine greenish-gray to yellowish sand with fossils in the lower part	1½
4. Greenish-gray to brown nodular fossiliferous fine-grained sandstone containing large numbers of Sphenodiscus. Many square rods of the bed of the creek above the falls are formed of this rock	1
3. Greenish-gray to yellow fine massive sand which erodes easily	2½
2. Greenish-gray to brown nodular fossiliferous fine-grained sandstone with many specimens of Sphenodiscus	1
1. Greenish-gray fine calcareous, irregularly indurated massive sand containing fossils; erodes easily	5

Layers 1 and 2 form the head of a shallow gorge which is a waterfall when there is running water in the creek. (See Pl. XIX, *A*.) Layer 4 also forms a small waterfall a few rods farther up the creek.

The following fossils (field No. 221) were obtained from layers 1 to 5 of the section:

Ostrea cortex Conrad.
Ostrea sp.
Anomia sp.
Cardium sp.
Lunatia?
Turritella sp.
Undetermined gastropods.
Nautilus sp.
Sphenodiscus pleurisepta Conrad.
Sphenodiscus (several varieties or species).

About a quarter of a mile below Rock Crossing 12 feet of strata lithologically corresponding to layers 1 to 5 of the section appear in a vertical bluff along the left bank of the creek. Several fine large specimens of Sphenodiscus were obtained here (field No. 223).

According to these observations, the Cretaceous-Eocene contact must intersect the creek between stations 16 and 17, which are 2 or 2½ miles apart. It is probably nearer station 16 than station 17.

About a quarter of a mile above the crossing of the road leading due east from Elstone (station 18, fig. 20) the left bank of Hondo Creek exposes 12 or 15 feet of hard, sandy, slightly glauconitic limestone, somewhat like coquina in appearance. (See Pl. XIX, *B*.) The rock is poorly fossiliferous, but Ostrea sp. and *Turritella mortoni* Conrad? (field No. 219) were recognized. About three-eighths of a mile below this point, one-eighth of a mile below the crossing of the road leading due east from Elstone, a loose bowlder found in the bed of the creek and obviously derived from the limestone yielded a few poorly preserved fossils, among which Messrs. Cooke and Vaughan have recognized the following species (U. S. G. S. collection 6280; field No. 220):

Leda elongatoidea Aldrich var.? Harris.
Glycymeris sp.
Ostrea sp.
Modiola saffordi Gabb.
Venericardia sp.
Cytherea sp.
Corbula sp.
Turritella sp.

The rock is therefore of Eocene age. It has the general appearance of the basal limestone of the Midway formation noted 7½ miles southeast of D'Hanis and near the Schuddemagen ranch and is believed to correspond to the basal limestone of the Midway exposed on the Rio Grande in southern Maverick County (division *c* of the profile section, fig. 19).

Half a mile above the locality just mentioned large masses of gray medium-grained cross-bedded, slightly calcareous sandstone, weathering brown, appear along the left bank of the creek (station 19, fig. 20). They are slightly out of place, having fallen from their original position. These rocks are unlike the fine-grained sandstones of the underlying Escondido formation (Upper Cretaceous) and closely resemble some phases of the Eocene in this part of Texas. The sandstone and the limestone noted a quarter of a mile above the road crossing east of Elstone (p. 179), occurring 1½ to 2 miles above the Cretaceous strata exposed at Rock Crossing on Hondo Creek, indicate a fold or fault which brings the Eocene down to the level of the creek bed, farther upstream than it would be if the strata were regularly inclined.

About 3 miles upstream from the sandstone just described and 1½ or 1¾ miles below the San Antonio and Hondo road crossing (station 20, fig. 20), Cretaceous sand was found exposed in the right bank of the creek as described in the following section:

Section in right bank of Hondo Creek 1½ or 1¾ miles below the San Antonio-Hondo road bridge.

	Feet.
Pleistocene (terrace deposit):	
3. Brownish massive loam	20–25
2. Conglomerate composed of pebbles and cobbles of chert and flint with intermixed bowlders and slabs of brownish sandstone; the cementing material is lime	2–6
Upper Cretaceous (Escondido formation):	
1. Fine greenish-gray argillaceous sand, in part cemented into a rather soft sandstone	2

A few hundred yards above this exposure numerous large slabs of gray sandstone, weathering brown, appear in the bed of the creek, and though not seen in place they mark the outcrop of a ledge of sandstone of the Escondido formation. With the exception of Pleistocene terrace deposits, no strata younger than Cretaceous were observed along Hondo Creek between the locality last described and the Balcones escarpment.

SUMMARY OF RESULTS IN SOUTHWESTERN TEXAS.

The data set forth on the preceding pages show that along the Rio Grande in the southern part of Maverick County the following succession of formations exists:

General section on Rio Grande in southern Maverick County, Tex.

	Feet.
Eocene:	
Sandstone of Midway or Wilcox age:	
4. Irregularly bedded medium to coarse sandstone, with interbedded layers and lenses of clay (maximum thickness not determined).	
Unconformity.	
Midway formation:	
3. Massive dark-gray, more or less argillaceous and glauconitic, slightly indurated sand, with harder ledges at intervals of 5 to 15 feet and with subordinate layers of shaly clay; concretions of iron carbonate in upper 50 feet; contains some poorly preserved marine fossils of Midway age	150–200
2. Gray fossiliferous limestone, with interbedded thinner layers of greenish-gray sand; contains marine fossils of Midway age	12–13
Unconformity.	
Upper Cretaceous:	
Escondido formation:	
1. Greenish-gray shaly clay conformably underlain by greenish-gray glauconitic, partly indurated sand containing characteristic Upper Cretaceous fossils. (Total thickness of formation estimated by Dumble to be 3,300 feet, but probably much less.)	

The basal limestone of the Midway formation has been traced eastward as far as Hondo Creek, Medina County, the underlying formation being the Escondido formation of the Upper Cretaceous. In an area including the northeastern part of Maverick County, the northwestern part of Zavalla County, and the southwestern part of Uvalde County the Midway appears to be completely overlapped by a northwestward transgression of younger sandstone of Midway or Wilcox age.

The lower part of the Escondido formation of southwestern Texas certainly corresponds to at least a part of the *Exogyra costata* zone of the eastern Gulf region. *Exogyra costata* Say has not been found in the upper part of the Escondido formation, and it may be that that part is somewhat younger than this zone. The fauna of the formation has not been critically studied, but the ammonite *Sphenodiscus pleurisepta* Conrad ranges throughout practically the whole thickness of the terrane, being most abundant near the top, where it is represented by several varieties. The fauna is therefore strictly Mesozoic in its aspects, and in a geologic sense the upper part of the Escondido is not very much younger than the *Exogyra costata* zone. These uppermost strata probably do not appreciably bridge the great hiatus between the Cretaceous and Eocene.

LITERATURE.

It is impracticable in this paper to give a complete bibliography of the literature relating to the Cretaceous-Eocene contact in the Atlantic and Gulf Coastal Plain. The papers enumerated below include only those in which may be found compilations of the available data relating to the contact in the areas treated. Nearly all the papers cited contain bibliographies and references to older literature and maps showing the outcrop of the contact.

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1887. Smith, E. A., and Johnson, L. C., Tertiary and Cretaceous strata of the Tuscaloosa, Tombigbee, and Alabama rivers: U. S. Geol. Survey Bull. 43, 189 pp.
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THE HISTORY OF A PORTION OF YAMPA RIVER, COLORADO, AND ITS POSSIBLE BEARING ON THAT OF GREEN RIVER.

By E. T. Hancock.

Few regions offer more interesting geologic problems relating to drainage than the Uinta Mountains, in Utah and Colorado, and the area immediately east of them. In fact, the writer's attention was primarily attracted to this field by the diversity of opinion regarding the antecedent origin of Green River. Although the present paper deals mainly with that portion of Yampa River east of Juniper Mountain, the conclusions reached are believed to have a definite bearing on the Green River problem itself. The paper is introduced by a brief discussion of the structural features of the region east of the Uinta Mountains, for a clear understanding of the relation of the minor uplifts to the great Uinta fold will better enable the reader to appreciate the possible bearing which the writer's conclusions may have in the solution of that problem.

The main range of the Uinta Mountains is a broad, flat-topped anticline, which has an easterly trend and a length of over 150 miles and which separates the Green River Basin on the north from the Uinta Basin on the south. The conspicuous portion of the Uinta fold terminates in northwestern Colorado, but along the continuation of its axis to the east lies a long, gentle anticline which reaches the foothills of the Park Range. This anticline was called by White [1] "the inceptive portion of the Uinta fold." The axis of the anticline is coincident with the low, broad valley known as Axial Basin, and in a recent report Gale [2] refers to it as the Axial Basin anticline. According to White, along the eastern end of the main fold the strata abruptly dip east beneath the younger Tertiary beds. Upon the Axial Basin anticline have been developed two local uplifts which he called the Junction Mountain upthrust and the Yampa Mountain upthrust. These he regarded as the result of a locally intensified application of the same force by which the main fold was elevated. The peculiar relation which exists between these two "upthrusts" and the course of Yampa River renders it necessary that the reader shall clearly understand their character.

According to White,[3] the western base of Junction Mountain is 2 or 3 miles east of the east end of the main Uinta fold. There the same strata that plunge down on the east side of the Uinta Range rise even more abruptly, and the Paleozoic formations which constitute the high mountain peaks of the Uinta Range are uplifted to a maximum height of nearly 2,000 feet above the surrounding lowland. White says that the strata involved in the Junction Mountain uplift occupy an elongate oval area, the longer diameter of which is nearly 12 miles and the shorter about 4 miles in length. The direction of the longer diameter, being approximately northwest, is obliquely transverse to the general direction of the axis of the main fold. White [4] describes Juniper Mountain (then known as Yampa Mountain) as another "upthrust" of the Paleozoic formations which also rises directly upon the axis of the inceptive fold. It is likewise oval in outline, and has a longer diameter of about 7 miles and a shorter diameter of less than 4 miles. The longer diameter is almost at right angles with that of the Junction Mountain "upthrust" and nearly transverse with the inceptive portion of the Uinta axis. The Uinta Mountain uplift involves many thousand feet of sedimentary rocks of Paleozoic, Mesozoic, and Cenozoic age. According to Powell,[5] the great mass of the Uinta Range is composed of

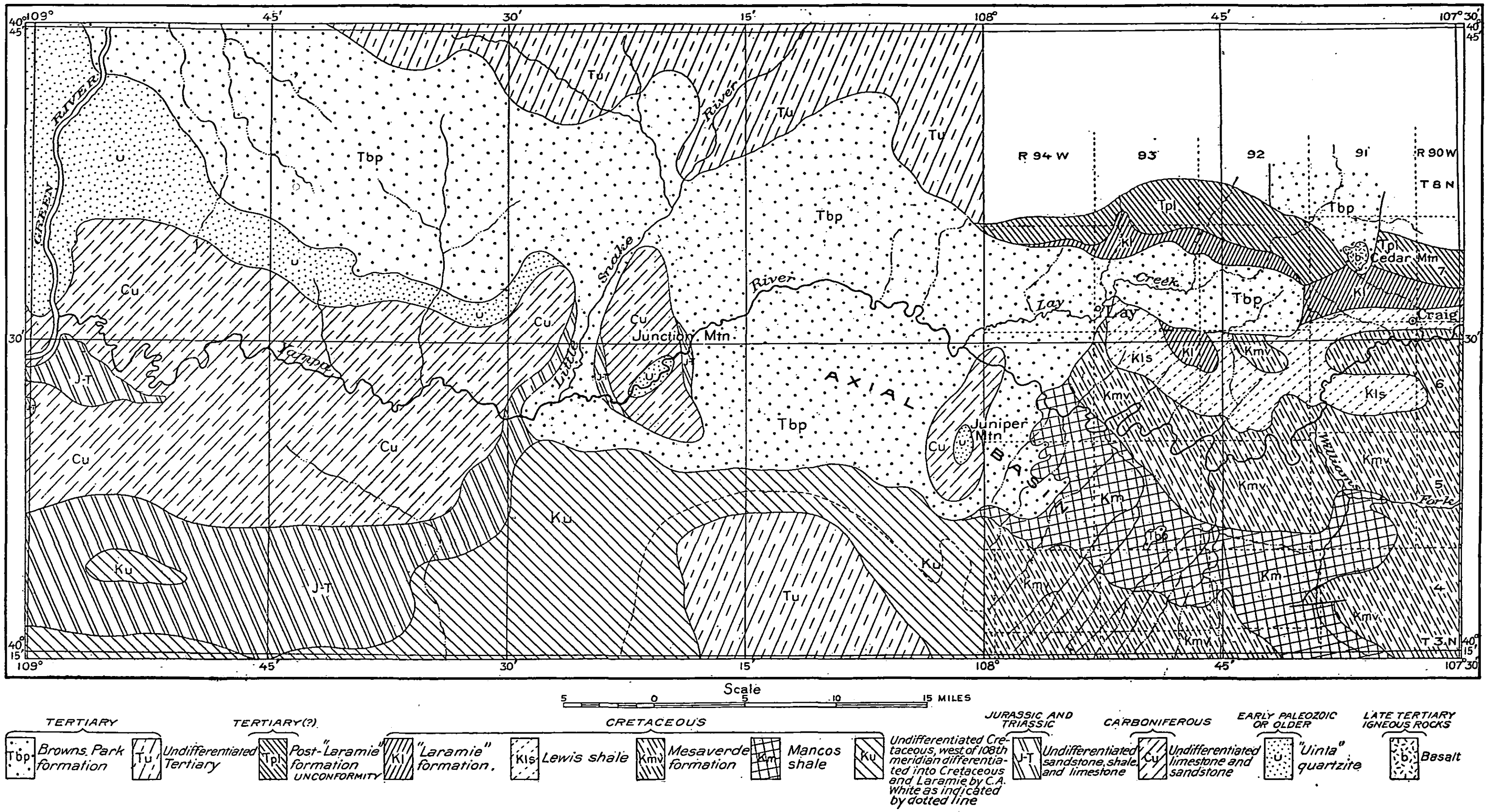
[1] White, C. A., On the geology and physiography of a portion of northwestern Colorado and adjacent parts of Utah and Wyoming: U. S. Geol. Survey Ninth Ann. Rept., p. 692, 1889.
[2] Gale, H. S., Coal fields of northwestern Colorado and northeastern Utah: U. S. Geol. Survey Bull. 415, p. 97, 1910.
[3] White, C. A., op. cit., p. 701.
[4] Idem, p. 702.
[5] Powell, J. W., Report on the geology of the eastern portion of the Uinta Mountains and a region of country adjacent thereto, p. 141, 1876.

sandstones of what he called the "Uinta group." The map given by White,[1] compiled in part from the published maps of Powell, Hayden, and King, shows the Junction Mountain and Juniper Mountain uplifts as being composed mainly of carboniferous beds, with a small area of the so-called "Uinta" quartzite outcropping near the summit in each uplift. Clearly, then, the only essential difference between the two local uplifts and the main Uinta Mountains uplift is one of magnitude. The relation of some of the recent Tertiary formations to these uplifts will be discussed later. Readers desiring a terse description of the course of Green River through the Uinta Mountains are referred to White's report.[2]

The course of Green River across the uplifted Paleozoic rocks of the Uinta Range with entire disregard for structure is so remarkable as to arrest the attention of every observer. The peculiar course of the river is even more striking in view of the fact that apparently it might easily have gone east of the uplift, making its channel in the soft formations of the lowland. But the course of Green River through the Uinta Range is no more remarkable than that of the Yampa, which empties into Green River from the east, in its relation to the Junction Mountain and Juniper Mountain uplifts. Yampa River has its origin among the mountains of the Park Range, where its numerous tributaries flow as turbulent streams through rocky defiles and narrow valleys. Emerging from the foothills of the Park Range, it enters a more or less open country and traverses the formations involved in the Axial Basin anticline and the Juniper uplift with apparent disregard for rock structure. Throughout most of this part of its course, which leads diagonally across the strike of the beds upturned along the north side of the Axial Basin anticline, it has developed well-defined intrenched meanders. Finally it reaches the hard Paleozoic metamorphosed limestones and sandstones of Juniper Mountain, where, instead of continuing in the soft beds around the north end of the uplift, it swings southward and cuts its way by means of a short canyon through the hard Paleozoic rocks that form the north flank of the uplift. From Juniper Mountain the river flows quietly over the lowlands of Axial Basin to Junction Mountain, which it cuts through in a similar manner. The opportunity seems to have been especially favorable for the Yampa to join Snake River near the north end of Junction Mountain, for it trends in that direction throughout more than half its course after leaving Juniper Mountain. Instead of that, however, it makes a distinct bend southwestward to Junction Mountain, and without swerving to the right or left cuts through the upturned strata of hard rock in a narrow canyon, the almost perpendicular walls of which, according to White, reach a maximum height of 1,000 to 1,200 feet above the lowland at either end of the canyon. Beyond Junction Mountain the river flows quietly for about 10 miles through Lily Park. Then instead of joining Green River by way of the lowland on either the north or the south side of the Uinta Range it boldly enters the east end of the range itself by crossing the upturned strata, as in the two uplifts previously described. The remainder of the river's course is through a narrow canyon, in places 1,200 feet deep, which opens into the canyon of Green River northeast of the point where that river emerges on the south side of the Uinta Range. (See Pl. XX.)

As an introduction to the discussion of the drainage east of Juniper Mountain, the views that have been held by some of the earlier geologists regarding the origin of Green and Yampa rivers will be very briefly stated. Powell,[3] as a result of his early explorations, says that the proof is abundant that Green River cut its own channel and that it was running before the mountains were formed—"that the river did not cut its way down through the mountains from a height of many thousand feet above its present site, but, having an elevation differing but little perhaps from what it now has, as the fold was lifted it cleared away the obstruction by cutting a canyon, and the walls were thus elevated on either side." The antecedent origin of certain of the river valleys of the great Rocky Mountain region had previously been suggested by Hayden.[4] In a paper read in May, 1896, Irving [5] says: "It is a fact no longer disputed that these

[1] White, C. A., op. cit., p. 684.
[2] Idem, p. 707.
[3] Powell, J. W., Exploration of the Colorado River of the West and its tributaries, p. 152, 1875.
[4] Hayden, F. V., Am. Jour. Sci., vol. 33, May, 1862; U. S. Geol. Survey Terr. Sixth Ann. Rept., for 1872, p. 85, 1873.
[5] Irving, J. D., The stratigraphical relations of the Browns Park beds of Utah: New York Acad. Sci. Trans., vol. 15, p. 258, 1896.



MAP SHOWING THE COURSE OF YAMPA RIVER, IN MOFFAT COUNTY, COLO., FROM GREEN RIVER EAST TO 107° 30′ WEST LONGITUDE.

deep canyons in the quartzite, by which the river crosses the mountains, were first established in the softer overlying formations and that these formations furnished much of the corrosive material by means of which the harder rocks were cut away." In 1897 Davis,[1] in commenting on the above-quoted statement of Irving, said:

It is not clear whether the overlying formations here mentioned were higher members of the Uinta arch or unconformably overlying Tertiaries. If the former, the writer would support Powell's explanation of the antecedent origin of the river; if the latter, he would support Emmons's view that the river is of superposed origin. In either case discussion on the question is hardly closed. Indeed, considering how frequently the Green is referred to as an antecedent river, it is remarkable that so little attention is given to the doubts that have been expressed regarding that manner of origin and to the difficulties that such an origin involves.

Davis also calls attention to the fact that two recent textbooks on geology[2] credit the antecedent explanation. Davis[3] himself says:

The Green River was unquestionably laked by the uplift of the Uinta Range, and to this extent it is a defeated and not an antecedent river. Between its two meridional portions, north and south of the range, the river makes a great bend to the east, turning from the higher toward the lower part of the uplift—a remarkable coincidence if this was an antecedent turn.

A few months later Emmons,[4] referring to the above-cited article by Davis, said:

Long before the appearance of the two textbooks he quotes (Tarr and Scott), Le Conte and Geikie had each referred to it as antecedent and illustrating the slow uplift of mountain ranges, in apparent unconsciousness that any other view is possible. Suess,[5] on the other hand, in his exceedingly careful review of the structure of this region, adopted my view without any reference to that of Powell.

Throughout the remainder of his article Emmons points out some of the difficulties involved in the antecedent origin advanced by Powell, and finally closes[6] by saying:

I have for a long time been hoping, and still hope, that some other geologist may make a more thorough examination than I was able to make at that time and determine the nature and extent of this singular formation [referring to the Bishop ("Wyoming") conglomerate], which has never been satisfactorily accounted for. Whatever may be the outcome of such an examination, it would seem proper that the antedecent origin of this river should be held in abeyance until some positive evidence of it can be furnished.

White,[7] in his concluding remarks on the geology of northwestern Colorado, lays especial emphasis on the antecedent origin of Green and Yampa rivers. In order that his views on the origin of Yampa River, as related to the Junction Mountain and Juniper Mountain uplifts, may be clearly understood a passage is quoted directly from his closing remarks:

The facts already presented show that the elevation of not only the narrowest folds but even that of the two upthrusts which have been described did not cause the rivers under which their elevation began to swerve from their original courses, as the elevation progressed, to the extent of more than a few rods. This fact is exemplified in Split Mountain, where Green River cuts a short deep canyon through that prominent spur of Yampa Plateau; but it is more conspicuously shown where Yampa River traverses both the Junction and Yampa [Juniper] Mountain upthrusts.

The writer's field observations during the last two years lead to conclusions that are not wholly in accord with those of White relative to the antecedent origin of Yampa River where it cuts its narrow canyon through Juniper Mountain. The field observations opposed to the view of antecedent origin are briefly as follows:

The main portion of the mountain is composed of sandstone and hard red quartzite, including layers of conglomerate. This formation was mapped by White as equivalent to that forming the core of Junction Mountain and also to the typical quartzite and sandstone forming the main core of the Uinta Range. The summit and northern flank of the mountain are composed of metamorphosed limestones and sandstones interbedded. In passing east up Yampa River as far as the Government bridge, and thence northeast and finally north for several miles, one crosses approximately at right angles to the strike the same formations that

[1] Davis, W. M., Current notes on physiography: Science, new ser., vol. 5, p. 647, 1897.
[2] Tarr, R. S., Elementary geology, p. 319, New York, 1897. Scott, W. B., An introduction to geology, p. 325, New York, 1897.
[3] Davis, W. M., op. cit., pp. 647–648.
[4] Emmons, S. F., Origin of Green River: Science, new ser., vol. 6, p. 19, 1897.
[5] Suess, E., Antlitz der Erde, vol. 1, p. 736.
[6] Emmons, S. F., op. cit., p. 21.
[7] White, C. A., op. cit., p. 710.

are involved in the structure of the Axial Basin anticline and the Juniper Mountain uplift. With the exception of that portion of the section included between the Carboniferous beds and the White Cliff sandstone (Jurassic) the entire sequence is well exposed. In all probability from 15,000 to 20,000 feet of beds are included in the section between the top of the "Laramie" and the highest Carboniferous beds exposed. The highest Carboniferous beds exposed at the east end of the canyon dip about 15° E. From this point the dip increases to 31° at Juniper Hot Springs, about a mile farther east along the south bank of Yampa River. From the hot springs eastward the dip decreases; for example, the basal beds of the Mesaverde formation about three-quarters of a mile northeast of the Government bridge dip about 15° NE., and near parallel 40° 30′ the Lewis shale dips 6°–8° NE. If the erosion accompanying and following the formation of the Axial Basin anticline and the Juniper Mountain uplift were the last event in the geologic history recorded by the rocks of this region, then the hypothesis of the antecedent origin of the deep canyon through Juniper Mountain might be accepted, but such is not the case. The period of erosion must have been followed by one of subsidence and deposition, for upon the upturned and eroded edges of all the formations studied by the writer, from the Carboniferous to the post-"Laramie," rest a series of horizontal Eocene (?) beds known as the Browns Park formation. The basal beds of this formation where best exposed consist of soft, more or less unconsolidated reddish and yellowish-brown sandstones. These beds usually contain a large amount of conglomerate, the pebbles of which consist of schist, gneiss, coarse and fine grained granite, white and red quartzite, and white and reddish vein quartz. At least 50 feet of such beds lie horizontally above the gently dipping Mancos shale in the bank of the river in the southwest corner of sec. 22, T. 6 N., R. 94 W. These basal beds grade within a few feet into the overlying soft white sandstone which comprises much the greater part of the formation. Powell[1] describes the Browns Park "group" as occurring in the valley of Browns Park, a deep basin of erosion in the axis of the Uinta fold, near the east end of the Uinta Range. He says:

> Eastward, both on the north and south sides of the area of outcrop, the beds are seen to rest unconformably upon all of the Carboniferous, Mesozoic, and Cenozoic formations previously mentioned. The unconformity with the upper Green River, lower Green River, and Bridger beds is well exhibited in the Dry Mountains in many fine exposures. * * * Conglomerates are found at the base, in some localities having a great development.

White,[2] who afterward studied the region, described the eastward extension of the beds from Browns Park to Cedar Mountain (then known as Fortification Butte). The map accompanying his report, compiled in part from the published maps of Powell, Hayden, and King, represents these beds as completely surrounding both the Junction Mountain and Yampa [Juniper] Mountain uplifts. They were seen by the writer to be in almost a horizontal position and in direct contact with the Carboniferous beds around the north end of the Juniper Mountain uplift. For about 3 miles east along the river only a narrow belt of the older beds intervenes between the alluvium and the Browns Park formation, which occurs as a thin cap on the low hills. The original thickness and the height to which this formation reached can not be ascertained. The fact, however, that there are points on the Browns Park formation in almost any direction from Juniper Mountain at elevations equal to or greater than that of the highest Carboniferous beds exposed where the river cuts through the mountain strongly indicates that the rocks of the canyon were at one time covered by the Browns Park formation.

Beds resembling in every way the yellowish-brown conglomerate beds at the base of the Browns Park formation in sec. 22, T. 6 N., R. 94 W., cap the hills near the center of Axial Basin, about 12 miles southeast of the east end of the canyon. Gravel, probably resulting from the disintegration of these beds, occurs as a mantle over the upper part of the Mesaverde formation along the high ridge about 7 miles east of the canyon. The easternmost beds of the Browns Park formation observed by the writer occur about half a mile east of Cedar Mountain (Fortification Butte in the old reports). The mountain itself is about 20 miles east and 6 miles north of the canyon and is composed of the Browns Park formation protected by a capping of basalt.

[1] Powell, J. W., Report on the geology of the eastern portion of the Uinta Mountains and a region of country adjacent thereto, p. 168, 1876.
[2] White, C. A., op. cit., p. 691.

In 1878 White[1] maintained that the Browns Park formation could not be of later date than Pliocene Tertiary. In the course of his argument he said:

> Furthermore, a remarkably extensive flow of basaltic trap, covering a large region which lies mainly to the eastward but which formerly extended much within the limits of this district, took place after the deposition of the Uinta group [referring to the Browns Park formation] and also after it had suffered displacement and erosion, to some extent at least. This is known to be the case because the trap is found resting upon the unevenly eroded surface of a portion of the Uinta group at Fortification Butte.

In the field season of 1913 the writer succeeded in finding a portion of the sandstone resting upon the basalt at Cedar Mountain and on examination found the sandstone to contain numerous rounded masses of the basalt, indicating that instead of being all much older than the basalt, as White had supposed, it is really in part younger. The fact that deposition of some sandstone beds occurred after the formation of the basalt indicates that the Browns Park formation may have been much thicker than has hitherto been supposed. The elevation of the Browns Park formation on Cedar Mountain is about 860 feet higher than that of the highest Carboniferous beds exposed at the canyon where Yampa River cuts through the north end of Juniper Mountain. The Browns Park formation is also from 800 to 1,000 feet higher than the tops of the ridges across which Yampa River has intrenched its meanders in the rocks of the Mesaverde formation east of Juniper Mountain.

As previously stated, the conspicuous portion of the Uinta fold terminates in northwestern Colorado, but in line with its axis to the east there is a long, gentle anticline which reaches the foothills of the Park Range and which is commonly known as the Axial Basin anticline. Upon this anticline have been developed two distinct uplifts—Junction Mountain and Juniper Mountain. If Yampa River is antecedent its present course must have been established prior to the uplift which resulted in the formation of the Axial Basin anticline and the Junction Mountain and Juniper Mountain uplifts, and it must have lowered its channel through Junction and Juniper mountains and intrenched its meanders down through the Mesaverde formation east of Juniper Mountain while the beds were being uplifted into their present position. But attention has already been called to the fact that during and after the period of upheaval sediments many thousand feet in thickness were eroded almost to a common plane. After the period of erosion the region was submerged and many hundred feet of additional sediments were laid down. Powell,[2] in his table of the groups of sedimentary strata of the Plateau province, gives the thickness of the Browns Park "group" as 1,800 feet, while White[3] gives it as 1,200 to 1,800 feet. If Yampa River was antecedent to the formation of the Axial Basin anticline and the Juniper Mountain and Junction Mountain domes, its channel from the east end of the Uinta Mountains to a point as far east as Cedar Mountain—a distance of about 50 miles—would obviously have been completely buried by Browns Park sediments. The river, therefore, could not have maintained its channel, and it is beyond the bounds of probability that, after cutting through the Browns Park sediments, it should have reestablished itself in its original bed and discovered its old canyons through Junction and Juniper mountains.

The distribution of the Browns Park formation and the altitudes at which the beds have been observed make it very probable that the upper beds of the formation were sufficiently high to cover to a considerable depth all that portion of the Juniper Mountain uplift which is traversed by the canyon, as well as the Cretaceous beds down through which the river has intrenched its meanders. This probability is strengthened by the wide distribution throughout northwestern Colorado and southern Wyoming of beds which have not yet been definitely correlated with the Browns Park formation but which bear a similar relation to the underlying Cretaceous and Tertiary beds.

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[1] White, C. A., Report on the geology of a portion of northwestern Colorado: U. S. Geol. and Geog. Survey Terr. Tenth Ann. Rept., p. 38, 1878.

[2] Powell, J. W., Report on the geology of the eastern portion of the Uinta Mountains and a region of country adjacent thereto, p. 40, 1876.

[3] White, C. A., On the geology and physiography of a portion of northwestern Colorado and adjacent parts of Utah and Wyoming: U. S. Geol. Survey Ninth Ann. Rept., p. 686, 1889.

On the basis of the field observations here briefly recorded the conclusion is reached that Yampa River, instead of being antecedent, is superimposed and that the present course of the river was not established until after the emergence that followed the deposition of the Browns Park sediments. These observations would seem to indicate that the series of events in the development of the present course of the stream was as follows:

After the river had deepened its channel in the Browns Park formation sufficiently to encounter the hard Paleozoic rocks of the Juniper Mountain uplift these rocks acted for a time as a barrier. The gradient of the stream for some distance above the barrier was diminished, and there resulted a condition of local base-leveling. In other words, the stream for some distance above the obstruction approached the condition of old age. After it reached grade and lost the power of degrading its bed, lateral planation resulted in the development of a flood plain upon which the river established its meandering course. Below the barrier the stream was able to deepen its channel much more rapidly in the soft beds of the Browns Park formation. As a result the river developed a steep gradient for some distance below the barrier of uplifted Paleozoic rocks and in all probability formed a series of falls on the lower side of the barrier. Ultimately it succeeded in cutting through the barrier. This being accomplished, the gradient of the channel and the velocity of the water above the hard-rock obstruction were increased, and consequently the river was enabled to intrench its previously established meanders down through the Cretaceous beds along the north limb of the Axial Basin anticline. An appreciable dip was observed at many places where the Browns Park beds are in contact with the older formations. This may be due entirely to original deposition on a sloping surface or in part to minor subsequent uplift. If subsequent uplift occurred, that may also have been a factor in the rejuvenation of the stream and the formation of the intrenched meanders.

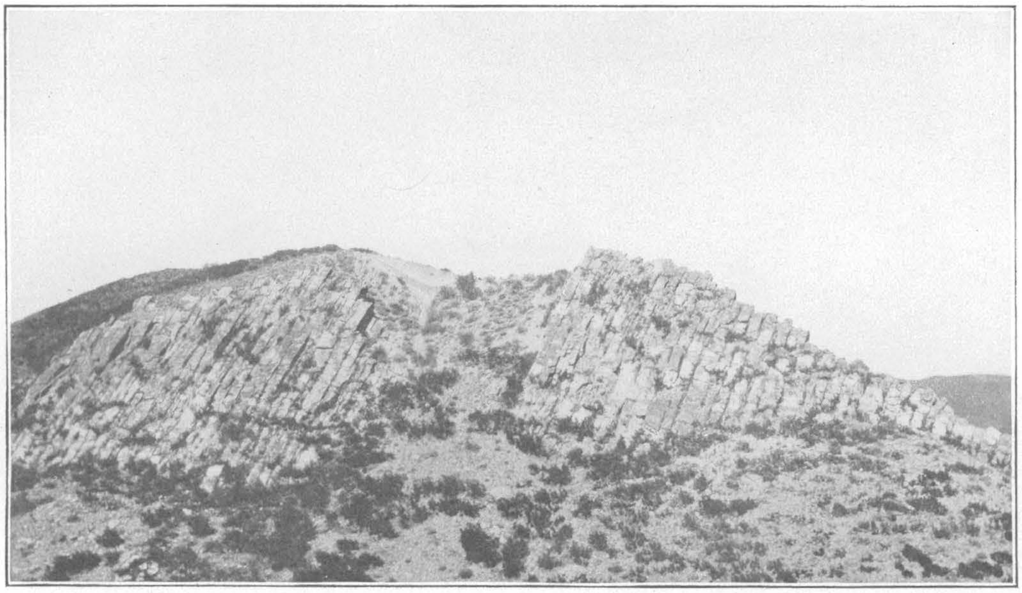
There is a very noticeable parallelism of the smaller streams both north and south of Axial Basin. The writer has observed numerous exposures where the sandstone of the Mesaverde formation is traversed by a very pronounced system of parallel joints. The joints in most places appear to have been developed almost at right angles to the strike of the formation, especially where the beds are dipping rather steeply. This is well shown in Plate XXI. As the courses of the smaller streams are nearly at right angles to the strike of the Mesaverde formation, it is quite probable that they were determined to a considerable extent by the existence of joints.

Published descriptions indicate that the structure of Junction Mountain is not unlike that of Juniper Mountain. The map prepared by White[1] shows the Browns Park formation as a continuous belt extending from Yampa [Juniper] Mountain to the western border of Browns Park. It surrounds the Paleozoic beds of the Junction Mountain uplift. Powell,[2] in his structure section through Junction Mountain, shows the Browns Park formation as lying about 500 feet below the older beds where the mountain is traversed by Yampa River. The Browns Park formation, where it laps over the Mesaverde formation, about 5 miles southeast of Junction Mountain, is mapped by Gale[3] at an elevation that is about 650 feet higher than that of the older beds at the canyon as shown on Powell's atlas map of the Uinta Mountains. These facts strongly suggest that at one time the Browns Park formation entirely covered at least that portion of Junction Mountain through which Yampa River cut its deep canyon. The fact that the present channel of the river is in the Browns Park formation through the entire distance from Juniper Mountain to Junction Mountain, together with the probability that the Browns Park beds at one time completely covered that portion of Junction Mountain including the canyon, certainly justifies the conclusion that this portion of Yampa River also established its course subsequent to the emergence following the deposition of the Browns Park formation.

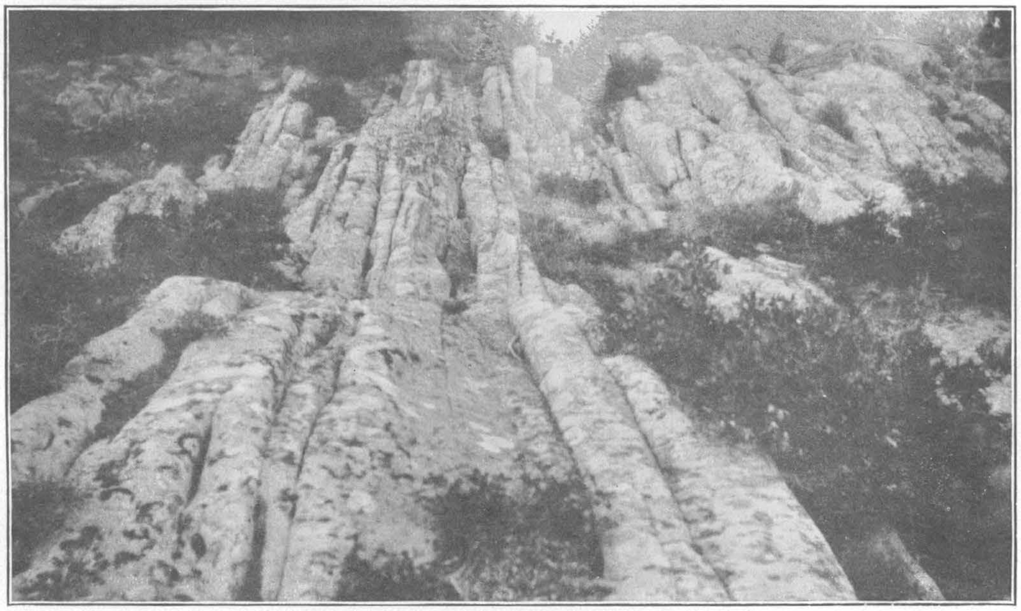
[1] White, C. A., Geology and physiography of a portion of northwestern Colorado and adjacent parts of Utah and Wyoming: U. S. Geol. Survey Ninth Ann. Rept., Pl. LXXXVIII, 1889.

[2] Powell, J. W., Report on the geology of the eastern portion of the Uinta Mountains and a region of country adjacent thereto, p. 10, 1876.

[3] Gale, H. S., Coal fields of northwestern Colorado and northeastern Utah: U. S. Geol. Survey Bull. 415, Pl. XVIII, 1910.



A.



B.

JOINTING IN SANDSTONE OF MESAVERDE FORMATION.

A, At the "Transfer," T. 2 N., R. 92 W., Meeker quadrangle, Colo.; *B*, In T. 4 N., R. 91 W., Monument Butte quadrangle, Colo.

As regards the course of Yampa River from this point to Green River, and of Green River itself, no suggestions based on personal observations can be offered. However, those who have studied the Uinta uplift, including Powell and Emmons, agree that the uplift began at the close of the Cretaceous period, and that later at least 8,000 feet of Tertiary sediments, derived in part, if not wholly, from the degradation of the arch itself, were deposited along both flanks of the range. According to Powell, these Tertiary formations bent down, while the older beds were uplifted. The present course of Green River for a distance of about 30 miles through Browns Park is in the Browns Park formation. In view of these facts, together with the conclusions which have been reached relative to the origin of one of the principal tributaries of Green River, it is believed that the assertions of the antecedent origin of Green River should be accepted only after more facts have been obtained bearing on the original extent and thickness of the late Tertiary formations, as well as on the diastrophic history of the Uinta Range.

THE INORGANIC CONSTITUENTS OF ECHINODERMS.

By F. W. Clarke and W. C. Wheeler.

INTRODUCTION.

In a recent paper [1] on the composition of crinoid skeletons we showed that crinoids contain large quantities of magnesia, and that its proportion varies with the temperature of the water in which the creatures live. This result was so novel and surprising that it seemed desirable to examine other echinoderms and to ascertain whether they showed the same characteristics and regularity. A number of sea urchins and starfishes were therefore studied, their inorganic constituents being analyzed in the same manner as those of the crinoids. The specimens for analysis were carefully selected by Mr. Austin H. Clark, of the United States National Museum, to whom our thanks are due

SEA URCHINS.

The following sea urchins were chosen for analysis:

1. *Strongylocentrotus dröbachiensis* (O. F. Müller). Upernivik, Greenland, latitude 72° 48′ N.
2. *Strongylocentrotus fragilis* (Jackson). *Albatross* station 2946, off southern California. Latitude 33° 58′ 00″ N., longitude 119° 30′ 45″ W. Depth of water, 274.5 meters; bottom temperature, 13.6° C.
3. *Echinarachnius parma* (Lamarck). Coast of New England.
4. *Encope californica* (Verrill). Galapagos Islands, on or near the Equator.
5. *Lytechinus anamesus* (H. L. Clark). *Albatross* station 2938, off Wilmington, California. Latitude 33° 35′ 15″ N., longitude 118° 08′ 30″ W. Depth, 86 meters; bottom temperature 15° C.
6. *Loxechinus albus* (Molina). Port Otway, Patagonia. Latitude about 46°–47° S.
7. *Tetrapygus niger* (Molina). Coast of Peru.
8. *Tretocidaris affinis* (Philippi). *Albatross* stations 2316 and 2317, off Key West, Florida. Latitude 24° 25′ N., longitude 81° 47′ W. Depth, 85 meters; bottom temperature 24° C.
9. *Heterocentrotus mammillatus* (Linné). Low or Paumotu Archipelago, southern Pacific Ocean. Latitude between 14° and 24° S.

In the following analyses the loss on ignition covers carbon dioxide, water, and organic matter, the last item being often large. The deficiencies in summation are due to undetermined sea salts, adherent to or inclosed by the specimens. The CO_2 needed is calculated to satisfy the bases.

Analyses of sea urchins.

	1	2	3	4	5	6	7
SiO_2	0.12	0.26	0.14	3.86	8.52	0.05	0.31
R_2O_3	.34	.65	.27	5.03	3.01	.17	.30
MgO	2.58	2.68	2.97	4.75	3.04	3.07	2.82
CaO	47.34	41.08	49.17	43.42	37.92	45.87	48.86
P_2O_5	Trace.	.39	.05	Trace.	.19	Trace.	Trace.
Loss on ignition	48.53	52.21	45.74	43.01	45.38	49.47	44.98
	98.91	97.27	98.34	100.07	98.06	98.63	97.27
CO_2 needed	40.04	33.87	41.80	40.40	32.90	39.41	41.41

[1] U. S. Geol. Survey Prof. Paper 90-D (Prof. Paper 90, pp 33–37), 1914.

Rejecting the excess of volatile matter and recalculating to 100 per cent, we have the following composition of the inorganic constituents of the seven sea urchins of the preceding table:

Revised analyses of sea urchins.

	1	2	3	4	5	6	7
SiO_2	0.13	0.31	0.15	3.92	9.95	0.05	0.33
R_2O_3	.37	.80	.28	5.10	3.52	.19	.32
$MgCO_3$	5.99	7.05	6.61	12.26	7.45	7.27	6.31
$CaCO_3$	93.51	90.79	92.84	78.72	78.60	92.49	93.04
$Ca_3P_2O_8$	Trace.	1.05	.12	Trace.	.48	Trace.	Trace.
	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Sea urchins Nos. 8 and 9, Tretocidaris and Heterocentrotus, must be considered separately from the others. No. 9, a giant form, was the subject of four analyses, the shell or test, the dental pyramid, the small white spines on the border of the peristome, and the large purplish-red spines. The large red spine analyzed was 15 centimeters long and weighed 13 grams.

Analyses of Heterocentrotus mammillatus.

	Actual analyses.			
	Test.	Dental pyramid.	White spines.	Red spines.
SiO_2	0.02	0.02	0.05	0.05
R_2O_3	.13	.08	.13	.26
MgO	5.21	5.50	3.74	4.47
CaO	43.60	46.02	48.26	47.72
P_2O_5	Trace.	Trace.	Trace.	Trace.
Loss on ignition	49.62	47.00	46.46	45.99
	98.58	98.62	98.64	98.49
CO_2 needed	39.99	42.21	42.03	42.41
	Revised analyses.			
	Shell.	Dental pyramid.	White spines.	Red spines.
SiO_2	0.02	0.02	0.05	0.05
R_2O_3	.15	.09	.14	.28
$MgCO_3$	12.30	12.31	8.33	9.89
$CaCO_3$	87.53	87.58	91.48	89.78
$Ca_3P_2O_8$	Trace.	Trace.	Trace.	Trace.
	100.00	100.00	100.00	100.00

From these analyses we see that the inorganic constituents of Heterocentrotus are not uniformly distributed. The shell and teeth are alike and rich in magnesium carbonate; the coarser spines are much less magnesian. The composition of the entire skeleton, if it can be called so, would probably be somewhere near that of the red spines alone, only a little higher in magnesia.

A similar example is offered by No. 8, Tretocidaris. In the specimen analyzed the shell and spines were taken separately, but the spines were dead when the urchin was collected. The analyses are as follows:

Analyses of Tretocidaris affinis.

Actual analyses.			Revised analyses.		
	Shell.	Spines.		Shell.	Spines.
SiO_2	0.11	0.53	SiO_2	0.12	0.56
R_2O_3	.15	.14	R_2O_3	.17	.15
MgO	4.02	2.07	$MgCO_3$	9.33	4.63
CaO	45.80	49.79	$CaCO_3$	90.38	94.66
P_2O_5	Trace.	Trace.	$Ca_3P_2O_8$	Trace.	Trace.
Loss on ignition	48.32	46.28		100.00	100.00
	98.40	98.81			
CO_2 needed	44.40	41.41			

Here again the spines are lower in their content of magnesia than the shell.

In two of the analyses, Nos. 4 and 5, large percentages of silica and sesquioxides appear. These are due to inclosed or adherent sand and mud, which were visible in the specimens but not readily removable. On rejecting these impurities and recalculating to 100 per cent, the percentages of magnesium carbonate become 8.49 and 13.47, respectively. With these corrections, and assuming the percentages found for the shells rather than the spines in Nos. 8 and 9, the following table has been constructed:

Percentage of magnesium carbonate in sea urchins.

	Locality.	Latitude.	Depth.	Temperature.	$MgCO_3$.
			Meters.	*°C.*	*Per cent.*
Strongylocentrotus dröbachiensis	Greenland	72° 48′ N	(?)	(?)	5.99
Tetrapygus niger	Peru	(?)	(?)	(?)	6.31
Echinarachnius parma	New England	42°–45° N	(?)	(?)	6.61
Strongylocentrotus fragilis	California	33° 58′ N	274.5	13.6	7.05
Loxechinus albus	Patagonia	46°–47° S	(?)	(?)	7.27
Lytechinus anamesus	California	33° 35′ N	85	15	8.49
Tretocidaris affinis	Key West	24° 25′ N	85	24	9.33
Heterocentrotus mammillatus	Paumotu	14°–24° S	(?)	(?)	12.30
Encope californica	Galapagos	Equator	(?)	(?)	13.47

A comparison of these figures with those found for the crinoids shows the same regular variation with temperature. The sea urchins from cold regions are relatively low in magnesia; those from the Tropics are high. There is, however, one apparent exception—the urchin from Peru. This abnormality may be due to growth in very deep water, which is almost always cold, or to the Humboldt current, which flows northward from the Antarctic Ocean. It is unfortunate that actual temperature observations are so few in this series of analyses. They resemble those of the crinoids very closely, except that the latter seem to average somewhat higher in magnesium carbonate. More analyses are needed to determine the fact.

STARFISHES AND OPHIURANS.

Eleven starfishes, including brittle stars, were analyzed, as follows:

1. *Asterias vulgaris* (Packard). Eastport, Maine. Latitude 44° 55′ N., longitude 67° 00′ W.
2. *Asterias tanneri* (Verrill). *Albatross* station 2309. Latitude 35° 43′ 30″ N., longitude 74° 52′ W. Depth, 102 meters; bottom temperature not given.
3. *Asterina miniata* (Brandt). Pacific Grove, California. Latitude 36° 36′ N., longitude 121° 55′ W.
4. *Leptasterias compta* (Stimpson). *Albatross* station 2250. Latitude 40° 17′ 15″ N., longitude 69° 51′ 45″ W. Depth, 86 meters; bottom temperature, 10.8° C.
5. *Benthopecten spinosus* (Verrill). *Albatross* station 2568. Latitude 39° 15′ 00″ N., longitude 68° 08′ 00″ W. Depth, 3,249 meters; bottom temperature, 2.7° C.
6. *Luidia clathrata* (Say). Near Charleston, South Carolina. Latitude 32° 47′ N., longitude 79° 57′ W. Depth, between 2 and 22 meters.
7. *Acanthaster planci* (Linné). Palmyra Island, in the Pacific Ocean, west of south from Hawaii. Latitude 5° 49′ N.
8. *Gorgonocephalus arcticus* (Gray). Off Cape Cod, Massachusetts. About latitude 42° N.
9. *Gorgonocephalus caryi* (Lyman). Alaska.
10. *Ophioglypha sarsii* (Lütken). *Albatross* station 2176. Latitude 39° 32′ 30″ N., longitude 72° 21′ 30″ W. Depth, 553 meters; bottom temperature, 5° C.
11. *Ophioderma cinereum* (Müller and Troschel). Ensenada Honda, Culebra Island, east of Porto Rico. Latitude 18° 20′ N., approximately.

The last locality is in or on the edge of the equatorial current. The *Albatross* stations were all fixed on cruises between Cape Hatteras and Nantucket. The analyses are as follows:

Analyses of starfishes.

	1	2	3	4	5	6	7	8	9	10	11
SiO_2	0.45	0.79	0.03	1.21	2.06	0.27	0.19	1.77	1.08	0.98	0.21
R_2O_3	.21	.55	.20	.48	.79	.36	.14	.62	.72	.53	.09
MgO	2.59	3.83	3.98	3.05	3.93	4.89	4.36	3.36	2.82	3.99	5.80
CaO	35.71	38.51	36.85	30.35	40.54	41.30	33.18	36.13	29.80	42.14	41.32
P_2O_5	.07	.24	.14	.13	.11	.14	.07	.22	.32	.29	.07
Loss on ignition	60.18	54.89	57.64	63.91	51.66	52.03	62.07	55.72	63.37	50.95	51.58
	99.21	98.81	98.84	99.13	99.09	98.99	100.01	97.82	98.11	98.88	99.07
CO_2 needed	30.84	34.30	33.05	27.08	35.94	37.70	30.81	31.65	25.80	37.29	38.79

Revised analyses of starfishes.

	1	2	3	4	5	6	7	8	9	10	11
SiO_2	0.64	1.01	0.03	1.94	2.47	0.32	0.27	2.39	1.77	1.15	0.24
R_2O_3	.30	.70	.27	.77	.94	.42	.20	.84	1.18	.62	.12
$MgCO_3$	7.79	10.28	11.24	10.27	9.88	12.13	13.33	9.53	9.71	9.84	14.11
$CaCO_3$	91.06	87.44	88.06	86.57	86.42	86.77	85.99	86.60	86.18	87.65	85.34
$Ca_3P_2O_8$	.21	.57	.40	.45	.29	.36	.21	.64	1.16	.74	.19
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

In the following table the analyses are arranged in the order of ascending magnesium carbonate, like those of the sea urchins:

Percentage of magnesium carbonate in starfishes.

	Locality.	Latitude.	Depth.	Temperature.	$MgCO_3$
			Meters.	° *C.*	*Per cent.*
Asterias vulgaris	Eastport	44° 55′ N.	(?)	(?)	7.79
Gorgonocephalus arcticus	Cape Cod	42° ± N.	(?)	(?)	9.53
Gorgonocephalus caryi	Alaska	(?)	(?)	(?)	9.71
Ophioglypha sarsii	Station 2176	39° 32′ N.	553	5	9.84
Benthopecten spinosus	Station 2568	39° 15′ N.	3,249	2.7	9.88
Leptasterias compta	Station 2250	40° 17′ N.	86	10.8	10.27
Asterias tanneri	Station 2309	35° 43′ N.	102	(?)	10.88
Asterina miniata	California	36° 36′ N.	(?)	(?)	11.24
Luidia clathrata	Charleston	32° 47′ N.	(?)	(?)	12.13
Acanthaster planci	Palmyra Island	5° 49′ N.	(?)	(?)	13.33
Ophioderma cinereum	Culebra	18° 20′ N.	(?)	(?)	14.11

CRINOIDS.

In order to make the comparison between the three groups of echinoderms more complete, two additional crinoid skeletons were analyzed, as follows:

1. *Zygometra microdiscus* (Bell). Aru Islands, near the western tip of New Guinea. Latitude 5°–6° S.
2. *Chlorometra rugosa* (A. H. Clark). Near Rotti, Lesser Sunda Islands. Latitude 10° 39′ S., longitude 123° 40′ E. Depth, 520 meters.

Analyses of crinoids.

Actual analyses.			Revised analyses.		
	1	2		1	2
SiO_2	0.04	0.05	SiO_2	0.05	0.06
R_2O_3	.48	.23	R_2O_3	.62	.27
MgO	4.92	3.99	$MgCO_3$	13.37	9.87
CaO	37.19	42.72	$CaCO_3$	85.48	89.80
P_2O_5	.17	Trace.	$Ca_3P_2O_8$	.48	Trace.
Loss on ignition	55.05	51.69		100.00	100.00
	97.85	98.68			
CO_2 needed	34.47	37.95			

Combining these data with those given in our paper upon the crinoids, we have the following table:

Percentage of magnesium carbonate in crinoids.

Genus.	Locality.	Latitude.	Depth.	Temperature.	$MgCO_3$.
			Meters.	° *C.*	*Per cent.*
Heliometra	Northern Japan	43° N	315	1.5	7.28
Promachocrinus	Antarctic	67° S	375	−1.8	7.86
Ptilocrinus	British Columbia	52° 39′ N	2,858	1.8	7.91
Anthometra	Antarctic	67° S	375	−1.8	8.23
Psathyrometra	Northern Japan	44° N	(?)	1.6	9.25
Hathrometra	Massachusetts	39° 56′ N	329	7.8	9.36
Florometra	Washington	47° 29′ N	1,145	3.3	9.44
Chlorometra	Rotti	10° 39′ S	520	(?)	9.87
Bythocrinus	Gulf of Mexico	28° 38′ N	255	(?)	10.09
Pentametrocrinus	Southern Japan	34° N	1,123	3.4	10.15
Hypalocrinus	Philippine Islands	9° 37′ N	612	10.2	10.16
Metacrinus	Southern Japan	30° 58′ N	278	13.3	10.34
Parametra	Philippine Islands	9° 15′ N	502	12	11.08
Ptilometra	Australia	33° 15′ S	(?)	(?)	11.13
Isocrinus	Cuba	24° N	(?)	(?)	11.56
Catoptometra	Philippine Islands	8° N	104	(?)	11.68
Crinometra	Cuba	23° 10′ N	59	26.2	11.69
Tropiometra	Brazil	25° 54′ S	(?)	(?)	11.77
Endoxocrinus	Cuba	24° N	(?)	(?)	11.79
Pachylometra	Philippine Islands	8° N	1,044	(?)	12.20
Craspedometra	Philippine Islands	5° 12′ N	32	(?)	12.34
Capillaster	Philippine Islands	6° N	36	(?)	12.69
Zygometra	Aru Islands	5°–6° S	(?)	(?)	13.37

The percentage of magnesium carbonate in Chlorometra is low for the latitude of the locality; but that is doubtless due to the depth of the water (520 meters) in which the crinoid lived. The probable temperature at that depth was between 7° and 10° C.

GENERAL CONSIDERATIONS.

From the evidence now available, it seems almost certain that the inorganic constituents of any echinoderm will have the composition of a moderately magnesian limestone. There may be exceptions, but none has yet been found. The three tables, for crinoids, sea urchins, and starfishes, all tell the same story, and with remarkable unanimity. Furthermore, the proportion of magnesium carbonate appears to be a function of temperature, the organisms from warm regions being richer in it than the cold-water forms. The exceptions to this rule are apparent rather than real; for cold or warm currents and varying depths of water account for all seeming irregularities. The sea urchins seem to be a little poorer in magnesia than either of the other groups, but the analyses are fewer and therefore less conclusive. Silica and sesquioxides are probably altogether extraneous, although it is possible that small quantities of them may really belong to the organisms. In phosphate of lime the starfishes are richest, and all the specimens analyzed contain it in small amounts. Whether it is an essential constituent or not is uncertain. As shown by Meigen's reaction, all the echinoderms studied are calcitic, and no evidence of aragonite in them was found.

The temperature regularity shown by the analyses offers an interesting biological problem with which we can not undertake to cope. It is not due to differences of composition in the solid matter of sea water, for that is practically uniform all the world over. In all the great oceans, and even in minor bodies of water like the Mediterranean, the Baltic, and the Black Sea, the proportion of magnesia to lime is very nearly if not actually constant. In gaseous contents and especially in carbon dioxide the waters vary; the gases being more soluble in cold than in warm water. Whether this fact has any relation to the phenomenon under discussion we can not attempt to say. We can only report the facts and leave their biological discussion to others.

On the geological bearing of the evidence now before us it is easy to speculate; but here great caution is needed. It would be unwise to assume that magnesian sediments are more abundantly deposited in warm than in cold climates, and so to develop a system of what might be called paleoclimatology. Against such an attempt there are two obvious reasons. First, the sediments are only in small part derived from echinoderm remains. Other agencies are more important in the formation of marine limestones. Secondly, a dense population, so to speak, of cold-water organisms may deposit much more magnesia than a sparse population of warm-water forms. The data now in hand, with all their suggestiveness, are too few to warrant any far-reaching generalizations. It is our intention to carry the investigation still further, studying other marine invertebrates by the same methods as those which we have followed here. If other analysts choose to enter this field of research, their results will be welcomed by us.

INDEX.

A.

Page.

Apishapa quadrangle, Colo., dike rocks in, distribution and character of 17-18
dike rocks in, petrography of 18-28
geographic relations of .... 18 (Pl. IV), 29
Arapahoe formation, vertebrate fossils from 117-153
Augite minette and tinguaite dike, occurrence and character of... 20-21
Augite vogesite dike, olivine bearing, analyses of 22
occurrence and character of .... 21-24, 22 (Pl. V)

B.

Bartsch, Paul, fossils examined by 85
Basalt, olivine plagioclase, analyses of 27
olivine plagioclase, occurrence and character of.. 26 (Pl. VII), 26-28
types of 27
Bassler, R. S., fossils identified by, in Cooper marl 85
Bastin, E. S., Geology of the pitchblende ores of Colorado 1-5
Bearpaw shale, distribution and character of 102
Belly River formation, correlation of 64-66
invertebrate fossils from 115-117
vertebrate fossils from 117-153
Bowen, C. F., The stratigraphy of the Montana group, with special reference to the position and age of the Judith River formation in north-central Montana 95-153
Bridgeport Landing, Ala., Cretaceous-Eocene contact at 161
Browns Park formation, position of 186-187, 188

C.

Calhoun mine, Colorado, pitchblende from .... 4-5, 5 (Pl. II)
Canyon Range, Utah, field work on 51
geology of 53-59
ore deposits in 59-60
stratigraphy of 53-57
structure of 57-58
topography of 52
Charleston, S. C., artesian wells at, mineralogy of waters from.... 90-94
Citadel Green well at, record of 84-85
deep well at, method employed in drilling 69-70
origin of water from 89-90
quantity and quality of water from 70-71
record of 71-79
strata penetrated by 85-89
Chesapeake Bay, erosion and deposition in. *See* Choptank River.
maps of 7-8
Choptank River, Md., mouth of, erosion and sedimentation at... 7-15
mouth of, geology of 9
maps of 9
topography of .... 9-15, 10 (Pl. III)
Claggett formation, distribution and character of 98-100
fossils from 102, 114-115
Clark, Austin H., acknowledgments to 33, 191
Clarke, F. W., and Wheeler, W. C., The composition of crinoid skeletons 33-37
and Wheeler, W. C., The inorganic constituents of echinoderms 191-196
Clayton, Ala., Cretaceous-Eocene contact near 160
Coast and Geodetic Survey, charts by 7-8
Coastal Plain, Atlantic and Gulf, formations in contact in 157
Colorado, dike rocks in. *See* Apishapa quadrangle.
pitchblende in. *See* Quartz Hill, Colo.
uranium in 1
Colorado shale, distribution and character of 97
Colorado, southwestern, stratigraphy of 39-50

Page.

Cook Point, Md., changes at .... 10 (Pl. III), 12, 15
Cooke, C. Wythe, fossils determined by 163, 166, 167, 178, 179
Cope, E. D., cited 99, 106, 110
Copper, occurrence of, in the Canyon Range, Utah 59-60
Cornwall, England, pitchblende in 3
Cretaceous-Eocene contact, at Old Canton Landing, Ala., plate showing 163
at White Bluff, Texas, plates showing 172
east of New Albany, Miss., plate showing 168
in the Atlantic and Gulf Coastal Plain 155-182
literature of 181-182
south of Macon, Ala., plate showing 163
trend of, map showing 156
in Maverick County, Tex., map showing 170
Cretaceous fauna compared with Eocene 157-159
Crider, A. F., cited 166
Crinoid skeletons, analyses of 34-35, 37, 194-195
composition of existing 33-36
composition of fossil 36-37
Cross, Whitman, Dike rocks of the Apishapa quadrangle, Colo... 17-31
and Larsen, Esper S., Contributions to the stratigraphy of southwestern Colorado 39-50
Cushman, Joseph A., fossils identified by 79-83
Cutler formation, occurrence of, in Piedra Valley, Colo 48

D.

Dakota sandstone, overlap of 40-44
Davis, W. M., cited 185
Dawson, G. M., cited 107
Denver formation, vertebrate fossils from 117-153
Diabase, sodic, occurrence and character of 28
Dolores formation, distribution of, in Piedra Valley, Colo 47-48
Domes in north-central Montana 103
Dumble, E. T., cited 170, 171

E.

Eagle sandstone, distribution and character of 97-98
fossils from 114-115
Echinoderms, inorganic constituents of 191-196
Elbert formation, occurrence of, in Piedra Valley, Colo 50
Emmons, S. F., cited 185
Eocene conglomerate, distribution of, in the Canyon Range, Utah 56-57
Eocene fauna compared with Cretaceous 157-159
Eocene sandstone, plate showing 178
Escondido formation, plate showing 179

F.

Faults in north-central Montana 104
Folds in north-central Montana 103
Fool Creek canyon, Utah, generalized section along, figure showing. 55
Fossils, Cretaceous and Eocene compared 157-159
from Claggett formation and Bearpaw shale 102
from deep well at Charleston, S. C 79-83
from Eagle sandstone, Claggett formation, and Fox Hills sandstone 114-115
from Judith River, Belly River, and Lance formations 115-117
from Judith River, Belly River, Lance, Denver, and Arapahoe formations 117-153
from Judith River formation 111-112
from limestone of the Canyon Range 54
from Montana group on Two Medicine River 62, 63, 64
Fox Hills sandstone, fossils from 114-115

G.

Page.

German mine, Colo., pitchblende from ... 4
Gilbert, G. K., work of ... 17
Gilmore, C. W., cited ... 152
Girty, G. H., fossils determined by ... 54
Granite gneiss, pre-Cambrian, pitchblende in ... 4
Green River, bearing of history of Yampa River on ... 183-189
course of ... 184
Gulf region, east-central part of, generalized section in ... 156
Gulliver, F. P., work of ... 17
Gunnison Valley, Colo., overlap in ... 40-44

H.

Hall, James, cited ... 83-85
Hancock, E. T., The history of a portion of Yampa River, Colo., and its possible bearing on that of Green River ... 183-189
Harris, G. D., cited ... 155, 171
Hatcher, J. B., and Stanton, T. W., cited ... 99, 107-108, 152
Hayden, F. V., cited ... 104, 105, 106, 109
and Meek, F. B., cited ... 106
Hayden Survey, stratigraphic breaks and overlap established by. 39-44
Hermosa formation, occurrence of, in Piedra Valley, Colo ... 48-49
Hess, F. L., aid of ... 1
Hills Point, Md., changes in ... 10 (Pl. III), 12, 15
Horsethief sandstone, exposure of, on Two Medicine River ... 62-63
Houston, Miss., Cretaceous-Eocene contact near ... 168-169
Hunter, J. F., Erosion and sedimentation in Chesapeake Bay, around the mouth of Choptank River ... 7-15

I.

Idaho Springs formation, occurrence and character of ... 3-4
Irving, J. D., cited ... 184-185

J.

James Island, Md., changes in ... 9-10, 10 (Pl. III), 15
Judith River formation, age of, paleontologic evidence on ... 112-153
correlation of ... 64-66, 110-112
distribution and character of ... 100-101
invertebrate fossils from ... 115-117
flora of ... 113
literature on ... 104-110
vertebrate fossils from ... 117-153
Junction Mountain, Colo., how formed ... 183
Juniper Mountain, Colo., how formed ... 183-184

K.

Knapp, I. N., cited ... 70
Knowlton, F. H., cited ... 113
fossil plants identified by ... 63

L.

Lake Bonneville beds, exposures of, in the Canyon Range, Utah ... 57
Lamprophyre, character of ... 29
Lance formation, distribution and character of ... 103
invertebrate fossils from ... 115-117
vertebrate fossils from ... 117-153
La Plata sandstone, distribution of, in Piedra Valley, Colo ... 46-47
on schist of Uncompahgre formation, plate showing ... 44
position of, in Piedra Valley, Colo ... 44-46
stratigraphic break below ... 39-44
Larsen, Esper S., and Cross, Whitman, contributions to the stratigraphy of southwestern Colorado ... 39-50
Lead, occurrence of, in the Canyon Range, Utah ... 59-60
Leidy, Joseph, cited ... 106
Limestone, Carboniferous, distribution of, in Canyon Range, Utah. 53-54
Livingston, Ala., Cretaceous-Eocene contact near ... 163-164
Loughlin, G. F., A reconnaissance in the Canyon Range, west-central Utah ... 51-60

M.

McElmo formation, distribution of, in Piedra Valley, Colo ... 46
Macon, Miss., Cretaceous-Eocene contact near ... 167
Magnesium carbonate in crinoid skeletons ... 33-37
in echinoderm skeletons ... 191-196
Matthew, W. D., cited ... 152
Maverick County, Tex., Cretaceous-Eocene contact in ... 169-176, 180
map of ... 170
Medina County, Tex., Cretaceous-Eocene contact in ... 178-180

Page.

Meek, F. B., cited ... 106
and Hayden, F. V., cited ... 106
Mesaverde formation, jointing in, plates showing ... 188
Mesozoic formations, structure of ... 44
Midway formation, basal limestone of, plates showing ... 178, 179
and overlying sandstone, contact between, plate showing ... 173
and Selma chalk, contact between, plates showing ... 162
Midway or Wilcox time, sandstone of, in Maverick County, Tex., plate showing ... 173
Minette dike, analyses of ... 19
occurrence and character of ... 18-20
Molas formation, distribution of, in Piedra Valley, Colo ... 49-50
Montana, area between Judith and Musselshell, geologic map of .. 104
area between Judith and Musselshell, stratigraphy of ... 96-103
structure of ... 103-104
Montana group of northwestern Montana, relations of ... 61-68
relations of, to the Belly River and Judith River formations .. 64-66
relations of the continental to the marine sediments in ... 66-68
stratigraphy of ... 95-153
Monzonite porphyry, character of ... 29
Moscow Landing, Ala., Cretaceous-Eocene contact at ... 162-163

N.

New Albany, Miss., Cretaceous-Eocene contact near ... 169

O.

Oak Creek canyon, Utah, generalized section along, figure showing. 55
Old Canton Landing, Ala., Cretaceous-Eocene contact near ... 162
Olivine. *See* Augite vogesite *and* Basalt.
Ophiurans, analyses of ... 193-194
Osborn, H. F., cited ... 107, 152
Ouray limestone, occurrence of, in Piedra Valley, Colo ... 50
Overlap in the Gunnison Valley, Colo ... 40-44

P.

Palmer, Chase, Mineralogy of waters from artesian wells at Charleston, S. C ... 90-94
Peale, A. C., cited ... 108, 111
Penrose, R. A. F., jr., cited ... 170
Piedra Valley, Colo., stratigraphy of ... 42-44
Pirsson, L. V., cited ... 30
Pitchblende, occurrence of, in foreign countries ... 1-3
occurrence of, in United States ... 1
origin of ... 5
Pontotoc, Miss., Cretaceous-Eocene contact near ... 169
Potholes in Midway formation, in Maverick County, Tex., plate showing ... 168
Powell, J. W., cited ... 184, 186

Q.

Quartz Hill, Colo., geology of ... 3-5
pitchblende at ... 1
Quartzite, distribution of, in the Canyon Range, Utah ... 54-56

R.

Ragged Point, Md., changes in ... 10 (Pl. III), 13, 15
Roemer, Ferdinand, cited ... 169-170

S.

San Juan Mountains area, Colo., stratigraphy of ... 42-44
Scooba, Miss., Cretaceous-Eocene contact near ... 164-166
Sea urchins, analyses of ... 191-193
Selma chalk and Midway group, contact between, plates showing. 162
Sevier Canyon, Utah, Lake Bonneville beds at mouth of, plate showing ... 56
Sharps Island, Md., changes in ... 10 (Pl. III), 11, 15
Shuqualak, Miss., Cretaceous-Eocene contact near ... 166-167
Spanish Peaks, Colo., relations of, to Apishapa quadrangle ... 17, 18 (Pl. IV), 29
Stanton, T. W., cited ... 155
and Hatcher, J. B., cited ... 99, 107-108, 152
Starfishes, analyses of ... 193-194
Starkville, Miss., Cretaceous-Eocene contact near ... 167-168
Stebinger, Eugene, The Montana group of northwestern Montana. 61-68
Stephenson, Lloyd William, A deep well at Charleston, S. C ... 69-94
The Cretaceous-Eocene contact in the Atlantic and Gulf Coastal Plain ... 155-182
Stose, G. W., aid of ... 17

T.

Page.

Talbot formation, distribution and character of 9
Tilghman Island, Md., changes in .... 10 (Pl. III), 12, 15
Tinguaite and augite minette dike, occurrence and character of .. 20–21
Troy, Ala., Cretaceous-Eocene contact near 161
Two Medicine formation, exposure of, on Two Medicine River, Mont 63
Two Medicine River, Mont., section on 61–62

U.

Uinta Mountains, how formed 183
Uncompahgre formation, distribution of, in Piedra Valley, Colo .. 50
Uranium, sources of, in United States 1
Utah, uranium in 1
  west-central, reconnaissance in 51–60
Uvalde County, Tex., Cretaceous-Eocene contact in 176–177

V.

Vaughan, T. W., cited 155, 159, 170–171
  fossils determined by 177, 179
Virgelle sandstone, exposure of, on Two Medicine River, Mont ... 62–63
Vogesite, hornblende augite, analyses of 25
  occurrence and character of .... 24 (Pl. VI), 24–26
  See also Augite vogesite.

W.

Page.

Wahalak, Miss., Cretaceous-Eocene contact near 164–166
Water analyses, interpretation of 91–92
Wheeler, W. C., and Clarke, F. W., The composition of crinoid skeletons 33–37
  and Clarke, F. W., The inorganic constituents of echinoderms 191–196
White, C. A., cited 185, 187
Whiteaves, J. F., cited 107
Wilcox or Midway time, sandstone of, in Maverick County, Tex., plate showing 173
Wood mine, Colo., pitchblende from .... 4, 4 (Pl. I), 5 (Pl. II), 5

Y.

Yampa River, Colo., course of 184, 187, 188
  history of part of 183–189
  map showing part of 184
Yates, Charles, aid of 8

Z.

Zavalla County, Tex., Cretaceous-Eocene contact in 176–177
Zinc, occurrence of, in the Canyon Range, Utah 59–60