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ADVERTISEMENT.

[Tenth Annual Report.]

The publications of the United States Geological Survey are issued in accordance with the statute approved March 3, 1879, which declares that—

"The publications of the Geological Survey shall consist of the annual report of operations, geological and economic maps illustrating the resources and classification of the lands, and reports upon general and economic geology and paleontology. The annual report of operations of the Geological Survey shall accompany the annual report of the Secretary of the Interior. All special memoirs and reports of said Survey shall be issued in uniform quarto series if deemed necessary by the Director, but other wise in ordinary octavos. Three thousand copies of each shall be published for scientific exchanges and for sale at the price of publication; and all literary and cartographic materials received in exchange shall he the property of the United States and form a part of the library of the organization: And the money resulting from the sale of such publications shall be covered into the Treasury of the United States."

On July 7, 1882, the following joint resolution, referring to all Government publications, was passed by Congress:

"That whenever any document or report shall be ordered printed by Congress, there shall be printed, in addition to the number in each case stated, the 'usual number' (1,900) of copies for binding and distribution among those entitled to receive them."

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ANNUAL REPORTS.

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II. Second Annual Report of the United States Geological Survey, 1880-'81, by J. W. Powell. 1882. 8°. lv, 588 pp. 62 pl. 1 map.

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X. Tenth Annual Report of the United States Geological Survey, 1888-'89, by J. W. Powell. 1890. 8°. 2 v. xv, 774 pp. 98 pl. and maps; viii, 123 pp.

The Eleventh Annual Report is in press.

MONOGRAPHS.

I. Lake Bonneville, by Grove Karl Gilbert. 1890. 4°. xx, 438 pp. 51 pl. 1 map. Price $1.50.

II. Tertiary History of the Grand Cañon District, with atlas, by Clarence E. Dutton, Capt. U. S. A. 1882. 4°. xiv, 264 pp. 42 pl. and atlas of 24 sheets folio. Price $10.12.

III. Geology of the Comstock Lode and the Washoe District, with atlas, by George F. Becker. 1882. 4°. xv, 422 pp. 7 pl. and atlas of 21 sheets folio. Price $11.00.

IV. Comstock Mining and Miners, by Eliot Lord. 1883. 4°. xiv, 451 pp. 3 pl. Price $1.50.

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X. Dinocerata. A Monograph of an Extinct Order of Gigantic Mammals, by Othniel Charles Marsh. 1886. 4°. xviii, 243 pp. 56 l. 56 pl. Price $2.70.

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XVI. The Paleozoic Fishes of North America, by John Strong Newberry. 1889. 4°. 340 pp. 53 pl. Price $1.00.

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— Gasteropoda of the New Jersey Cretaceous and Eocene Marls, by R. P. Whitfield.
— The Penokee Iron-Bearing Series of Northern Wisconsin and Michigan, by Roland D. Irving and C. R. Van Hise.
— Mollusca and Crustacea of the Miocene Formations of New Jersey, by R. P. Whitfield.
— Description of New Fossil Plants from the Dakota Group, by Leo Lesquereux.
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— Sauropoda, by O. C. Marsh.
— Stegosauria, by O. C. Marsh.
— Brontotheridæ, by O. C. Marsh.
— Report on the Denver Coal Basin, by S. F. Emmons.
— Report on Silver Cliff and Ten-Mile Mining Districts, Colorado, by S. F. Emmons.
— Flora of the Dakota Group, by J. S. Newberry.
— The Glacial Lake Agassiz, by Warren Upham.
— Geology of the Potomac Formation in Virginia, by W. M. Fontaine.

BULLETINS.

1. On Hypersthene-Andesite and on Triclinic Pyroxene in Augitic Rocks, by Whitman Cross, with a Geological Sketch of Buffalo Peaks, Colorado, by S. F. Emmons. 1883. 8°. 42 pp. 2 pl. Price 10 cents.

2. Gold and Silver Conversion Tables, giving the coining values of troy ounces of fine metal, etc., computed by Albert Williams, jr. 1883. 8°. 8 pp. Price 5 cents.

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In press:

65. Comparative Stratigraphy of the Bituminous Coal Rocks of the Northern Half of the Appalachian Field, by I. C. White.

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76. A Dictionary of Altitudes in the United States (second edition), compiled by Henry Gannett.

77. The Texas Permian and its Mesozoic types of Fossils, by C. A. White.

In preparation:

— A report of work done in the Division of Chemistry and Physics, mainly during the fiscal year 1889-'90. F. W. Clarke, Chief Chemist.

— A Late Volcanic Eruption in Northern California and its Peculiar Lava, by J. S. Diller.

— The Compressibility of Liquids, by Carl Barus.

— The Eruptive and Sedimentary Rocks on Pigeon Point, Minnesota, and their contact phenomena, by W. S. Bayley

— A Bibliography of Paleobotany, by David White.

STATISTICAL PAPERS.

Mineral Resources of the United States, 1882, by Albert Williams, jr. 1883. 8°. xvii, 813 pp. Price 50 cents.

Mineral Resources of the United States, 1883 and 1884, by Albert Williams, jr. 1885. 8°. xiv, 1016 pp. Price 60 cents.

Mineral Resources of the United States, 1885. Division of Mining Statistics and Technology. 1886. 8°. vii, 576 pp. Price 40 cents.

Mineral Resources of the United States, 1886, by David T. Day. 1887. 8°. viii, 813 pp. Price 50 cents.

Mineral Resources of the United States, 1887, by David T. Day. 1888. 8°. vii, 832 pp. Price 50 cents.

Mineral Resources of the United States, 1888, by David T. Day. 1890. 8°. vii, 652 pp. Price 50 cents.

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TO THE DIRECTOR OF THE
UNITED STATES GEOLOGICAL SURVEY,
WASHINGTON, D. C.

WASHINGTON, D. C., *December*, 1890.

TENTH ANNUAL REPORT

OF THE

UNITED STATES GEOLOGICAL SURVEY

TO THE

SECRETARY OF THE INTERIOR

1888-'89

BY

J. W. POWELL
DIRECTOR

PART I—GEOLOGY

WASHINGTON
GOVERNMENT PRINTING OFFICE
1890

TENTH ANNUAL REPORT

OF THE

DIRECTOR

OF THE

UNITED STATES GEOLOGICAL SURVEY

Part I—GEOLOGY

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GENERAL ACCOUNT OF THE FRESH-WATER MORASSES OF THE UNITED STATES, WITH A DESCRIPTION OF THE DISMAL SWAMP DISTRICT OF VIRGINIA AND NORTH CAROLINA, BY NATHANIEL SOUTHGATE SHALER.

Part I. Inundated lands—Continued.

THE PENOKEE IRON-BEARING SERIES OF MICHIGAN AND WISCONSIN, BY ROLAND DUER IRVING AND CHARLES RICHARD VAN HISE.

THE FAUNA OF THE LOWER CAMBRIAN OR OLENELLUS ZONE, BY CHARLES D. WALCOTT.

ILLUSTRATIONS.

LETTER OF TRANSMITTAL.

Department of the Interior,
United States Geological Survey,
Washington, D. C., July 25, 1889.

Sir: I have the honor to transmit herewith a report of the operations of the Geological Survey for the year ending June 30, 1889.

I am, sir, with great respect, your obedient servant,

J. W. Powell
Director.

Hon. John W. Noble,
Secretary of the Interior.

TENTH ANNUAL REPORT OF THE UNITED STATES GEOLOGICAL SURVEY.

By J. W. Powell, Director.

CHANGES IN ORGANIZATION.

In the act making appropriations for the sundry civil expenses of the Government for the fiscal year ending June 30, 1889, certain new duties were assigned to the Geological Survey under the direction of the Secretary of the Interior. These duties comprise the investigation of the extent to which the arid regions of the United States can be redeemed by irrigation, the segregation of the irrigable land in such arid regions, the selection of sites for reservoirs and other hydraulic works necessary for the storage and utilization of water for irrigation and for the prevention of floods and overflows, and the making of the necessary maps. By reason of this addition to the work of the Geological Survey considerable additions to the working force became necessary; and with the enlargement of the corps some minor modifications in organization were made.

The principal change in the geologic branch of the Survey was the transfer of Capt. C. E. Dutton, formerly in charge of the Division of Volcanic Geology, to the Irrigation Survey. Mr. J. S. Diller, who was previously his principal assistant, was placed in charge of the division, its functions were somewhat modified and it was renamed the Cascade Division.

The changes in the geographic branch of the Survey were more extensive. The California Section of Geography was reorganized and transferred to the Irrigation Survey; the geographic branch of the Geological Survey became limited to that portion of the country lying east of the Rocky Mountains; the organization of the different sections of the geographic branch was modified in consequence of the transfer of a part of the force to the Irrigation Survey; and a new section was organized under the name of the Southern Central Section, which includes the southern part of the Mississippi Valley. The geographic work of the Geological Survey remains in charge of Mr. Henry Gannett; and the changes in organization and personnel are set forth in his administrative report.

As shown at length in the Eighth Annual Report the business organization of the Survey is dependent upon scientific organization, and from time to time is modified to meet its needs. Accordingly some modification of the business organization resulted from the inauguration of the irrigation work; but the general business methods of the Geological Survey were extended to the new organization, and in the interests of economy the business growing out of the irrigation work was assigned to the force already employed. Mr. John D. McChesney, the chief disbursing clerk, continues to transact the fiscal and custodial business of the Geological Survey and also has charge of that of the Irrigation Survey; but a number of additional disbursing agents and custodians of property have been appointed

A noteworthy change in organization has grown out of the ever varying progress of geologic science as developed and applied by the Geological Survey. One of the immediate objects of geologic research, and one upon which the practical value of geologic science largely depends, is a determination of the relations among widely separated rock masses—i. e., the correlation of rocks. In the infancy of the science, when the demands upon the geologist were less exacting than now, the formations discovered from time to time were roughly correlated by means of paleontology with those already known. But with the development and practical application of geology such approximate correlations have sometimes been found unsatisfactory; and, moreover, grave question has arisen as to the sufficiency of paleontologic correlation for a detailed geologic survey covering an extensive area. Questions concerning geologic nomenclature and the methods of correlation have lately arisen not only in the Geological Survey but among other geologists, both official and unofficial, and not only in this country but abroad. An international congress of geologists has been convened, largely for the purpose of devising systems of geologic correlation and geologic nomenclature, and many important contributions to this branch of geologic science have been made during the last five years. So important, indeed, has the subject become that, as pointed out in previous reports, it has seemed inexpedient to commence publication of the atlas sheets composing the geologic map of the United States pending the settlement of at least some of the questions involved. By reason of the practical and immediate importance of this subject to the Geological Survey it was deemed wise to organize a division of geologic correlation; and, at the beginning of the fiscal year, such a division was established and placed in charge of Mr. G. K. Gilbert, formerly in charge of the Appalachian Division of Geology. The details of organization and of the work already accomplished are set forth in Mr. Gilbert's report.

For a part of the year Mr. Gilbert remained in charge of the Appalachian Division, and devoted his energies to the work in this extended field, to the completion of the work of the old division of the Great Basin and to that connected with correlation; but operations in the first named division were gradually transferred to Mr. Bailey Willis, and toward the close of the year he was formally placed in charge of the Appalachian Division. Mr. Willis's report of operations in this division for the entire fiscal year is appended. During the year the Great Basin work has been completed, and a final report upon the subject—a monograph upon the extinct Lake Bonneville—has been sent to press.

PROGRESS OF TOPOGRAPHIC WORK.

During the fiscal year the operations of the topographic branch of the Survey have been carried on in twenty-three States and Territories, and an area of 43,222 square miles has been surveyed and mapped. The distribution of this work is shown graphically upon Plate I in the pocket at the end of the volume. The details are set forth in the accompanying administrative report by Mr. Gannett. The present condition of the topographic surveys is exhibited in the accompanying table:

Table showing the present condition of topographic surveys and the areas surveyed in 1888–'89, by States and Territories.

State.	Total area.	Area surveyed to date.	Area surveyed in 1888–'89.	Scale.	Contour interval.
	Sq. miles.	*Sq. miles.*	*Sq. miles.*		*Feet.*
Alabama	52,250	11,620	2,300	1 : 125,000	100
Arizona	113,020	41,000	....	1 : 250,000	200 and 250
Arkansas	53,850	7,500	3,500	1 : 125,000	50
California	158,360	25,200	2,200	1 : 125,000 1 : 250,000	100 and 200
Colorado	103,925	2,500	....	1 : 62,500 1 : 125,000	50 and 100
Connecticut	4,990	700	550	1 : 62,500	20
District of Columbia	70	70	....	1 : 62,500	20
Georgia	59,475	10,530	1,500	1 : 125,000	50 and 100
Iowa	56,025	2,450	1,500	1 : 62,500	20
Kansas	82,080	32,200	4,200	1 : 125,000	50
Kentucky	40,400	7,070	800	1 : 125,000	100
Maine	33,040	320	320	1 : 62,500	20
Maryland	12,210	3,480	400	1 : 62,500 1 : 125,000	20, 50 and 100
Massachusetts	8,315	8,315	....	1 : 62,500	20
Missouri	69,415	26,000	....	1 : 125,000	50
Montana	146,080	10,400	4,400	1 : 250,000	200
Nevada	110,700	14,000	....	1 : 250,000	200 and 250
New Hampshire	9,305	675	575	1 : 62,500	20
New Jersey	7,815	7,815	....	1 : 62,500	10 and 20
New Mexico	122,580	17,500	2,500	1 : 250,000	200
New York	49,170	645	645	1 : 62,500	20
North Carolina	52,250	9,900	....	1 : 125,000	100
Oregon	96,030	11,000	3,000	1 : 250,000	200
Pennsylvania	42,215	842	842	1 : 62,500	20
Rhode Island	1,250	1,250	1,000	1 : 62,500	20
South Carolina	30,570	2,300	....	1 : 125,000	100
Tennessee	42,050	12,615	....	1 : 125,000	100
Texas	265,780	26,250	6,250	1 : 125,000	50
Utah	84,970	6,000	....	1 : 250,000	250
Vermont	9,565	100	....	1 : 62,500	20
Virginia	42,450	27,775	5,550	1 : 62,500 1 : 125,000	20, 50 and 100
West Virginia	24,780	15,750	600	1 : 125,000	100
Wisconsin	56,040	1,590	590	1 : 62,500	20
Wyoming, including Yellowstone National Park	97,890	4,000	....	1 : 125,000	100
Total	....	349,362	43,222		

From this table it appears that during the year there were mapped 6,472 square miles upon a scale of 1 : 62,500; 26,850 square miles upon a scale of 1 : 125,000; and 9,900 square miles upon a scale of 1 : 250,000. The survey of this area finishes 99 atlas sheets, making the entire number completed up to the present date both by survey and compilation 406. Of these sheets 138 are on the scale of 1 : 62,500; 207 on the scale of 1 : 125,000; and 61 on the scale of 1 : 250,000.

In the spring of 1888 an appropriation was made by the legislature of Rhode Island for the survey of that State in co-operation with this organization under an agreement similar to that made with Massachusetts. Under this arrangement Rhode Island has been surveyed during the past season, the State paying one-half the expense. The maps have been drawn and are now being engraved. On the north of Massachusetts work has been extended into New Hampshire and the southwestern corner of Maine; and on the west certain atlas sheets projecting into New York have been completed. The sheets comprising New York city and its suburbs have been mapped, in part from survey and in part by compilation from existing material. A number of sheets projecting northward and westward from New Jersey into adjoining States have also been finished.

At present parties of the Northeastern Division are engaged in mapping the anthracite region of Pennsylvania; in extending the surveyed area in southwestern Maine; and in making a survey of Connecticut under a joint arrangement with that State, by the conditions of which the State assumes one-half of the expense of the survey.

In the southern Appalachian region work has been carried on actively by the Southern Central Division. A large area in Virginia has been surveyed, and parties are now at work in West Virginia. Triangulation has been extended in eastern Kentucky, and a party is at work mapping topographic details. The work in Alabama and Georgia has been extended southward, and a party is engaged mapping the drainage basin of the Savannah River in Georgia and South Carolina

In the Mississippi Valley the two sheets comprising St. Louis and its suburbs upon both sides of the Mississippi River have been surveyed. Work has been extended westward in Kansas and northward and westward in Iowa. Some work has also been done in southern Wisconsin, and a map is being prepared of the iron region of Michigan.

In the Ozark Hills of Arkansas an area of 3,500 square miles has been surveyed lying east of that executed during the previous year. In Texas the surveyed area has been extended northward. Five atlas sheets have been completed, while a considerable area in the iron region of northeastern Texas has been surveyed.

In the Far West work has been prosecuted in New Mexico, upon the southwestern slope of the Sierra Nevada in California, in southwestern Oregon, and in the mountain region of Montana.

It has been noted in former reports that in the improvement of methods of work there has been a constant tendency toward graphic methods. During the past year a long step forward in this direction has been made in devising and introducing into general use a plane table suitable for traverse work, by means of which the topographer is relieved of the labor of platting traverses whether in field or in office, while at the same time he has a correct skeleton upon which to sketch. An improved quality of work is a conspicuous result.

The engraving of the maps has gone forward during the year about as rapidly as they have been prepared. At the date of the last report 166 sheets had been engraved. This number has now been increased by 83. The contract for engraving 100 sheets made with Messrs. Bien & Co. during the previous year has been completed, while during the past year contracts have been made by the Public Printer with Messrs. Sinclair & Son for engraving 100 sheets, with Mr. H. C. Evans for engraving 30 sheets, and with Messrs. Harris & Son for engraving 21 sheets. Altogether contracts for engraving 151 sheets have been made during the past year, and under these contracts 29 sheets have been engraved. Detailed information concerning all the atlas sheets published up to date will be found in a table accompanying Mr. Gannett's report. The following table shows in summary form the number, distribution and areas of the sheets thus far engraved, grouped by States:

Table showing number, distribution, etc., of the atlas sheets engraved to June 30, 1889.

State.	Wholly within State.	Partly within State.	Scale.	Contour interval.	Approximate area.
				Feet.	*Sq. miles.*
Alabama	8	3	1 : 125,000	100	9,200
Arizona	14	2	1 : 250,000	200 and 250	58,000
California	8	1	1 : 125,000 1 : 250,000	100 and 200	25,000
Colorado	2	....	1 : 62,500	100	450
Connecticut	....	5	1 : 62,500	20	130
District of Columbia	....	2	1 : 62,500	20	70
Georgia	3	4	1 : 125,000	100	5,800
Kansas	23	5	1 : 125,000	50	27,000
Kentucky	1	6	1 : 125,000	100	4,300
Maryland	....	6	1 : 62,500 1 : 125,000	20,50 and 100	1,100
Massachusetts	25	11	1 : 62,500	20	7,650
Missouri	17	5	1 : 125,000	50	18,000
Montana	4	....	1 : 250,000	200	13,300
Nevada	4	3	1 : 250,000	200 and 250	23,500
New Hampshire	....	3	1 : 62,500	20	130
New Jersey	22	....	1 : 62,500	10 and 20	5,000
New Mexico	4	....	1 : 250,000	200	16,000
North Carolina	2	9	1 : 125,000	100	5,000
Oregon	1	....	1 : 250,000	200	3,500
Rhode Island	2	3	1 : 62,500	20	700
South Carolina	1	1	1 : 125,000	100	1,200
Tennessee	6	12	1 : 125,000	100	11,600
Texas	18	....	1 : 125,000	50	18,000
Utah	17	1	1 : 250,000	250	65,000
Virginia	5	21	1 : 62,500 1 : 125,000	20, 50 and 100	14,700
West Virginia	4	11	1 : 125,000	100	10,000
Wisconsin	1	....	1 : 62,500	20	225
Wyoming	....	2	1 : 125,000	100	600
Yellowstone National Park	2	2	1 : 125,000	100	3,000

PROGRESS IN GEOLOGIC WORK.

WORK IN GEOLOGIC CORRELATION.

The institution of a Division of Geologic Correlation has already been noted, and the work accomplished by the division is set forth in detail in the accompanying administrative report of the geologist in charge, Mr. G. K. Gilbert.

In geology, as in other branches of science, growth of knowledge is accompanied by differentiation of ideas and specialization of labor: so the subordinate branches of paleontology, petrography, mineralogy and physiography have sprung from the main stem of geology. Moreover, the subordinate branches themselves have sometimes been subdivided into many minor branches. Thus paleontology has been subdivided into the science of fossil plants and the science of fossil animals; the science of fossil animals has been again divided into the science of fossil vertebrates and the science of fossil invertebrates, and a branch of the latter is the science of fossil insects; and still further, the subject matter of paleontology is classified by the remoteness of the period represented by the fossils into Cenozoic paleontology, Mesozoic paleontology and Paleozoic paleontology. So definite is this differentiation of a single branch of geology that nearly all students of the science have become specialists, and nearly all the valuable work in paleontology is done by specialists. The specialization is logical and necessary, and it is fully recognized in the organization of the Geological Survey as set forth at length in the Seventh Annual Report.

There is a parallel specialization in the purely geologic work, though the limits of the divisions of the subject matter and the definitions of the specialties are generally less trenchant than in paleontology. The primary division is determined proximately by the characters of the rocks studied, and ultimately by the agencies or processes to which these rocks owe their origin; so there are special students of the ancient crystalline or archean rocks, of the sedimentary rocks, of the rocks of volcanic origin, of the glacial deposits, of the metamorphic rocks produced by alteration of several primary kinds, of the mineral deposits and accumulations formed within various rocks, and of the soils and subsoils derived from all rocks; and, as in paleontology, there is with respect to some of these subjects a further classification by the period during which the rocks were formed. Thus the sedimentary or clastic rocks, which are by far the most extensive and economically important, are grouped chronologically; most students confine their studies as far as practicable to single groups, and the best work upon the groups of rocks is generally done by such specialists. This differentiation of labor among geologists is fully recognized in the organization of the Survey; but since each clastic group is distributed over a considerable part of the country, and since in nearly all parts of the country it is intimately associated with other groups, it has been deemed expedient to organize the geologic work primarily by geologic provinces and only secondarily by geologic groups; yet within every geologic division the desirability of assigning to specialists in a given group of rocks any necessary investigation of that group is fully recognized and provided for as far as seems feasible in each case. The practical working and beneficial results of this policy are incidentally shown in the administrative reports of the various officers of the Geological Survey.

The differentiation of thought and specialization of labor in geology were fully recognized in instituting the Division of Geologic Correlation and in inaugurating its work; and accordingly the greater part of the work of the division is performed by specialists eminent in their various departments and particularly competent to deal with the comparatively restricted though profound subjects severally assigned to them. In general these subjects are geologic groups or systems, and each specialist is directed to prepare an essay on the group or system assigned to him, as set forth in Mr. Gilbert's report. The general purpose of the essay is threefold: (1) To exhibit in a summary way the present state of knowledge of North American geologic systems; (2) To formulate the principles of geologic correlation and taxonomy; (3) To set forth from the American standpoint the possibility or impossibility of using in all countries the same set of names for stratigraphic divisions smaller than these systems. In addition to these essays on geologic groups, provision has been made for certain more general treatises prepared upon different bases.

The assignment of the work is as follows:

Pleistocene: T. C. Chamberlin.
Neocene: William H. Dall.
Eocene: W. B. Clark.
Cretaceous: [including the Laramie] C. A. White.
Jura-Trias: I. C. Russell.
Carboniferous: } H. S. Williams.
Devonian: }
Silurian: } C. D. Walcott.
Cambrian: }
Algonkian: } C. R. Van Hise.
Archean: }
Correlation by Vertebrate Paleontology: O. C. Marsh.
Correlation by Paleobotany: Lester F. Ward.
Resumé of North American Stratigraphy: W. J. McGee.
Discussion of Principles of Correlation: G. K. Gilbert.

The essays on the Cretaceous, the Jura-Trias and the Carboniferous and Devonian are well advanced and portions of the manuscripts completed; the preliminary study of the Silurian and Cambrian is completed with respect to the latter system, and a memoir embracing a portion of its results forms one of the accompanying papers of this volume; and, as will be seen from the reports of the various specialists, substantial progress has been made in the preparation of the other essays.

Several problems which the Division of Geologic Correlation was instituted to investigate and several other problems of immediate consequence to the Geological Survey were discussed at length during a convention of geologists held in the office of the Survey early in the present year. An abstract of the results reached in this convention appears on another page.

WORK IN ARCHEAN GEOLOGY.

The field occupied by the Division of Archean Geology and the methods and purposes of the work were set forth in detail in the Seventh Annual Report, and the progress of the work has been shown in subsequent reports. Prof. Raphael Pumpelly, with other students of New England geology, has long believed that the Green Mountain range contained a key to the structure of a considerable part of New England; but in this range, as elsewhere in that region of protean and complicated rocks, the structural relations are obscure; protracted study has been required to classify the various rocks and to ascertain their structural relations; and although the subject is of great difficulty it is gratifying to state that a solution has been reached.

From Prof. Pumpelly's report it may be seen that the Green Mountains consist of a long range of compressed folds overturned to the West in such manner that nearly all bedding planes dip eastward, the axes of these folds extending in the same general direction as those of the Appalachian mountain system, or north-northeast. The folded formations comprise in the natural order (1) hydro-mica schist, sometimes albitic; (2) another series of hydro-mica schists, sometimes replaced by limestone; (3) an albitic hydro-mica schist; (4) a garnetiferous hydro-mica schist replaced by limestone on the west side of the range; (5) a quartzite conglomerate, yielding Olenellus on the west side of the range and becoming gneissoid on the east; (6) granitoid gneiss; (7) chondroditic limestone; and (8) coarse biotite gneiss. Of these formations numbers 1 to 5 are essentially detrital throughout and evidently represent metamorphosed sediments, while numbers 6 to 8 show no trace of clastic origin and seem to be pre-Cambrian crystallines. The former are sometimes fossiliferous on the west flanks of the range, and still farther westward pass into the Cambrian formations of the Taconic range recently investigated and satisfactorily defined by Mr. Walcott, while the latter correspond with the holocrystalline rocks of central New England, long regarded as Archean. Between the two series there appears to be considerable unconformity, probably representing an important time break; and above that unconformity there is progressive alteration of the evidently detrital series from the little metamorphosed slates and limestones of the West to the greatly metamorphosed garnetiferous hydro-mica schists and quartzite-gneisses of the East. In short, the Green Mountains represent a range of closely appressed and overturned folds with a pre-Cambrian crystalline core (generally hidden), and a surface made up of rocks apparently representing the Silurian from the Hudson river downward and the whole of the Cambrian as represented in eastern New York.

Substantial progress has also been made in determining the areal geology of western Massachusetts. Berkshire, Franklin, Hampshire, Hampden, and the west half of Worcester Counties are nearly or quite finished, and thus the areal geology of about one-half the State of Massachusetts is now mapped. The work has also been extended into Vermont, and a considerable area within that State is ready for final mapping as soon as topographic bases are available.

Detailed lithologic studies of the rocks of the Green Mountains and western Massachusetts generally have been made in this division, largely by Mr. J. E. Wolff; and the results of these studies, which promise to afford a guide to the lithology of New England as satisfactory as the structural key found in the Green Mountains, are ready for publication.

WORK ON THE ATLANTIC COAST.

The investigation of the coast marshes and inundated lands, together with the associated lowlands and the deposits of phosphates, iron ores, etc., which they sometimes contain, and also the lands adjacent to the coast submerged during recent geologic times, which was assigned to Prof. N. S. Shaler some years ago, continues to yield valuable results.

During the year an extended study has been made of the district in eastern Virginia and North Carolina including the Dismal Swamp. As its name implies, this district was in early days regarded as one of the most inhospitable and forbidding in the land. In recent years steps have been taken toward draining and reclaiming the central morass, and thus converting it into fields fertilized naturally by the vegetal débris accumulated during many centuries. A part of the work of reclamation was inspired by Prof. Shaler and conducted in accordance with his suggestions, and already a considerable part of the once impenetrable morass is under agricultural control, while all parts promise to be soon transformed into a teeming garden of vegetables and small fruits. The methods of reclamation devised and tested in the Dismal Swamp are being gradually extended to other swamp tracts which have been worthless in the past, but which will assuredly become practically inexhaustible sources of wealth at no distant day. A detailed report upon the Dismal Swamp, prepared by Prof. Shaler, will be found elsewhere in this volume.

A part of Prof. Shaler's work related to the eastern shore of Florida, and led to a discovery of immediate scientific and ultimate economic importance. It is found that the reefs of living coral characteristic of tropical islands and shores do not, as previously supposed, terminate at Cape Florida, but extend many miles farther north. The coral reef, indeed, dwindles in size and diminishes in extent on the coast of Florida, but it is practically continuous to a point ten or twelve miles north of Jupiter Inlet. The observation bears upon the origin of certain formations of Florida not clearly exposed to view. It forms a datum plane for a comparison of the modern fauna of the Floridian peninsula with the extinct fauna whose remains are entombed in the Neocene and Eocene formations. Moreover, the determination of the boundaries of the tropical zone of the earth, as indicated by the habitat of marine organisms, suggests important possibilities in the way of introducing tropical land plants and animals barred from that part of their normal zone by broad seas; for during later geologic times the Floridian peninsula has grown southward from the temperate zone into the tropics. The marine life of the tropics become fixed upon it, but the luxuriant flora and rich fauna of the tropics await the aid of man to bridge the Caribbean, the Gulf and the Straits of Florida and extend their crowded habitat.

Another part of Prof. Shaler's work has lain in New England, and appertained to superficial deposits. During the year he has mapped the morasses and most of the superficial deposits included within fifty-six atlas sheets, covering the greater part of Massachusetts and extending into Rhode Island and New Hampshire, the maps being designed to represent the conditions of subterranean water rather than the agricultural capabilities of the soil itself. The details of the work are set forth in the accompanying administrative report.

One of the results is of special interest to students of glacial geology. In investigating the present and past geographic configuration of New England Prof. Shaler has found that in general there is a progressive increase in rearranged dritf material and a progressive decrease in unmodified drift from the Berkshire hills to the seaboard, suggesting considerable submergence of the land during the ice invasion and rapid emergence following the retreat of the ice; but, at the same time, evidence has been obtained to show that in the course of the glacial work the drift material has repeatedly passed from the stratified condition to the unstratified condition of unmodified glacial deposits. In addition, numerous obscure moraines have been discovered in the interior of Massachusetts far within the great terminal moraine forming the crest of Long Island; marine benches have been detected at altitudes reaching 180 to 200 feet above present sea level; it has been found that the peculiar structures at first called lenticular hills, but now known as drumlins, grade insensibly into ordinary sheet till; a series of early Pleistocene deposits called the Naushon formation has been found beneath the drift in eastern Massachusetts, extending from Massachusetts Bay to Martha's Vineyard, and it has been ascertained that the promontory of Cape Cod, from Wellfleet westward, is not simply a bar or spit as commonly supposed, but is the remnant of a considerable watershed carved in Tertiary or Cretaceous strata before the first advent of the Pleistocene ice sheet.

WORK IN THE APPALACHIAN REGION.

Ever since its inception two objects have been kept in view in the geologic survey of the Appalachian region: (1) The exact definition of the formations of the region; and (2) the determination of the areal and structural relations of these formations. With the first of these objects chiefly in view, Mr. Gilbert commenced the construction of three distinct sections through the region as described in previous reports; and as these sections approached completion and the formations intersected by each became known the second object came into prominence, and the surveys were extended northward and southward from the lines of sections for the purpose of ascertaining the extent and areal relations of the various formations. The results of this work, particularly those attained during the fiscal year, are of great interest; and they are especially timely in view of their bearing upon the general problem of geologic correlation.

Among the first fruits of the State survey was the discovery that the rocks exposed in New York fall into a certain series of limestones, shales and sandstones, and that the rocks exposed in parts of Pennsylvania fall into a closely coincident series; and as investigations were carried from State to State it was found that the rocks of the eastern half of the country generally represent more or less closely the same coincident series, and that the fossils characteristic of a formation in one State are frequently found in the corresponding formations of other States. So the rocks and fossils of the eastern United States were reduced to a simple series, the key of which was found in New York, every considerable New York formation being supposed to be represented with little change in other States hundreds or thousands of miles away, and every formation of distant States being assumed to be necessarily equivalent to some formation of the New York series. But with the refinement of methods and with the extension of surveys into new regions, particularly when the surveys were undertaken by a Federal organization and were no longer limited by State boundaries, it became evident that the succession of rocks in each State is measurably independent, and that no succession in any State even approximately duplicates the succession in any other State. Moreover it was found that, even within the limits of a State, formations vary from place to place, limestones passing into shales, shales into sandstones, and sometimes sandstones into limestones. It was also found that the fossils do not represent everywhere constant and consistent chronologic succession, but that in a measure the fauna varies with the character of the rocks in which its remains are embedded.

The inconstancy in character and succession of the rock formations is well illustrated by the three sections traversing the Appalachian region. The thickness of strata deposited in Virginia is much greater than that in Alabama; the changes in character of the sediment are much more frequent in Virginia than in Alabama; and the passage from the longer Virginia column to the shorter one of Alabama is traced through a great number of stratigraphic variations. It is evident from a study of these sections, indeed, that the Paleozoic ocean in which the various systems were laid down suffered local changes in depth and in direction and force of currents from time to time; and that in consequence shoal water deposits, littoral deposits and deep sea deposits alternated and interdigitated in a great complex of lenses of every grade of lithologic character from pure limestones through argillaceous limestones, shales and sandstones to conglomerate. Accordingly the geologists of the Appalachian region, instead of extending exact correlation from State to State and province to province, have been compelled to define and map formations as local masses, varying sometimes from atlas sheet to atlas sheet.

Ever since the infancy of American geology the Appalachian region has been regarded as one of the most interesting mountain provinces in the world by reason of the great length and symmetry of the corrugations of the strata to which the mountains owe their existence. The treatises of the Rogers Brothers on Appalachian structure are classic, and although the investigations of Appalachian structure hitherto made are far less complete than those of some other mountain provinces, they have probably contributed as much to current knowledge of orogeny as any others. The observations of Mr. Bailey Willis and his collaborators have thrown much light upon the origin of these mountains; but with the view of supplementing his observations and corroborating his inferences Mr. Willis has undertaken a series of experiments, in the course of which he has been able to imitate in miniature the structure of the Appalachian Mountains by subjecting layers of plastic material to lateral thrust. These experiments fall into line with those of Daubrée and Favre in France and Cadell in Scotland.

WORK IN THE LAKE SUPERIOR DIVISION.

During the year an important monograph on the Penokee iron-bearing series, projected and partly written by the late Prof. Irving, was completed by Prof. Van Hise, and is now in press. This monograph represents a good share of the practical results of work by Profs. Irving and Van Hise and their collaborators, extending over several years; the details of the progress of this work have been set forth from time to time in successive annual reports, and its outcome constitutes perhaps the most elaborate treatise ever prepared in this country upon the origin, structural relation and technology of a rich iron region. Inspection of the monograph will show that all of the ore bodies thus far exploited have been carefully studied and their relations to the general geologic structure surveyed and mapped with high exactitude; that a large number of ore prospects not yet exploited have been surveyed and mapped, and that the structural relations and genesis of the ores have been ascertained and set forth in such manner as to guide prospectors and investors in further exploitation throughout the entire iron-bearing region. A summary of this monograph forms one of the Accompanying Papers of this volume.

The determination of the volume and value of the Lake Superior iron ores was rendered possible only by an extended yet detailed study of the geologic structure of a large area about the south and west shores of Lake Superior in northern Michigan and Wisconsin and northeastern Minnesota. The rocks of this region are of great diversity and the structure complex; many geologists have visited the region and examined the formations, and an enormous literature has grown out of their work; but by reason of the diversity in the rocks and the complexity in structure there was until recently great variety of opinion concerning the place of the rock series in the geologic column, and portions of the strata have been referred to different parts of the Silurian and Cambrian and even to the Jura-Trias. But the detailed surveys which resulted in the determination of the origin, character and distribution of the iron ores led also to the discovery that a large part of these rocks belong to a great system representing a considerable fraction of the geologic column and a vast period of geologic time not previously recognized in any part of the world. This series of rocks lies beneath the Cambrian and above the Archean, and represents a period of the earth's history during which lowly forms of life doubtless existed, but left few definite traces of their existence in the form of fossils. The necessity for the discrimination of this rock series from the previously known geologic column and for the admission of the period in geologic chronology was recognized by Profs. Irving and Chamberlin some years since, and a treatise on the subject by the former of these geologists appeared in the Seventh Annual Report. The name "Agnotozoic" was there given to these rocks, being designed as one of the greater terms of geologic classification, coordinate with Paleozoic, Mesozoic and Cenozoic. In the geologic atlas of the United States such larger classification will not be employed, but the largest time unit recognized will be the period. At a recent conference of geologists, an account of which appears in another part of this report, it was decided to make but one period of the Agnotozoic, and the name "Algonkian" was chosen to designate that period. It is not proposed to cancel the name Agnotozoic, but to leave its use to students having occasion to employ terms of higher classification.

Another of the four leading iron regions of the country is that around Iron Mountain, Missouri; and during the year the operations of the division have been extended also into this region. Thus far the work amounts to little more than a preliminary reconnaissance, which, although little productive of economic results, is essential to the guidance of further work, and has indeed already brought forth fruits of importance to scientific students. The details of this work, which was executed by Prof. Haworth, are recited in the accompanying administrative report of the division.

As will appear from Prof. Van Hise's report, the operations of the division during the year have extended over a wide area in northeastern Minnesota, a considerable area in northern Michigan and Wisconsin and a lesser area in eastern central Minnesota. Data for mapping the geology of a large area as soon as the topographic surveys now under way yield the necessary maps, were secured in the three States.

WORK IN GLACIAL GEOLOGY.

For several years the energies of this division have been directed chiefly to the collection of data through field work; but during the past year the principal work, under the direction of Prof. T. C. Chamberlin, the chief of the division, has been the digestion of this material and the preparation of final reports upon the various lines of study.

The voluminous data relating to Lake Agassiz—a water body confined between the Mississippi-Red River divide and the southern edge of the retreating ice sheet in the Red River Valley—have been reduced to system and elaborated by comparison with the recorded glacial phenomena of all parts of the world, and the writing of the final report on this subject has been begun. The author of the report, Mr. Warren Upham, collected a large number of elevations of the northern border region in the progress of his work, which have now served their primary purpose in the study of Lake Agassiz; but in order that they may be of further service, primarily in prospective topographic surveys of Minnesota and Dakota and incidentally for other economic and scientific uses, they have been correlated, reduced and tabulated for publication as a bulletin.

The data relating to the glacial gravels of Maine, collected and digested by Prof. George H. Stone, have been placed in form for publication; Mr. J. M. Buell completed his study of the bowlder trains of southern central Wisconsin, and spent the greater part of the year in working up the data relating to these phenomena for final publication; Mr. Frank Leverett continued his work upon the lateral and terminal moraines and the compound drift sheets in eastern central Illinois and contiguous parts of Indiana during a part of the year, but a greater part of his time was spent in elaborating results of earlier observations, and deducing, testing and applying methods for the graphic illustration of glacial surfaces; and during a part of the year Prof. R. D. Salisbury has been employed in studies of glacial and aqueo-glacial deposits in southern Illinois, Missouri, Tennessee and Arkansas, required for purposes of general correlation of previous studies.

As an illustration of the excellence of the methods developed in this division it is proper to mention certain results attained by one of its members in another country while temporarily disconnected from the Geological Survey. After spending several years in investigating the glacial phenomena of the northern United States under Prof. Chamberlin's direction, Prof. R. D. Salisbury spent most of last summer in Germany, partly in University study and partly in amateur work. During some of his field excursions his trained eye and skilled powers of discrimination enabled him to detect a system of terminal moraines analogous to those recognized by a score of American geologists in different parts of this country, but unlike anything previously discriminated by German geologists. The discovery attracted immediate and widespread interest; and the initial observations of the American geologist have already been repeated, verified and extended by local students; and the introduction of American methods developed in the Geological Survey has already materially modified glacial geology in northern Europe.

Other results of the work of the division may be found in the accompanying administrative report of Prof. T. C. Chamberlin.

WORK IN MONTANA.

In the early days of geologic exploration in the western Territories, as in the beginnings of geology in the Mississippi Valley, paleontology was supposed to afford all necessary criteria for the classification and correlation of the formations of the country; and accordingly in this region, as in the Mississippi Valley and in the southern Appalachians, the original definitions of the formations were made to coincide with those of the east, and the formations themselves were correlated strictly with those of the classic New York series. But with more refined surveys it was found that the succession of rock masses and the succession of faunas are measurably diverse east and west; and here, as in the Appalachian region, it was found necessary to commence the construction of local key sections based entirely upon the local stratigraphy and paleontology. One of these key sections, which promises to unlock the structure of the northern Rocky Mountain system, is that of central Montana. Upon this section Dr. A. C. Peale has been at work for some years, as indicated in previous reports. As shown in detail in the accompanying administrative report, he has now finished the construction of the Paleozoic section extending from the Carboniferous to the Algonkian; and, as has been for some time anticipated, he finds every formation distinctive. At the same time, the fauna characterizing each great series of rocks is sufficiently related to the local faunas of other parts of the country to warrant him in referring all but one of these formations to the well recognized geologic systems. This hybrid formation—the Three Forks limestone—contains representatives of characteristic Devonian and Silurian faunas in approximately equal numbers, and graduates both stratigraphically and paleontologically into the well defined Devonian shales overlying.

The areal geology of the northern half of the Three Forks atlas sheet, including the newer sedimentary and volcanic as well as the Paleozoic formations, has been mapped; much progress has been made in the construction of the newer as well as the older part of the Montana geologic column; substantial contributions have already been made to the volcanic history of the region; and with the new vantage ground afforded by the researches of the field seasons of 1888 and earlier years, exceptionally rapid progress has been made in the early part of the present field season. The details of the work are set forth at length in Dr. Peale's report.

WORK IN YELLOWSTONE PARK.

As indicated in the administrative report of Mr. Arnold Hague, the field season of 1888, in the picturesque National Park on the Yellowstone, was an exceptionally successful one, whether measured by quantity or quality of the data placed upon record. The field work included a continuation of the series of observations on the behavior of the geysers described in previous reports; a careful study of a great geyser, which, after years of inactivity, suddenly and unexpectedly broke out afresh; the continuation of the survey of the Absaroka range which bounds the Park on the east; the preparation of a geologic map of the region; the continued study of the petrography of the rocks of the Park; and several subordinate investigations, the details of which are recited by Mr. Hague.

Observations on the behavior of the Park geysers have now extended over a series of years, and they have been given such a quantitative character as to render possible the detection of important changes in the distribution or amount of thermal activity. Various irregularities have thus been detected, but the most noteworthy change has occurred during the year. The Excelsior geyser, after lying dormant for nearly six years, has burst into renewed activity, and sends forth wonderful eruptions, reaching many thousand barrels of thermal water, at intervals of about an hour and a half; and concurrently with the resurrection of the long dormant great geyser, several hot springs and small streams of the Middle Basin ceased to flow, the Excelsior apparently draining the southern end of the Basin. Several smaller geysers have recently broken out in the Upper Basin, but without observed extinction of smaller springs, thus indicating rather an increase than a diminution of the aggregate discharge. So on the whole it appears that the discharge of the geysers has increased during the year, and thus that the energy of geyser action in the picturesque National Park is waxing rather than waning. Most of the observations upon geyser action have been made by Mr. W. H. Weed under Mr. Hague's direction.

An interesting demonstration of the excellence of the methods pursued in the Yellowstone National Park Division, and indeed of the certainty of scientific reasoning in general, has been recently made. As set forth in previous reports, and particularly in a bulletin emanating from this division (Bull. No. 47, Analyses of waters of the Yellowstone National Park, by F. A. Gooch and J. A. Whitfield), the geyser waters have been analyzed and found to carry arsenic and sulphuretted hydrogen in greater or less quantities; and Mr. Hague at once inferred that sulphide of arsenic must necessarily be deposited under favorable conditions in vents and chambers of some of the hot springs and solfataras. Accordingly diligent search was made for such sulphides; and after repeated failure this search was at last rewarded by the discovery in the Norris Basin of two sulphides. Both orpiment, the yellow sulphide (61 per cent. arsenic) and realgar, the brilliant red sulphide (70 per cent. arsenic) were found coating silicious sinter in narrow fissures.

The topographic maps of the Yellowstone National Park having been completed several months since, the areal geology has been ascertained and depicted in detail, and the maps are practically ready for publication.

For several years the Director, in the brief intervals during which the administrative work of the Survey is sometimes interrupted in summer, has been engaged upon a study of the Tewan Mountains of New Mexico. During the summer of 1887 an interesting suite of volcanic rocks, comprising certain basalts containing porphyritic grains of quartz, were collected; and during the year, Mr. J. P. Iddings, of the Yellowstone National Park Division, subjected these specimens to careful examination, and has thereby been able to throw new light on the conditions of the mineral origin of lavas. The quartz grains in the basalts appear to be primary crystallizations from the original molten magma and exhibit no definite relation to its chemic composition. Their production is accordingly to be referred to antecedent conditions of the magma; and from analogy with the occurrence of iron olivine in rhyolitic obsidian, it seems probable that the segregation of the quartz took place under the influence of water when subjected to great pressure at considerable depths beneath the surface.

WORK IN COLORADO.

The energies of the Rocky Mountain Division have been directed largely toward the digestion of data collected during previous years, and the preparation of material for publication. Work upon the two monographs mentioned in the last report—i. e., on the Ten Mile and Silver Cliff mining districts, and on the Denver Basin region—has been pushed forward. The former is now nearly completed, and the latter practically finished; but in view of the extension of the irrigation surveys into the region, it has been deemed wise to postpone publication until the new topographic maps growing out of these surveys are available as bases for the necessary geologic maps. These monographs, like other special treatises on mines and mining published by the Geological Survey, are made as nearly as practicable exhaustive, and it is believed that they will prove valuable to the rich mining districts to which they relate.

In Colorado, as in California and the Lake Superior region, the development of the mineral resources is rendered possible only by detailed studies of rock composition and structure, and these studies directly advance geologic science One of the purely scientific discoveries of the year made by the geolgists of this division is that of a distinctive formation found only in the vicinity of Denver and named after that city, which is not only so thoroughly unique in composition, structure and age as to be incapable of correlation with any other known formation, but it is made up almost exclusively of materials of unknown source. These materials are indeed known to be of volcanic origin; but no trace of the volcano whence they came or of the great lava sheet from which they must have been immediately derived has been found, and none of the materials have been found in other formations. The Denver formation is thus a strictly local unit, and must retain its local and distinctive name, whatever conclusions may be reached in regard to its correlation.

Another interesting discovery of the year is that of the distinctive superficial deposit known as loess in southern Colorado. It is this deposit which supports the vineyards of the Rhine, the grain fields of southern Russia, the orchards of Nebraska, and the rich corn fields of the central States; its porous materials retain moisture and resist drought better than those of any other deposit; and its recognition in the plains and foothills toward the base of the Rockies will encourage agriculture and related industries. To the scientific student the discovery is of equal interest; for it enables him to make progress in correlating the hitherto obscure Pleistocene deposits of the Plains with glacial and aqueo-glacial formations of the Mississippi Valley and eastern United States

The details of the work of the division are set forth in Mr. S. F. Emmons's administrative report.

WORK IN CALIFORNIA

The progress of work upon the quicksilver deposits of the Pacific slope has been noted from year to year in previous reports; and the assembling of the results of this long continued investigation for publication in the form of a monograph was mentioned in the last report. The manuscript went to press during the last fiscal year, and the early part of the present year was spent by Mr. George F. Becker, the chief of the division, in revising proofs. The work has recently appeared as Monograph XIII of the Geological Survey series. Quicksilver is a rather rare mineral, generally occurring in small quantities, and it is found in commercial quantities only in very few localities. The subjects of quicksilver mines and mining, and of the geology of quicksilver, are thus well adapted to monographic treatment. It has been the aim in the preparation of this monograph to treat these subjects exhaustively from the standpoint of the geologist and mining engineer; and it is believed that Mr. Becker's monograph is one of the most complete treatises upon a special subject in mining geology that has ever been published

The greater part of the year was spent in surveys of the Gold Belt; and as will be seen from an accompanying administrative report half of the auriferous region has been geologically mapped in a tentative way and much work has been done in determining the petrography and structure of the region with a view to discriminating the formations in such manner as to permit final mapping This study is rendered exceptionally laborious by reason of the diverse character of the rocks—granite of different ages, gabbros, peridotites, diorites, diabases, rhyolites and basalts occurring in great variety and invariable sequence; and many of these rocks have suffered metamorphism to such an extent as to greatly increase the difficulty of identification.

During the year careful attention has been given to the colossal domes which characterize the granitic portion of the Sierras, particularly throughout the Yosemite region—structural features that have puzzled explorers, geologists and tourists since the region was first visited. The various hypotheses thus far offered in explanation of the phenomena have been scrutinized and tested in the field and several have been found insufficient; but it would appear from Mr. Becker's study that the great granite domes are simply gigantic examples of exfoliation, similar, except in scale, to those often observed in basaltic and other terranes.

Attention has also been given to the much mooted question as to the existence of glaciers in the Yosemite during Pleistocene time; and in view of the great interest which this question has excited in the minds of geologists and laymen alike it is especially noteworthy that well preserved striæ and ice-polish have been found at different points about the walls of this unique and colossal canyon. It is also of interest to note that unmistakable evidences of local glaciation have been found in the Mineral King mining district on the headwaters of the Kaweah River at a much lower latitude than any locality previously known. Here, as elsewhere in the Sierras, the ice marking is wonderfully fresh. Although the streams are roaring torrents of high declivity, they have corraded but a few feet of rock since the glaciers disappeared.

WORK OF THE CASCADE DIVISION.

The work of the Division of Volcanic Geology, in charge of Capt. C. E. Dutton, was widely varied, and a large portion of it was intrusted by Captain Dutton to his principal assistant, Mr. J. S. Diller. At the beginning of the fiscal year Captain Dutton was transferred, as already stated, to the Irrigation Survey, and Mr. Diller was placed in charge of the division. The researches to which Captain Dutton had given his personal attention are completed, and the division now carries forward only those works that had previously occupied Mr. Diller. As the principal part consists in the mapping of the areal geology of a district, it has seemed proper to give the division a geographic title. It has accordingly been renamed the Cascade Division. The Petrographic Laboratory remains in charge of the division.

As explained in earlier reports, the Survey has been engaged for some years in the collection of a large number of identical suites of rock specimens to be deposited in the educational institutions of the country as standard series. From considerations of economy the work of collecting these rocks was at first distributed among the various geologic divisions so as to obtain as many typical varieties as possible without the necessity of making special journeys therefor. When a certain amount of progress had been made it became advantageous to give more concentrated attention to the work, and its completion was made one of the duties of the Petrographic Laboratory.

The field season of 1888 was spent by Mr Diller partly in the prosecution of areal work in the upper portion of the Sacramento basin, but more largely in visiting the widely scattered localities at which were to be obtained specimens of the rock types not already acquired for the educational collection. Nepheline-bearing eruptive rocks were obtained from the Crazy Mountains of Montana. Oregon yielded specimens illustrating spheroidal weathering, faulted pebbles and the rock species peridotite. Lavas were obtained from Mount Shasta and other points in northern California, from the Ice Spring Craters in Utah and from the Uinkaret Mountains in northern Arizona. In all twenty-six varieties of rocks and two hundred and fifty specimens of each variety were gathered during the season.

The work of the Petrographic Laboratory is described in detail in Mr. Diller's administrative report appended hereto. An account of the petrographic work of the Survey appears on a later page of the present report.

WORK OF THE POTOMAC DIVISION.

This division was instituted some years since for the purpose of investigating the geology of the District of Columbia. As the work progressed the field of the division was gradually extended up and down the Potomac River over the terranes found in the District but stretching beyond its limits, and then over the entire Coastal Plain of the Middle Atlantic slope. Moreover, under the exigencies of administration, other lines of research in different parts of the country were assigned to the division, as shown in the present and preceding reports. Thus the designation of the division scarcely indicates the scope of its work.

The chief work of the fiscal year was the completion of certain researches commenced several years ago upon a region of anomalous topographic configuration and unique Pleistocene structure in northeastern Iowa. This territory is a part of the vaguely defined region once designated the "Great Plains;" but its extreme eastern portion extends into the Driftless Area of Wisconsin, Iowa, Minnesota and Illinois, and so belongs rather to the rugged and forest covered tract bordering the Great Lakes than to the Plains region. The Pleistocene deposits of the territory comprise two sheets of glacial drift, an intercalated forest bed and a superposed bed of loess, the drift sheets coinciding approximately in area and the forest bed failing frequently, while the distribution of the loess is singular and in many ways noteworthy. The topography is equally singular and noteworthy over a considerable part of the territory. The most striking topographic feature is a broad ridge skirting the southwestern flank of the Driftless Area, and overlooking the low lying drift plain to the west and southwest by some hundreds of feet; but the rivers instead of flowing down the slopes of this ridge either run parallel to its axis or diverge towards it, and several have cleft its crest at right angles; and many of these rivers on their way towards the ridge or along its slopes diverge from lowlands and flow in narrow gorges through plateaus or in the axes of minor ridges extending towards the larger one. These singular phenomena have been exhaustively studied by the geologist in charge of the division, Mr. W. J. McGee, and their interpretation has thrown much light on the Pleistocene history of the upper Mississippi region.

In addition to the Iowa work, two other investigations were carried to completion within the year in the Mississippi Valley.

The first of these was the geologic survey of the Fort Riley Military Reservation in central Kansas, by Mr. Robert Hay. This survey was made in response to a request by the military authorities for special information concerning the local supply of building materials and other mineral products of value, and its results are now in press as a bulletin of the Survey. The other investigation was that of the Indiana rock gas field noted in the last report. This field is the most extensive thus far discovered; and the survey just completed has thrown much light on the origin and laws of distribution of the lighter bitumens. The results of this work are also in press as a bulletin.

The study of the Potomac, Columbia and Appomattox formations described in previous reports was continued in the District of Columbia, in eastern Virginia, western Maryland, and central North Carolina, and new data concerning all of them have been secured. The Potomac formation was defined as a distinct structural unit in accordance with the principles now governing the taxonomy adopted by the Geological Survey. The Columbia and the Appomattox formations were subsequently established in the same way. It has been found that this recognition of distinct structural units greatly facilitates the interpretation of geologic history; and accordingly during the past year the operations of the division have been extended into the Neocene and Eocene deposits of the Coastal Plain in Virginia and Maryland with the object of discriminating additional structural units, and thus gradually raveling the obscure geologic history of this region by a method which may be characterized as synthetic.

For convenience in administration, the study of the crystalline rocks of the Piedmont region in the Middle Atlantic slope, by Dr. George H. Williams, is carried on in this division. The territory to which attention has thus far been mainly devoted covers an area of about 1,700 square miles between Chesapeake Bay and the Potomac River on the east and the Catoctin Mountains on the west. Within this territory the rocks are mainly crystalline. Here, as in the territory in New England now under investigation by Prof. Pumpelly, the crystalline character varies: Towards the west the prevailing rocks are slates, little different from the unmetamorphosed Silurian slates of the Cumberland Valley, but to the east the crystalline character progressively increases, and the slates pass through various grades of phyllite, hydromica schists, mica schists and gneisses. But in this region the relief is lower than in New England, and in consequence the exposures are less numerous and extensive and the surface is more generally covered with products of rock decay and other superficial débris. Partly for these reasons it has not yet been ascertained to Dr. Williams's satisfaction whether the progressive increase in crystalline character eastward is due to progressive change in the same rock formation or whether the series represents a succession of formations either overlapping in normal sequence or juxtaposed by faulting. The outcome of this important investigation is anxiously awaited; for the entire problems of the geology of the Piedmont region, and of the relations of the Piedmont rocks to those of the Appalachian belt to the westward, appear to depend upon it. In addition to the study of these metamorphosed sediments, the special investigation of the volcanic and other highly crystalline rocks about Baltimore has been continued with satisfactory results. Among the volcanics a sequence of basic, ultra basic and acidic eruptions, following each other in accordance with the law formulated by Von Richthofen and corroborated by Dutton, has been made out. Some of these are older and others newer than the period of greatest crushing and metamorphism; and it would appear that they have themselves been active agents in producing the highly crystalline character of the altered sediment toward the east. The results of these investigations are set forth in greater detail in the accompanying administrative report.

One of the most difficult problems presented by American geology is that of the succession and distribution of the little disturbed formations flanking the south and east coasts, and forming the Coastal Plain of the United States from the Rio Grande to Long Island. Particularly difficult are those parts of the problem which relate to the Gulf slope on both sides of the Mississippi, to the Floridian peninsula and to the Southern Atlantic slope; for here the principal formations of the Coastal

Plain are generally buried beneath diverse and puzzling superficial deposits, and the surface is frequently mantled by forest. Moreover, the land lies low, the rivers are sluggish and the exposures are few; the Neocene and Eocene formations can be discriminated from the Pleistocene only with difficulty; deep water, littoral, and subaerial deposits blend in ever varying and confusing fashion; and, particularly in Florida, the ordinary mechanical agencies of geologic change are so sluggish as to be completely eclipsed by the little understood processes depending upon the extravasation of thermal waters and the operation of the organic acids set free by vegetal growth and decay and other chemic or chemico-mechanical agencies. Again, mineral accumulations occur with great frequency in the Neocene and Eocene formations, generally in sufficient volume only to excite speculative enterprise, though frequently in greater volume and value; and the authorities of States in which there are no geologic surveys, and in some cases the Federal authorities, have requested detailed examination of the real and pseudo mineral localities, and the energies of the geologist have accordingly been diverted from the more systematic study into channels promising immediate economic results to States or the Nation. For all of these reasons the progress of the survey of the Coastal Plain has been slow; yet results of great scientific and economic value have been secured by Mr. L. C. Johnson, the geologist to whom this branch of the work is intrusted. Some of these results have been published in bulletins of the Survey, and others are held for final coordination with the data accumulated in other branches.

Other details of the investigations of the division may be found in the accompanying administrative report.

PROGRESS IN PALEONTOLOGIC WORK.

WORK ON VERTEBRATE FOSSILS.

As shown in the Eighth Annual Report, the technical study of fossils, which finds its application in the identification, correlation and classification of the formations of the country required in the construction of geologic maps, must be carried on in the light afforded by a knowledge of the relations of their contained life. This principle is recognized in the organization of the work in invertebrate paleontology; and it is of equal importance in vertebrate paleontology and in paleobotany. There are but few students of these latter subjects, and the studies are comparatively recent; in general the founders of these branches of science are yet living and engaged in active work, and knowledge has not yet passed beyond that stage in which it carries the impress of individual genius and individual labor. Each of the few students of the subjects justly claims the right of the original investigator to interpret his own observations; in short, the standards and criteria of vertebrate paleontology and paleobotany are barely established, and none but students of the biotic relations of the fossils are competent to speak concerning the technic or utilitarian applications of vertebrate paleontology and paleobotany. Thus the work of the Geological Survey upon these lines is chiefly work of pure research, and is carried on mainly by eminent specialists.

During the year Prof. O. C. Marsh has continued his studies of vertebrate fossils and has made important additions to knowledge. One of the new discoveries is of special interest, and indeed materially enlarges previous conceptions concerning the succession of life upon the globe. The opinion, based upon the known laws of the origin and succession of animal forms, that mammalian life existed during the Cretaceous period, has long been held; yet hitherto no mammalian remains have ever been found within these rocks. But during the past year a fortunate discovery brought to light more than one hundred specimens of mammalian remains in Cretaceous strata in Wyoming, representing many individuals and several new genera and species. A number of the new genera show affinities with Jurassic and Triassic forms, and it is significant that the general facies is thus rather older than was anticipated. It is noteworthy that this horizon of mammals yields also remains of a new family of gigantic horned dinosaurs, which are by far the strangest of all the extravagant reptilian forms representing the life of the primeval world thus far known to science.

The details of the work of the division may be found in the administrative report submitted by Prof. Marsh.

In addition to the work on the higher vertebrates—chiefly mammalia and reptilia—conducted by Prof. Marsh, an investigation of the fossil fishes of the Mesozoic and Paleozoic rocks of the country has been carried on in the Geological Survey by Dr. J. S. Newberry. During the past year Dr. Newberry revised proofs of text and plates of a monograph on the fossil fishes and fossil plants of the Trias of New Jersey and the Connecticut Valley. This monograph has recently been published as the fourteenth in its series. He has also completed a monograph on the Paleozoic fishes of North America, the matter of which has been sent to press and a part of the proofs already received and revised. This monograph will appear within a few months as the sixteenth of the series.

Hitherto the fish fossils found in the rocks of the country have been studied in the biotic rather than in the technical aspect. A result of the study has been to vivify the history of the geologic past and people the seas with varied and wondrous forms of by-gone ages, and thus to enlarge and refine conceptions concerning the development of the earth and advance pure science. In the preparation of these monographs, however, it has been the aim to gather the scattered threads of testimony concerning fish life and weave them into a connected web, to set forth the relations between the various forms, and the formations in which they are imbedded, and thus to develop a basis for geologic classification by fish remains either in conjunction with other fossils or by themselves in case other fossils are not associated. It has long been recognized by students of paleontology that the different classes of fossils are chronometers of geologic time, but that their units of measure and their sensitiveness are unlike. The most sensitive chronometer is afforded by the highest vertebrate life, and the shortest periods may be measured by means of it. It appears from Dr. Newberry's researches, as was previously inferred on theoretic grounds, that the lower vertebrates afford a somewhat less sensitive chronometer, but one better adapted to the measurement of somewhat longer periods. A still less sensitive but more widely applicable chronometer is afforded by invertebrate animal life, and the prevailing geologic classifications are based upon it; and the least sensitive of all the time measures, but for that reason the most serviceable in certain respects, is afforded by plant life. It is the policy of the Geological Survey to make every investigation as thorough as the conditions of the investigation (including cost in time and money) will permit, and to recognize principles and accept classifications only in so far as they are consistent with the sum of knowledge derived from its own investigations and from all other sources. It is in accordance with this policy that constant efforts have been made to correlate the different time measures and thus to develop a time classification which shall be consistent with the several chronometers afforded by the various classes of fossils. The observance of this conservative principle sometimes results in delaying publication, but with this benefit: that the various lines of investigation pursued by different investigators are thereby brought into harmony and the validity or falsity of preliminary conclusions fully tested before final conclusions, frequently affecting great economic interests, are reached and put forth to the world.

For convenience in administration, Dr. Newberry's work is carried on in connection with the Division of Paleobotany. The details of his work will be found in connection with the administrative report of that division.

WORK IN PALEOBOTANY.

From the accompanying administrative report of Prof. Lester F. Ward, from the earlier accounts of the progress of the Survey, and from Prof. Ward's various official publications, it will be seen that in the organization of this division a practical reconstruction of the science of paleobotany was contemplated, and that all of the work of the division has been carried forward with this end in view. The commonly accepted geologic history of the earth, the division of the geologic column into groups or systems, and the classification of geologic time into periods, are all based primarily upon the evidence of invertebrates and secondarily upon that of vertebrates, and in only slight measure upon the evidence of plant fossils. It is true that with the growth of geology and the multiplication of students the remains of plants imbedded within the rocks received attention in many parts of the globe, and it is true that an extensive literature relating to plant fossils has grown up; but at the time of the organization of this division there was urgent need for coordinating the results of antecedent and current researches, reducing paleobotany to terms convertible into those of the older paleontology and systemizing this branch of science in such manner as to guide further investigation along lines leading toward the practical ends of utilitarian geology.

This task was undertaken by Prof. Ward. It involved a large amount of bibliographic and catalogue work, the collection of a large number of plant remains, the examination of all American collections, and the preparation of an immense series of illustrations of fossil plants for purposes of study as well as publication. The manner in which this work has been carried on and the results attained during the year are shown in Prof. Ward's report.

In the classification of plants into species, genera and higher groups, certain prominent characteristics are employed. In other respects the plants thereby discriminated may to casual observation appear similar, but close observation reveals differences in so many parts and of so many kinds that it is believed that any two plants which are properly separated as distinct are really different in all their parts. It is possible, therefore, to classify plants through their stems, leaves, fruits, roots, and through their minute internal structure. Heretofore classific work in the United States has taken account only of external form, ignoring external structure, and for some years Prof. Ward has desired to remedy this defect by instituting within the Survey the microscopic study of the fossil woods of the country. It was chiefly to this end that Mr. F. H. Knowlton was engaged as a member of this division, and, as elsewhere noted, the studies undertaken by him have already yielded valuable results.

The Potomac formation is poor in animal remains but in some localities wonderfully rich in plant fossils. These remains represent a specially interesting phase in the development of the plant life of the globe. They record the transition from the primitive or archaic flora to the predominantly dicotyledonous flora which has prevailed over most of the lands of the earth during half its geologic history. Prof. W. M. Fontaine, of the University of Virginia, who is connected with the division of paleobotany, has prepared monographs on the geology and on the fossil plants of this formation as developed in Virginia and Maryland. Both of these monographs are now in press. During the past year Prof. Fontaine continued his observations on the same formation southward into North Carolina and thence into the region of the Tuscaloosa formation of Alabama, provisionally correlated, through its structural relations, with the Potomac. Prof. Fontaine's account of the work is appended to Prof. Ward's administrative report.

Dr. Newberry has continued his work upon paleobotany during this year. A final revision for publication of his monograph on the fossil plants of the Cretaceous and Tertiary rocks of the Far West is well advanced; and a monograph on the flora of the Amboy clays of New Jersey, which is of special interest by reason of the abundance of new species, is also in progress. In completing the collections required for the preparation of these monographs Dr. Newberry has visited during the year at his own expense several localities in Colorado, and a number of plant localities and museums in England and on the Continent, thereby largely increasing his own material and extending his comparative studies. A study of a collection of plant fossils from the Devonian and Lower Carboniferous rocks of Ohio and Kentucky has been carried forward, and the illustrations and descriptions are nearly ready for publication as a bulletin.

WORK IN PALEOZOIC INVERTEBRATE PALEONTOLOGY.

The branch of science dealing with invertebrate fossils has been long established, and is now so well developed that these fossils can be used directly, after accurate identification, in correlating and classifying the rocks of the earth in the manner required for the construction of geologic maps. Accordingly, the operations of this division are largely confined to (1) the identification of fossils collected either by its own members or by other divisions of the Survey, and (2) the identification and correlation of formations in the field by the chief of the division, Mr. C. D. Walcott, and his principal collaborators. It was largely through Mr. Walcott's labors that the complex relations of the partly metamorphosed and greatly disturbed rocks of eastern New York and western New England were made out; and his careful identifications in the field afford a firm foundation for future surveys and geologic maps of that region. During the year his work was continued with good results—the most notable being the settlement of the long disputed question as to the relative ages of the Olenellus and Parodoxides zones of the Cambrian system.

Hitherto it has been held that the Olenellus zone overlay that of Parodoxides, and thus that the American succession was the reverse of that of Europe; but the work of last August developed the fact that the Olenellus horizon underlies the Parodoxides horizon.

A considerable part of the time of Mr. Walcott and his chief collaborator, Prof H. S. Williams, during the past year was spent in the preparation of essays designed for use in geologic correlation, in accordance with the plan set forth on an earlier page. An account of this work appears in the administrative report of the division; and some incidental results of part of it are represented in one of the accompanying papers included in this volume.

WORK IN MESOZOIC INVERTEBRATE PALEONTOLOGY.

This division remains in charge of Dr. C. A. White, and the work of the year has been carried forward in accordance with old plans, save that considerable energy has been directed toward the preparation of an essay designed for use in the work of geologic correlation.

One of the widest breaks in the geologic succession of the eastern United States is that between the Carboniferous and the Jura-Trias; and one of the most interesting geologic events of the year is the discovery that in Baylor, Archer and Wichita

Counties, in Texas, these groups of rocks are not definitely separable, and indeed that they intergraduate. The larger share of the fossils are of Paleozoic type, but some are of equally characteristic Mesozoic type. They are commingled in such manner as to leave no doubt that all are members of one and the same fauna, and the superior and unquestionably Mesozoic strata blend with and are conformable to the underlying Coal Measure series. It is of interest to note that a similar discovery has been made during the year in southern Kansas by Mr. Robert Hay, an attaché of the Survey connected with the Potomac Division.

The details of Dr. White's work are recorded in an accompanying administrative report.

WORK IN CENOZOIC INVERTEBRATE PALEONTOLOGY.

In this division, as in the last two, much work has been done upon geologic correlation during the year. In addition, field operations have been carried forward in Florida and in North Carolina; a large number of fossils have been identified for other collaborators of the Survey and for some other institutions and individuals; and much progress has been made in the work of preparing, identifying and labeling collections for storage in the National Museum in such manner as to be available for study. During the year 6,323 lots, including about 20,000 specimens, have been arranged on shelves in the National Museum and entered in the Museum catalogue.

The details of the work on various lines are set forth in the accompanying administrative report of Dr. W. H. Dall.

WORK ON FOSSIL INSECTS.

During the year Prof. Scudder has continued his study of fossil insects found in the various formations of the country. He has also continued field work among the Carboniferous strata of West Virginia, the Coal Measures of Alabama and the Tertiary strata of Florissant, Colorado, the most noted locality of fossil insects on the globe. A large number of specimens have been collected; many identifications have been made, some of new genera and species, and others of genera and species recognized for the first time in this country; the catalogue of fossil insects of the world, described in the last report, has been carried forward and nearly completed; and a number of illustrations and descriptions of Tertiary Carboniferous insects have been prepared.

PROGRESS IN ACCESSORY WORK.

WORK IN CHEMISTRY AND PHYSICS.

In this division Prof. F. W. Clarke has continued his researches upon the chemical structure of the silicates. These minerals include an enormous majority of all the rock-forming species, and together they constitute at least five-sixths of the earth's crust. The object of the investigation is to determine the laws governing their alterations and association, and so to shed some light upon the origin and metamorphoses of rock masses. The micas and serpentines have been the main objects of study during the year. Prof. Clarke has also done some work upon a partial recalculation of the atomic weights of the commoner chemic elements, and jointly with Mr. Charles Catlett, he has examined a remarkable nickel ore from the Algoma district in Canada. In that ore definite traces of platinum were found; and the discovery is specially noteworthy in view of the great promise of future value of this metal in the arts, and in view of the fact that its occurrence has never before been noted in a true metalliferous vein.

By the several assistant chemists the usual amount of routine analytic work required for other divisions of the Survey has been done, and several original and interesting investigations have been carried out. Dr. W. F. Hillebrand has studied a number of important mineralogic problems, especially in relation to the ores of the rarer metals; and Dr. T. M. Chatard has completed his long continued investigation upon the natural soda of Mono and Owen's Lakes. The latter research is one of great economic importance, for at present our alkalies are almost wholly imported from Europe.

In the Physical Laboratory, Dr. Carl Barus has made a series of elaborate investigations upon viscosity in solids, and has also studied the laws governing the deposition of fine sediments. He has further developed some of his methods for the measurement of extremely high temperatures, and has begun a systematic series of experiments upon the relations between melting and boiling points and pressure. All of this work is of the highest importance in its bearings upon the greater problems of dynamic geology. Dr. William Hallock, in the same laboratory, has continued his study of the expansion of rocks by heat, and is now engaged upon a determination of their linear coefficients. He has furthermore investigated certain cases of supposed chemic action between solids, and has shown that the phenomena so far observed are really due to the action of films of vapor.

At the branch laboratory in San Francisco Dr. W. H. Melville has studied the osmosis of liquids through septa of different materials, and the solubility of sulphides in many reagents under varying conditions of temperature and pressure, and has made some experiments upon the synthesis and decomposition of silicates. Many routine analyses were also completed.

WORK IN PETROGRAPHY.

Petrographic research, or the study of the composition and internal structure of rocks, began with the infancy of geology and has always been an inseparable adjunct to general geology or the study of the relations of rock masses. Within a few years great advances have been made in its methods, and it has steadily grown in importance until now it is coordinate with research in paleontology and in chemistry and physics, as an accessory to the stratigraphic, structural, and areal work of the Geological Survey. Partly from the manner of its development and partly from its intimate relation to general geology it has not been thoroughly differentiated in the personnel and organization of the Survey. The gentlemen who are engaged in petrographic studies are also engaged in general work as field geologists and carry the two forward in intimate conjunction.

The only part completely specialized and separated is the mechanical operation of preparing thin sections of rock for microscopic examination. This is one of the functions of the laboratory in charge of Mr J. S. Diller.

In each of the divisions of the Survey requiring a large amount of petrographic work, it is found advantageous to have it prosecuted by the same persons who pursue geology in the field, but it is not economical to follow this plan in the case of divisions requiring but a small amount of petrographic work, as the appliances for it are somewhat costly, and its methods require much special training. The work of such divisions is performed in the Petrographic Laboratory.

In this volume and in the earlier annual volumes most of the petrographic work has been mentioned in connection with that in geology to which it appertains, and the detailed descriptions of it are scattered through the various administrative reports. In order to exhibit its nature and extent, a brief account will here be given of its processes and of its progress and results.

PROCESSES.

The history of the origin of rocks is recorded in their external relations and in their internal constitution. It is the aim of petrographic study to discover that part of the history recorded in internal constitution. The elements of which rocks are composed, the mineral species in which these elements are combined, the arrangement of mineral grains to one another, and the physical structure of amorphous constituents—these make up the internal constitution of rocks. Much has long been known of the coarser grained rocks, but it is only within recent years that the structures of finer grained rocks have been successfully studied. The mineral grains of coarser rocks could readily be separated and subjected to chemic and other tests, and by close scrutiny the mutual relations of the grains could be discovered; but such methods could not be applied to rocks of finer texture.

Modern petrography has invented a method by which rocks of the finest grain can be separated into their constituent minerals. In this method advantage is taken of the fact that mineral species differ from one another in specific gravity. A rock to be examined is pulverized and the powder placed in a liquid of such density that the heavier minerals will sink through it while the lighter remain upon the top. By varying the density of the liquid and repeating the process each mineral constituent can be obtained separate from the others and can then be analyzed and otherwise studied.

A second modern method, and one of wider application, is that of the microscope. A flake of the rock to be studied is ground so thin as to be transparent. It is then viewed with the microscope by means of polarized light passing through from the opposite side, and the mineral grains are thus not only distinguished, but the character of each grain is determined. Each mineral is characterized by a special set of optical properties, and in virtue of these it modifies the transmitted light in ways leading to its identification. At the same time the manner in which the grains are aggregated is clearly seen.

ROCKS IN GENERAL.

The rocks of the earth may be classified according to genesis into three great groups: (1) Clastic or fragmental rocks, which originated in the deposition of sediments and form the greater portion of the known terranes of the earth's surface; (2) volcanic rocks resulting from the solidifiation of fused matter; and (3) ancient crystalline masses, such as those of the Archean, whose genesis, although not definitely known, may be essentially different from either of the other groups.

The first group has been carefully studied by geologists in the field, where the genesis of stratified formations is fully illustrated. It is the group which is wholly of surface origin, and the cycles of geologic changes which it chronicles are in the main well understood.

Of the second group, the members best known are those which have been effused upon the surface. The final stage of their development is open to inspection, but the source of the lavas and the earlier phenomena connected with the transference of the material to the surface can not be directly observed.

The circumstances attending the production of the rocks of the third group (deep within the earth or remote in time) can never be the object of direct scrutiny, and our knowledge of them must ever be based upon experimentation and a study of the finished, often wholly modified rocks themselves. It is probable that many or even all of the rocks now classed as members of this group may ultimately prove to be clastic or eruptive masses.

The crystalline rocks of all the groups are reservoirs of valuable metalliferous deposits, and they are the ones whose history it is most difficult to discover. It is evident, however, that the problems they present involve primarily the development of crystallization; and the microscope is now recognized as the most important means of investigating the evolution of crystalline masses.

VOLCANIC ROCKS.

The intimate relation between thermal action and metalliferous deposits gives importance to the study of heat products among geologic phenomena. Such products are best displayed in the volcanic fields of the great mountain belt lying between the valley of the Mississippi and the Pacific. A number of petrographers are engaged chiefly in studying such phenomena.

Rapid progress has been made in the investigation of volcanic rocks, and in considering the advances it is best to note them by rock groups separately, beginning with the most acid—the rhyolites.

The investigations of Messrs. Hague and Iddings among the volcanic rocks of the Great Basin have enabled them to successfully typify the varieties of rhyolite and propose the following classification, which in the main has been generally adopted.

- Rhyolites
  - Nevadite,
  - Liparite,
  - Lithoidal rhyolite,
  - Hyaline rhyolite.

Nevadite and liparite are the characteristic forms in Nevada, while lithoidal and hyaline rhyolite are better developed in the Yellowstone National Park, where they present certain remarkable peculiarities which Mr. Iddings has described in detail. At Obsidian Cliff the glassy lava is especially noteworthy on account of its columnar structure and lithoidal lamination and its abundance of spherolites and lithophysæ of great beauty and perfection. Excepting the columnar structure, these features appear to be of aqueo-igneous origin, and result from the action of absorbed vapors upon the molten glass during the process of crystallization consequent upon cooling.

The nevadite of Chalk Mountain, Colorado, described by Mr. Cross, is remarkable on account of the beautiful, lustrous sanidine crystals it contains, as well as those of topaz occurring in its small drusy cavities. Both topaz and garnet occur in the lithophysae of the rhyolite near Nathrop, Colo., while that of Silver Cliff, Colo., possesses special interest as the country rock of the famous silver-bearing deposits of that region. In structure and composition, both mineralogic and chemic, it is one of the simplest and most typical rocks of its kind.

A few years ago trachytes were supposed to be abundant in the western portion of the United States, but the investigations of Messrs. Hague and Iddings have shown that the rocks of the Great Basin formerly relegated to that group are really plagioclase rocks, and for a time the very existence of trachytes in this country was in doubt. The later studies of Mr. Cross, however, have definitely settled this question and have shown that in the vicinity of Rosita, Colorado, not only veritable rocks of this group, but also their deep seated equivalents, the syenites, are well exposed. The trachytes occur chiefly in the form of dikes, and in their simple structure and composition are closely related to trachytes of the Siebengebirge.

Concerning andesitic rocks, the first noteworthy contribution to knowledge by the Survey was made by Mr. Cross, in describing the hypersthene andesite of Buffalo Peak, Colorado, and recognizing the wide distribution and great importance of hypersthene as a constituent of modern lavas. Messrs. Hague and Iddings identified similar rocks in the Great Basin and among the lavas of several of the volcanoes of the Cascade Range. They discovered that the original nevadite of Richthofen, instead of being an orthoclase rock, as he supposed, is characterized by a predominance of plagioclase, and belongs to the dacites. These observations have been largely extended throughout the Cascade region by Mr. Diller, who, in mapping the region of Lassen Peak and the northern extremity of the Sierra Nevada, has found that although the andesitic and basaltic lavas predominate, rhyolitic forms are also represented.

The porphyries and porphyrites of the Leadville region, Colorado, are remarkable, according to Mr. Cross, for their evenly granular holocrystalline structure, and in one case for inclusions of pebble-like fragments of orthoclase. The valuable ore deposits of that region are derived at least in part from these rocks.

The most abundant of all the lavas of the Great West are basalts, and in a number of cases they present new and interesting forms. Messrs. Hague and Iddings, in describing some of the volcanic rocks of the Great Basin and elsewhere, called attention to the important role played by hypersthene in these rocks. Among the lavas of northern California and Oregon there are some basalts in which the prominence of hypersthene was deemed to be of sufficient importance, according to Mr. Diller, to characterize them as hypersthene basalts.

One of the most remarkable basalts lately found is the quartz basalt described by Mr. Diller as occurring ten miles northeast of Lassen Peak, California. The uniform distribution of the quartz grains throughout this lava and their relations to the other minerals of the mass indicate that they are not extraneous particles included in the lava, as many petrographers have supposed, but are indigenous, having developed in the lava at an early stage of its crystallization, and characterize the lava as quartz basalt.

Mr. Iddings has recently identified and described similar basalts from New Mexico and Arizona, and later researches have shown that such lavas are much more common than was at first supposed.

A large volume of extraordinary natural glass which gradually passes into basalt has been described by Mr. Becker as occurring near Clear Lake, California. It is especially exceptional in chemical composition, a fact to which its non-crystalline character has been attributed, and which has an important bearing in explaining the texture of massive rocks.

The genetic relations between the deep seated intrusive rocks, such as granites, diorites, diabases, etc., and the superficial lavas of essentially the same chemical composition, has long been a matter of study: but from the nature of the case exposures illustrating their relations must be rare and exceptional, for to lay bare the deep seated rocks the surface flows need to be swept away. It has long been argued that if eruptive masses which appear upon the surface in the form of andesites could be traced downwards into the earth they would gradually pass into diorites, but not until recently has a suitable opportunity occurred where this transition could be clearly made out. The extensive shafting and tunneling in mining the celebrated Comstock Lode has exposed the same eruptive masses at different levels, and according to Messrs. Hague and Iddings the glassy forms of the eruptive rocks at this place are onor near the surface. At any considerable distance beneath the original surface the rocks are holocrystalline, and in general at greater depths within the same mass the rock is more coarsely crystalline. The general conclusion to be drawn from this study is that the degree of crystallization developed in igneous rocks is mainly dependent upon the conditions of heat and pressure under which they have cooled.

The studies of Mr. Bayley upon the rocks of Pigeon Point, Minnesota, have led to the discovery that the bright red rocks which occur along the borders of the large mass of olivine gabbro are characterized by an alkaline feldspar rich in sodium, and belong to the quartz-keratophyres, a group of rocks which had not been previously recognized in this country. A zone of contact rocks between the eruptives and the adjacent sedimentary quartzites shows in places a complete transition from one rock to the other. The weight of evidence favors the important conclusion that the quartz-keratophyre has originated through the fusion of the impure slaty quartzite by heat from the gabbro and through its subsequent crystallization in such a way as exactly to simulate an ordinary eruptive rock.

Among the deep seated intrusive masses special interest has attached lately to the peridotites, on account of their economic relations. The nickel ore genthite, which has been mined both in Oregon and North Carolina, has been demonstrated to result from the alteration of the nickeliferous olivine of these basic eruptives, and the discovery of the occurrence of diamonds in South Africa associated with peridotites and carbonaceous shales has aroused considerable interest in such an occurrence in Kentucky and elsewhere in this country. In California, about the northern end of the Sierra Nevada Range and the central portion of the Coast Range west of Mount Shasta, peridotites are of common occurrence, and by alteration give rise to serpentines, whose history is strongly contrasted with that ascribed by Mr. Becker to the serpentines derived from the sandstones of the Coast Range farther south.

METAMORPHIC ROCKS.

Useful as is the microscope in unveiling the mineralogical composition and structure of the fine grained eruptive masses, its greater value is found in the light it throws upon metasomatic and metamorphic changes to which many rocks, both eruptive and clastic, have been subjected.

Prof. Irving showed that many of the quartz grains in the St. Peters and Potsdam sandstones of Wisconsin have actually increased in size within the stone by the deposition of quartz upon the outside of the original grains of sand, thus filling the interstices and indurating the mass. It was found also that the alteration which has produced from sandstone certain ancient quartzites is of the same nature and quite independent of any igneous action.

The widespread importance of the enlargement of quartz fragments led to the inquiry as to whether fragments of other minerals, each after its own kind, may not have received secondary enlargements; and, if so, how far such enlargements may have contributed to the production of metamorphic rocks. Prof. Van Hise discovered that feldspar fragments occasionally enlarge like those of quartz, and he describes the same phenomenon in connection with hornblende fragments of certain conglomerates of northeastern Minnesota. In certain mica schists and other rocks of the same region the feldspar fragments have altered to quartz and chlorite or mica, and in connection with the constructive changes just mentioned have produced from a completely fragmental rock, by metasomatic change only, a rock which presents every appearance of complete original crystallization, and which would be ordinarily classed as a genuine crystalline schist. The extent to which such changes have taken place in regional metamorphism can be determined only by further microscopic investigations, but it is already proven that these are of widespread occurrence in metamorphic rocks.

In this connection reference may be made to the important micro-petrographic work of Messrs. Irving and Van Hise in discovering that the vast deposits of valuable iron ore, especially in the Penokee-Gogebic region of Lake Superior, originated by concentration from crystallized carbonate of iron, widely distributed through the adjacent strata.

In the general processes of metamorphism there is not only a transference of material from place to place, but also, in some cases, a transformation of the molecular structure without change of place. This is especially noteworthy in the paramorphism of pyroxene to hornblende, a phenomenon which Messrs. Irving and Williams have shown to be of widespread geological importance. About Lake Superior, in the crystalline schists and acid and basic eruptives of a region 400 by 300 miles in extent and of three distinct geologic systems, Irving found all the hornblende to be either clearly or very probably secondary to augite. Throughout a large area near Baltimore, where gabbro and gabbro-diorite are intimately intermingled, Williams found a gradual transition from one to the other. The two rocks are of essentially the same chemical composition, and all the stages in the transformation of hypersthene and augite in the gabbro to hornblende in the diorite are well illustrated. An investigation by the same geologist of certain abundant green schists of the Marquette and Menominee iron-bearing regions shows these to be metamorphosed eruptives. In their transformation, in addition to the above changes, dynamic action has had an important influence.

The metamorphic changes to which reference has already been made occur in both eruptive and clastic rocks of high antiquity in the pre-Cambrian portion of the geologic column, but such great changes are not confined to these ancient terranes. Mr. Becker has traced remarkable metamorphic alterations in the late Mesozoic rocks of the Coast Range of mountains in California. Irregular portions of a great thickness of sandstone and shale, which by their stratigraphy and fossil contents have been determined to be Lower Cretaceous, are unequally but often highly metamorphosed, and all stages of the process are well displayed.

In the alteration of these rocks many new minerals have originated, among which mica, augite, hornblende, glaucophane, plagioclase, orthoclase, quartz, zoisite and serpentine are the most important. These gradually replace the original fragmental material, and if only the processes be carried far enough a product is obtained in which the clastic character of the rock ceases to be evident. The altered sandstones thus form under the microscope, as they do in the field, transitions from the clastic to the holocrystalline rocks.

The total area of the volcanic terranes in the United States is very great. This is especially true of the western half of the territory. The Archean terranes and those of metamorphic rocks that have been usually classified therewith are also of immense extent. The exploration of these rocks by means of the microscope is in its infancy. The ultimate product of such examination can not be foretold at present, but the progress of the past ten years augurs well for the future.

SEDIMENTARY ROCKS.

In the study of sedimentary formations comparatively little use has thus far been made of modern petrographic methods. Yet the microscope has been used in the study of the glacial drift by Messrs. Chamberlin and Salisbury with manifest advantage, as they are able thereby to differentiate from the flour of glacier-ground rock the deposits of comminuted materials having their origin in atmospheric and aqueous disintegration.

Mr. Russell has likewise received material assistance from the microscope in a comparative study of the residuary clays of the southern Appalachian region and of the rocks of the Newark system, and has been led to conclude that the Newark sandstones and shales were formed from the erosion and redeposition of the residuary products of a long period of subaerial rock decay.

WORK IN MINING STATISTICS AND TECHNOLOGY.

It has been found that the publications emanating from this branch of the Survey meet a decided want and are in constant demand; and the division, which remains in charge of Dr. David T. Day, has accordingly been gradually strengthened and the number of correspondents and contributing specialists increased until the annual reports upon the mineral resources of the United States are believed to be as nearly complete as it is practicable to render them without increase in cost. As in previous reports, tables exhibiting the metallic and non-metallic mineral products of the United States for the past year are introduced:

Metallic products of the United States in 1888.

Products.	Measure.	Quantity.	Value.
Pig iron, spot value	Long tons	6,489,738	$107,000,000
Silver, coining value	Troy ounces	45,783,632	59,195,000
Gold, coining value	do	1,604,927	33,175,000
Copper, value at New York City	Pounds	231,270,622	33,833,954
Lead, value at New York City	Short tons	180,555	15,924,951
Zinc, value at New York City	do	55,903	5,500,855
Quicksilver, value at San Francisco	Flasks	33,250	1,413,125
Nickel, value at Philadelphia	Pounds	195,182	115,518
Aluminum, value at Philadelphia	do	19,000	65,000
Antimony, value at San Francisco	Short tons	100	20,000
Platinum (crude), value at New York	Troy ounces	500	2,000
Total value			$256,245,403

Non-metallic mineral products of the United States in 1888 (spot values).

Products.	Measure.	Quantity.	Value.
Bituminous coal	Long tons	91,106,998	$122,497,341
Pennsylvania anthracite	....do	41,624,610	89,020,483
Building stone			25,500,000
Lime	Barrels	49,087,000	24,543,500
Petroleum	....do	27,346,018	24,598,559
Natural gas			22,662,128
Cement	Barrels	6,253,295	4,533,639
Salt	....do	8,055,881	4,377,204
Limestone for iron flux	Long tons	5,438,000	2,719,000
South Carolina phosphate rock	....do	433,705	1,951,673
Zinc-white	Short tons	20,000	1,600,000
Mineral waters	Gallons sold	9,628,568	1,709,302
Borax	Pounds	7,589,000	455,340
Gypsum	Short tons	96,000	430,000
Manganese ore	Long tons	25,500	255,000
Mineral paints	....do	24,000	380,000
New Jersey marls	Short tons	600,000	300,000
Pyrites	Long tons	54,331	167,658
Flint	....do	30,000	175,000
Mica	Pounds	48,000	70,000
Corundum	Short tons	589	91,620
Sulphur	....do		
Precious stones			64,850
Gold quartz, souvenirs, jewelry, etc			75,000
Crude barytes	Long tons	20,000	110,000
Bromine	Pounds	307,386	95,290
Feldspar	Long tons	8,700	50,000
Chrome iron ore	....do	1,500	20,000
Graphite	Pounds	400,000	33,000
Fluorspar	Short tons	6,000	30,000
Slate ground as pigment	Long tons	2,500	25,000
Cobalt oxide	Pounds	12,266	18,441
Novaculite	....do	1,500,000	18,000
Asphaltum	Short tons	53,800	331,500
Asbestus	....do	100	3,000
Rutile	Pounds	1,000	3,000
Total values			$328,914,528

Summary of the values of the metallic and non-metallic mineral substances produced in the United States in 1888.

Metals	$256,245,403
Mineral substances named in the foregoing table	328,914,528
	585,159,931
Estimated value of mineral products unspecified	6,500,000
Grand total	$591,659,931

WORK IN MATHEMATICS.

The varied work in the several branches of the Survey necessarily requires a considerable amount of mathematical calculation. This is especially the case with the topographic work, which entails more or less computation in the preparation of all data that serve as a basis for the resulting maps.

The fixation of maps in their proper relative form and dimensions requires a knowledge of the latitudes and longitudes of a series of points within the areas surveyed, and these elements must be determined by astronomic observation, or derived by triangulation from points already known. In order that existing information of this sort may be readily available it is necessary to collect and keep on file a list of all latitudes and longitudes which have been determined by the various bureaus of the Government, by State surveys, and by the astronomers of college and private observatories.

In planning the linear and angular measures essential to systems of triangulation, many questions arise concerning the appliances and methods which will secure the requisite efficiency with the greatest economy; and the determination of these questions requires a thorough familiarity with the details of the theory of instruments and of the theory and practice of observation. It is frequently necessary also to prepare plans and specifications for new instruments of the higher grades, or for repairs and advantageous alterations to old ones. New instruments furnished by contract in accordance with such specifications are carefully examined and tested by actual use before they are accepted.

This work is in charge of Mr. R. S. Woodward, hitherto in charge of the astronomic and computing section of the Division of Geography. But, though most of his time is occupied in the purely practical duties of the Survey, he has been assigned to the study of several problems in physical geology which require mathematical treatment in their elucidation. To the problems already enumerated in previous reports there was added during the past year the hydro-dynamical one of the laws of transportation and subsidence of coarse sediments.

Three bulletins by Mr. Woodward were published during the year, viz: No. 48, On the Form and Position of the Sea Level; No. 49, On the Latitudes and Longitudes of Certain Points in Missouri, Kansas, and New Mexico; and No. 50, Formulas and Tables to Facilitate the Construction and Use of Maps.

PUBLICATIONS.

During the year there have been printed for the Survey by the Public Printer one annual report, two quarto monographs, nine bulletins, and one annual statistical volume. These various publications are described on earlier pages and in the administrative reports of the several divisions from which they emanate, so that they need not be enumerated here.

The geologic and other investigations conducted by the Survey constitute a part of the scientific work of the world. They interlock with other investigations in an intimate and complex way, and by reason of this interlocking the students belonging to this organization are in constant communication with other students of cognate subjects. It is the policy of the Survey to delay publication upon each subject until investigation has made such progress as to permit thorough and, when possible, monographic treatment; but this policy does not lead to so rapid a communication of the results of investigation as is desirable in the interests of cooperation with investigations elsewhere. In view of these facts, permission has been granted to various members of the corps, from time to time, to publish preliminary statements of the results of their investigations and also various incidental problems and accessory products of their work in the scientific journals of the country and in the transactions of scientific societies. It is believed that by this policy the primary objects of the Geological Survey are advanced, the scientific work of individuals and private organizations is stimulated and the interests of the people of the country are promoted.

WORK IN THE DIVISION OF ILLUSTRATIONS.

The principles controlling the organization of the Division of Illustrations and the character of the work of the division are set forth at length in the Eighth Annual Report. The division has remained in charge of Mr. W. H. Holmes, from whose administrative report it will be seen that illustrations for four bulletins, three monographs, and one annual report have been prepared during the past year, in addition to a considerable amount of miscellaneous work and work upon illustrations of publications not yet sent to press.

WORK OF THE LIBRARY.

The library has remained in charge of Mr. C. C. Darwin, and its operations are described in detail in his administrative report. As shown in that report, the accessions for the year amount to 2,837 books and 4,000 pamphlets, by which the contents of the Survey library have been increased to 24,300 books and 34,100 pamphlets, or a total of 58,400 pieces, exclusive of a large number of maps. No fewer than 12,000 books, pamphlets and maps have been drawn from the library and used during the year, chiefly by collaborators of the Survey, but in small part by properly accredited students not connected with the institution. In addition, the sale and exchange of the regular publications of the Survey and the transmission of the special publications designed for gratuitous distribution have been carried on in this division. In all, 8,016 publications have been sent out in exchange, 3,029 have been sold and the proceeds covered into the United States Treasury, and 18,577 have been distributed gratuitously. Thus a total of 29,622 parcels have been transmitted.

Satisfactory progress has been made in the bibliographic work carried on in this division in accordance with the plan described at length in the Eighth Annual Report.

CONFERENCE ON MAP PUBLICATION.

THE OCCASION FOR THE CONFERENCE.

Shortly after the institution of the Geological Survey a cartographic system, embracing a scheme of colors and a plan of classification, was devised for use in publishing the sheets of the geologic map of the United States. This system was promulgated in the Second Annual Report and in a memoir communicated to the International Congress of Geologists at Bologna in 1881. The system has been tested and applied in the maps issued in connection with the regular publications of the Survey from 1882 to the present time. But during this period the subjects of geologic nomenclature and map notation have attracted attention in this country and abroad, and many significant experiments in map construction have been made; it has been an era of growth and differentiation in systematic geology and in geologic technics; moreover, the operations of the Geological Survey have extended over large areas in many parts of the country, and many contributions of the first importance have thereby been made to geologic science.

It was long ago well shown by Dana, and is now recognized by geologists everywhere, that the North American continent represents in itself an epitome of the geologic development of the globe—that every important event in world growth, every great rock group, every class of minerals, every type of fossils, every order of the superficial deposits formed by air, water, ice and the decay of older rocks, every kind of normal and deformed rock structure and every grade of surface configuration formed by geologic agencies found in any part of the earth is here well represented. During the decade all of these classes of phenomena have been under investigation by officers of the Geological Survey, and in the progress of the work it has been found that many of them are susceptible of delineation upon maps. In the course of their work upon different phenomena in the various parts of the country the collaborators of the Survey have devised methods of mapping well suited to their respective areas and to the classes of phenomena with which they respectively deal.

So, within the Geological Survey, there has been wide differentiation of ideas concerning geologic taxonomy and nomenclature and concerning their application in geologic mapping; within the Geological Survey there has grown up as great need for diverse systems of map publication as was ever felt during the days of numerous State surveys; within the Geological Survey, indeed, the range of thought and work concerning these matters has become practically as wide as the range of thought and work among the geologists of the world, and just as the North American continent represents an epitome of the geologic development of the earth, so the range of conception concerning geologic principles and methods among the Federal geologists has become an epitome of the geologic opinion of the earth.

Recognizing this fact, desiring to devise a cartographic system applicable throughout the country, and appreciating the ability and right of the geologist employed in each region to form and express convictions as to local needs, the Director deemed it wise to arrange a conference among the Federal geologists, with a view to full discussion of the various considerations involved in a cartographic plan for the entire country. Accordingly the accompanying letter was addressed to heads of geologic divisions and some other specialists in the Geological Survey.

CIRCULAR LETTER.

UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., December 7, 1888.

SIR: In the volume of regulations of the U. S. Geological Survey are certain rules affecting methods of publication, and in the Second Annual Report of the Director, pages XL–LIII, are certain specific regulations as to the publication of geologic maps and sections. These regulations have been applied in the preparation of geologic maps for the illustration of memoirs, but they have not yet been applied to the general geologic atlas sheets of the Survey. Geologic field work has now been completed for a number of atlas sheets, and various questions have arisen respecting their publication. It has been found that the regulations referred to answer these questions but imperfectly, and the subject of their revision has been under consideration for several years. The time has arrived when a general plan for the uniform publication of geologic atlas sheets should be adopted, and it has been determined to replace the existing rules by a new code, embodying the best results of later devising and experimentation. To this end a number of assistants, including yourself, will be requested to join the Director in a conference early in January, and in order that your attention previous to that time may be directed to the subjects for discussion, the following outline is presented for your consideration.

The outline will be found to consist of a series of statements and questions together with a tentative color scheme. The statements represent the present opinions of the Director, and the details of the color scheme are the outcome of much thought, but it should be understood that the opinions of the Director are subject to revision, and that the object of the submission of the color scheme is to direct your attention to specific questions and thus enhance the utility of the conference. All matters indicated by questions, those indicated by statements, the general plan and the details of the color scheme, the general subject of map coloration and all cognate matters are proper subjects for discussion by the conference.

If you have atlas sheets in preparation for publication it is desirable that you make the drawing of them experimental work in the line of this discussion, and that you bring the experimental drawings with you at the time of this conference.

If you desire to suggest any enlargement of the proposed scope of discussion, or have other important suggestions as to any branch of the subject, you are invited to correspond with the Director in advance of the conference.

UNIT OF PUBLICATION.

1. What shall be the unit of publication? Shall it be an atlas sheet geologically colored? Shall it be a group of contiguous atlas sheets representing some determined unit of area, as for example a square degree? With reference to this question it should be borne in mind that the scales of the maps are different in different regions, and that different scales may possibly be used in the same region.

2. Shall the geologic map or maps be accompanied by text? Shall such text take the form of an octavo bulletin of the Survey, or shall it be in folio, uniform in size with the atlas sheet?

3. Shall the geologic maps be accompanied by separate topographic maps, by soil maps, by economic maps, by sheets of sections?

4. Shall separate maps be made for the Quaternary?

NOMENCLATURE.

5. Is it desirable to establish for the regulation of the work of the Survey any general or specific rules on the nomenclature of formations?

6. It has been proposed that the Survey definitely recognize a series of geologic periods (arbitrary time divisions) approximately as follows: Archean, Eparchean, Cambrian, Silurian, Devonian, Carboniferous, Jura-Trias, Cretaceous, Eocene, Neocene, Quaternary. It is proposed that the assistants refer all formations either definitely or tentatively to the divisions of this time scale, and that the classification of the periods into larger chronologic units—as, for example, Mesozoic, Paleozoic, etc.—shall not appear on the map sheets of the regular series.

7. What is the most desirable system of formation names? Shall they be geographic only, or shall they combine geographic and lithologic words?

8. Shall paleontologic words be admitted?

9. If a general principle be adopted as to new names, shall it be applied to all names, or shall weight be given to the law of priority?

10. What principles of nomenclature shall apply when two or more formations separable in one area are determined to be collectively equivalent to a single inseparable formation in a contiguous area?

11. The Geological Congress has adopted the following hierarchy of stratigraphic terms: Group, System, Series, Stage. It has adopted the following parallel hierarchy of time terms: Era, Period, Epoch, Age. It has restricted the use of the term Formation to the designation of rocks with reference to their genesis. Shall these conventions be accepted by the Geological Survey?

NOTATION FOR MAPS.

12. It is desirable that a color be assigned to each geologic period, and that all formations belonging to that period be represented on the maps by the same color, their distinctions among themselves being indicated by geometric figures or patterns.

13. What color shall be assigned to each period? Shall a prismatic order be adopted, or shall a selection be made from the variety afforded by present usage?

14. It is not desirable to assign specific geometric figures to specific formations; the selection of figures for each sheet should have a wide range. Shall the order in which geometric figures are to be used within the same period be established by regulation, and if so, what order?

15. Special provision should be made for volcanic rocks. Shall special provision be made for the Quaternary? Shall special provision be made for metamorphic rocks?

16. Shall provision be made for the expression of doubt as to the proper chronological reference of a formation, and if so, what provision?

17. What provision shall be made for the representation of an indivisible formation believed to be transitional, that is, believed to be properly referable in part to one period and in part to another?

18. What provision shall be made for the representation on the same map of two formations which in one part are separable and in another part inseparable?

19. Shall lithologic differences receive any representation independent of the chronologic scheme?

20. What other phenomena—as for example mines, quarries, faults, dips, anticlinal and synclinal axes, glacial striæ—shall be represented on the maps and by what signs?

21. For security in case of doubt and in case of color blindness a letter symbol should connect each color area with the legend. What code shall be used?

SUGGESTED COLOR SCHEME.

22. Assign a special color to each period from Archean to Neocene as follows: Archean, pink; Eparchean, purple; Cambrian, blue; Silurian, emerald green; Devonian, normal green; Carboniferous, olive green; Jura-Trias, yellow; Cretaceous, orange; Eocene, vermilion; Neocene,

red. This series is prismatic from Neocene to Cambrian inclusive, and the purple and pink of the Eparchean and Archean are extra prismatic colors shown by the theory of color complements to naturally follow the blue in the order indicated.

23. Where the period is to be indicated without indication of subdivision, use the corresponding color solid. Where a subdivision is to be indicated, use the appropriate color solid with overprint of the same color in lines; the overprint being darker than the underprint, but of the same tone. Express the distinctions between the formations belonging to the same period by different combinations of overprinted parallel lines and by these only.

24. The number of geometric figures or patterns producible by parallel lines is very large, as the following suggestions will illustrate.

Parallel lines may be (a) straight or (b) waved.

They may be (c) vertical, (d) horizontal, or (e) oblique.

They may be (f) narrow, (g) broad, or (h) alternately narrow and broad.

They may be separated by spaces which are (i) narrow, (j) broad, or (k) alternately narrow and broad.

By the permutation and combination of these various factors of difference there may be produced fifty-four patterns, any one of which can be employed, but the number of patterns readily distinguishable each from the others on the same sheet is much smaller. Probably twenty or twenty-five are available for concurrent use; a number meeting all the practical needs of the geologic map.

25. Perhaps it is not advisable to attempt to use the same pattern for the same formation on all atlas sheets, lest the color scheme lose flexibility. It is suggested that upon each atlas sheet the patterns involving narrow lines and broad spaces be preferred for the younger formations of each period, and the patterns involving broad lines and narrow spaces for the older formations. Such selection would give to the color band representing each period a slight gradation from dark to pale, corresponding to the stratigraphic succession from below upward, and would thus aid the reading of the map. But experimentation is necessary to determine the practicability of such a plan. An alternative suggestion leaves the selection of patterns to be determined exclusively by considerations of convenience, as determined by the widths and directions of the formation bands on the particular sheet, and indicates the stratigraphic order by means of letter symbols. The following letter symbol code would accomplish this purpose. Assign to each period a capital letter, mnemonic as far as possible, and assign to each formation on a sheet a lower case letter to be used with its period letter. Give the formation letters alphabetic order within each period and within each atlas sheet, designating the lowest discriminated formation of the period by *a*, the next younger by *b*, and so forth. The lowest Silurian formation of an atlas sheet would thus be marked *Sa*.

26. Represent the various formations of the Quaternary by dots and other circular figures, using any and all colors. When the subterrane is unknown or it is undesirable to express it, print the Quaternary figures on white; otherwise overprint them on the colors (and color figures) representing the subterrane.

27. Represent volcanic rocks by angular figures (squares, triangles and crosses) and use any and all colors. When the age of the volcanic rock is to be expressed, print its color figure over the solid color of the corresponding period. When the age is not to be expressed, print the volcanic color figure on white.

28. When it is desired to express doubt as to the reference of a formation to a particular period, omit the underprint.

29. When it is desired to indicate a formation as transitional, implying that its undivided parts belong to different divisions of the arbitrary time scale, use the color of either period for the underprint and the colors of both periods for the overprint, arranging them in alternate lines.

30. When it is desired to distinguish on one part of a sheet two or more formations which are not distinguished on another part of the same sheet, use the same pattern for all, and add to the overprint a line or lines dividing the formation areas. Give to each formation a separate letter symbol and use a combination symbol in the region where they are not distinguished. The following symbol notation is one of several which might serve this purpose: The formations being severally marked *Sd*, *Se*, *Sf*; their undifferentiated area is marked *Sdef*.

NOTATION FOR SECTIONS.

31. Shall structure sections accompanying geologic maps be colored in the same way, with period colors and overprinted formation pattern? Shall they receive a lithologic notation, such as that given on page LIII of the Second Annual Report? Shall period, color and lithologic pattern be used in combination?

32. What notation shall be used for columnar sections?

Very respectfully yours,

J. W. POWELL, *Director*.

THE WORK OF THE CONFERENCE.

In accordance with the plan set forth in this letter, a conference was held at the office of the Geological Survey in Washington on January 28 to 31, 1889. There were present, besides the Director, the following geologists and lithologists: C. Whitman Cross, J. S. Diller, C. E. Dutton, George H. Eldridge, B. K. Emerson, S. F. Emmons, G. K. Gilbert, Arnold

Hague, W. H. Holmes, Joseph P. Iddings, W. J. McGee, A. C. Peale, Raphael Pumpelly, C. R. Van Hise, Walter H. Weed, George H. Williams and Bailey Willis. In addition was Mr. C. D. Walcott, a member of the paleontologic branch whose recent work has been stratigraphic.

The various points touched upon in the letter of December 7 were considered, most of them were discussed at length, and agreement was reached concerning many points previously at issue.

UNIT OF PUBLICATION.

There was general and ready agreement to the plan proposed that the unit of publication shall be an atlas sheet with legend on margin, accompanied by a full sheet of letter press description (so prepared as to be intelligible to users who are not trained geologists), and, when necessary, by a sheet of sections exhibiting the structure of the area; to be accompanied also in some cases either by a soil map or by a map of Pleistocene deposits, or by both; the whole to be arranged under a folio cover, bearing on its first page a suitable title and a key map showing the position of the atlas sheet in its State, and bearing on its inner pages an explanation of cartographic technics. It was incidentally agreed that when necessary the letter press description accompanying the atlas sheets shall be supplemented by a bulletin.

NOMENCLATURE.

Prolonged consideration was given to this subject. It was finally agreed that it is desirable, and indeed necessary, to establish for the regulation of the work of the Survey certain rules concerning the nomenclature to be used upon geologic maps. The following were agreed upon:

There shall be recognized for cartographic purposes and for use in the maps published by the Geological Survey four great classes of rocks, viz: (a) fossiliferous clastic rocks, (b) superficial deposits, (c) ancient crystalline rocks, and (d) volcanic rocks.

Among the clastic rocks there shall be recognized two classes of divisions, viz: structural divisions and time divisions; and the divisions of both classes shall be suitably designated.

The structural divisions shall be the units of cartography, and shall be designated *formations*. Their discrimination shall be based upon the local sequence of rocks, lines of separation being drawn at points in the stratigraphic column where lithologic characters change. It will be impossible to delineate on maps of the scale selected for the atlas sheets the limits of each lithologic change, and the geologist must select for the limitation of formations such horizons of change as will give to the formations the greatest practicable unity of constitution. Each formation should contain between its upper and lower limits either rock of uniform character or rock uniformly varied in character; as, for example, a rapid alternation of shale and limestone. When the passage from one kind of rock to another is gradual it will sometimes be necessary to separate two contiguous formations by an arbitrary line. In every case the definition should be that which best meets the practical requirements of the geologist in the field and the prospective user of the map; that is to say, each formation should possess such characteristics that it may be recognized on the ground alike by the geologist and by the layman.

As each lithologic unit is the result of conditions of deposition that were local as well as temporary, it is to be assumed that each formation is limited in horizontal extent; the formation should be recognized and should be called by the same name as far as it can be traced and identified by means of its lithologic characters, aided by its stratigraphic association and its contained fossils.

The formations shall receive distinctive designations. The most desirable designations are binomial, the first member being geographic and the other lithologic (e. g., Catskill Sandstone, Trenton Limestone, etc.). The geographic term should be the name of a river, town or other natural or artificial feature at or near which the formation is typically developed. Names taken from natural features are generally preferable, because less changeable than those of towns or political divisions. When the formation consists of beds differing in lithologic character, so that no single lithologic term is applicable, the word "formation" shall be substituted for the lithologic term (e. g., Potomac Formation).

In the application of formation names, the laws of priority and prescription shall be observed; but in general the name previously given to a structural unit of unlike definition shall not be given to the newly defined formation.

The time divisions shall be defined primarily by paleontology and secondarily by structure, and they shall be called *periods.* The formations of each district represented by an atlas sheet shall be grouped according to the periods during which they were deposited. In the case of most of the periods the classification or correlation of formations will be based on paleontology. When paleontologic evidence is inconclusive, leaving doubt as to the chronologic date of a formation, the formation shall be referred to some one period, according to the preponderance of paleontologic evidence, and the doubt as to the reference shall be indicated. When paleontologic evidence indicates that a formation was deposited partly in one period and partly in another, the entire formation may be referred to one period, according to the preponderance of the paleontologic evidence, or the formation may be indicated as transitional between the two periods.

The first (the latest) period shall cover the time beginning with the first ice invasion and continuing until the present, or that which is commonly called the Quaternary. Exception was taken to the name Quaternary on the ground that it is a vestige of a primitive and otherwise obsolete classification and nomenclature, and a proposal to substitute for it the more consistent term Pleistocene was advocated and finally agreed to.

The second period shall include the time divisions sometimes called Pliocene and Miocene. Its earlier delimitation shall be that indicated by paleontology, and its later the first ice invasion of the Pleistocene; and its designation shall be Neocene.

The third period shall be the Eocene, including therein the subdivision sometimes called Oligocene. Its definition shall be that commonly accepted by paleontologists and geologists as determined by fossil remains.

The fourth period shall be the Cretaceous Its definition shall be that indicated by paleontology and usually accepted.

The fifth period shall include the time divisions known as Jurassic and Triassic, and shall be designated Jura-Trias. Its definition shall be by paleontology.

The sixth period shall be the Carboniferous, including the subdivision sometimes called Permian. Its definition shall be by paleontology.

The seventh period shall be the Devonian. Its definition shall be that indicated by paleontology and usually accepted.

The eighth period shall include the time divisions sometimes styled Upper Silurian and Lower Silurian, and otherwise styled Silurian and Ordovician Its definition shall be by paleontology, and its designation shall be Silurian.

The ninth period shall be designated the Cambrian. The definitions of its upper limit shall be by paleontology, so as to include the time preceding that sometimes styled Ordovician. Its lower delimitation shall be the time of deposition of the lowest rocks thus far known to yield a well defined fauna.

The tenth period shall be the time of deposition of clastic rocks older than the Cambrian. Its lower delimitation can not be definitely fixed, but its upper is definitely determinate as just below the beginning of the Cambrian. The period is represented by some rocks which have been referred to the Cambrian, many which have been referred to the Huronian, and some formations which have not hitherto been classified. Exception being taken to the term Eparchean, and also to the term Huronian (proposed on the ground that it had been previously applied to a part of the rocks, but opposed on the ground that the definitions of this period are entirely unlike those accepted for the Huronian), the term Algonkian was offered and agreed to as the designation of the period.

The oldest time division shall cover the time of formation of the ancient crystalline rocks, and its designation shall be Archean.

In the preparation of a geologic map the areal distribution of the formations shall be represented by suitable notation in the body of the map, and the notation shall also represent the classification of the formations under periods. A legend accompanying the map shall employ the same notation and indicate the names of the formations together with their classification under periods.

All taxonomic divisions except the structural divisions and time divisions here indicated, viz, periods and formations, shall be excluded from the atlas sheets of the Geological Survey, but this prohibition applies only to the atlas sheets.

The rules of nomenclature for the fossiliferous clastic rocks shall be employed, so far as they may be applicable, in the naming of the superficial deposits, the ancient crystallines and the volcanic rocks.

In the superficial deposits, the primary classification shall be genetic rather than chronologic; but the secondary classification may be structural, as among the fossiliferous clastics.

Among the ancient crystallines, the divisions, major and minor, shall be for the present chiefly petrographic, though genetic and chronologic divisions may be made as knowledge progresses.

Among the volcanic rocks, the primary divisions shall be chronologic, when possible, and adjusted to the historic divisions of the fossiliferous clastic rocks; and the minor divisions may be petrographic, genetic, or structural, at the convenience of the geologist.

CONVENTIONAL SYMBOLS FOR GEOLOGIC MAPS.

During the conference of geologists in January last prolonged consideration was given to the subject of notation for maps, and various subsidiary questions were discussed at length. Concerning many of these questions there was complete agreement among the geologists present, but concerning certain minor points some difference of opinion was expressed.

After the dissolution of the conference the whole subject of geologic cartography was once more taken under consideration by the Director. During the past nine years much thought has been given to map making, as is in some measure indicated by the references to this subject in the annual reports and other publications; during this period, too, a large number of experiments in map construction have been made; and at the same time every opportunity to ascertain the opinions of practical map users as to desirable and undesirable features in geologic maps has been seized. Meantime large numbers of geologic maps have been published by geologic surveys in this and other countries, and the various cartographic methods have been studied and the experience of the cartographers utilized as fully as possible. Moreover, the opinions and experiences of the geologists of the world, set forth in the International Congress, have done much to elucidate the general subject of geologic cartography, and the conference of the past winter similarly served to elucidate the specific problems which the Geological Survey is called upon to solve. After availing himself of information from all of these sources, after further experimentation and further study of the cartographic systems of this and other countries, and after prolonged consideration of the conditions to be met in the construction of a map designed for the use of all classes of citizens of the United States, the Director decided to somewhat modify and after such modification to adopt for the use of the Survey the plan for constructing geologic maps set forth in the Second Annual Report and in the report of the International Congress for 1881. The plan thus adopted, together with some of the principal considerations upon which it is based, is embodied in the following paragraphs. It should be clearly understood that this plan was devised to meet the requirements of the organic law of the Geological Survey as completely as possible, and that the maps are designed primarily for the use of citizens of the United States, whether geologists or laymen. At the same time it is believed that the plan and resulting maps will meet the requirements of general students about as well as any other thus far devised.

There are four great classes of rocks which are more or less diverse in external appearance, internal characteristics and mode of genesis, and which are in the main readily distinguishable even by casual observation. These are (a) fossiliferous clastic rocks, (b) superficial deposits, (c) ancient crystalline rocks, and (d) volcanic rocks. Within each of these primary classes a large number of divisions and subdivisions have been established, and with the progress of geologic investigation these known divisions and subdivisions are further defined and classified and new divisions and subdivisions are established.

For the distinction of these four classes of rocks and of the numerous divisions within each class there are available three kinds of devices, each of which already has the sanction of general usage. These are (1) color, (2) pattern, and (3) name or name symbol. They are sometimes used singly, but they are most advantageously used in combination.

Colors vary through a wide range in tone and they likewise vary through a wide range in tint. When colors are used in combination with patterns, the patterns have the effect of producing variations in tint, and for this reason it is advantageous to restrict the distinctions made by colors to distinctions of tone only. Distinctions through tint may, however, be used to strengthen distinctions through pattern. Students of chromatics and optics have shown that the normal eye is capable of discriminating, under all possible associations, eight or nine of the pure colors of the spectrum, with one or two additional mixed colors.

The possible variety of patterns is infinite, and the number of simple patterns readily distinguishable from one another is large.

The use of names, or of initial letters or other abbreviations representing names, fails to express area and boundary, and is therefore not co-ordinate in efficiency with the use of colors and of patterns, but it has an important subordinate function. Colors sometimes bleach or are otherwise altered, and all eyes are not equally sensitive to color distinctions. Patterns cease to be distinctive when the areas to which they are applied are very narrow. The doubt liable to arise from these causes is removed by using initial letters in connection with colors and patterns so as to connect them unmistakably with the legend.

In view of these considerations, and of certain other considerations arising from general usage, the general plan of geologic cartography has been arranged as follows: To each of the four great classes of rocks there is assigned a group of patterns. Within each class subdivisions are represented by colors and by specific patterns, the two being ordinarily used in combination. The identification of each indication through color and pattern is secured by means of letter symbols.

In the selection of groups of patterns to represent the four rock classes, care has been taken to keep them distinct, avoiding the inclusion of patterns that might express gradation from one class to another; and, in consonance with certain tendencies of modern usage, patterns have been selected which connote the characteristics of the rock classes. The fossiliferous clastic rocks are indicated by patterns in parallel lines. Superficial deposits are indicated by patterns in circular figures. Ancient crystalline rocks are indicated by hachure patterns. Volcanic rocks are indicated by patterns in angular figures.

Color is used in two ways: First, solid, or completely covering the surface, and in pale tints; second, in patterns. The first use has a chronologic function; the second has various functions in the several rock classes. In the notation for the fossiliferous clastics the chronologic element is accented by combining an underprint in solid color with an overprint in pattern of the same color, differing only in tint. In the notation for the other classes of rocks, overprinted patterns are made to differ from underprints in tone as well as tint. In the notation for the superficial deposits all patterns are given paler tints than the patterns for the fossiliferous clastics. In the notation for volcanic rocks all patterns are given deeper tints than the patterns for the fossiliferous clastics. In the notation for ancient crystalline rocks one pattern is printed over another pattern of different tone, each being of medium tint.

The following paragraphs describe the notation in detail:

The general classification of the fossiliferous clastics is chronologic, and the larger divisions recognized are time divisions. While the general classification of the superficial deposits is structural, their relations to underlying terranes of the fossiliferous clastics are often such as to demand representation upon geologic maps. The class of ancient crystalline rocks necessarily includes metamorphic strata, which are from time to time correlated with the chronologic series more fully represented by the fossiliferous clastics, and this relation should be expressed on the maps. The volcanic rocks were extruded during the various periods recorded in the fossiliferous clastics, and it is desirable that the periods of extrusion be indicated on the maps. So in each of the four great classes of the rocks of the earth it is important that means be provided for indicating age in terms of a common scale. Such provision is made by the following collocation of periods and colors, each period being indicated in addition by a letter symbol (in upper case, block).

Period.	Letter symbol.	Color.
Neocene	N.	Orange.
Eocene	E.	Yellow.
Cretaceous	K.	Yellow-green.
Jura-Trias	J.	Blue-green.
Carboniferous	C.	Blue.
Devonian	D.	Violet.
Silurian	S.	Purple.
Cambrian	Є.	Pink.
Algonkian	A.	Red.

The arrangement of this color series is essentially prismatic, but the chromatic circle is completed by the addition of the extra-prismatic colors purple and pink, and the completed circle is redivided between the prismatic colors red and orange, for the sake of securing in the serial arrangement the largest possible number of correspondences with existing widely prevalent usage.

The period colors shall be printed solid in pale tint. For other purposes, as set forth in later paragraphs, the same series of colors will also be used in pattern, but in darker tint.

Among the fossiliferous clastic rocks the period color shall be used alone when it is impracticable or undesirable to indicate the component formations. When the formations are discriminated, they shall be indicated by overprinted patterns of parallel straight lines in darker tint of the same color. Each formation shall be further indicated by a letter symbol composed of the capital initial (or monogram) of the name of the period, and the lower case initial (and when necessary other letters) of the name of the formation. When the formation is defined and the period is not certainly known, the ground color may be omitted, and the overprint constituting the formation pattern may be used alone. In such case the associated letter symbol should include only the formation symbol in lower case. When boundaries of the formations are not accurately known, the overprints may be allowed to blend if the uncertainty is due to intergraduation, or to fade out without meeting if the uncertainty is due to concealment of contacts.

The parallel lines used for the distinction of formation terranes among the fossiliferous clastics may be vertical, horizontal, or oblique; narrow, broad, or alternately narrow and broad; and separated by spaces which are narrow, broad, or alternately narrow and broad. Combination and permutation of these differences will afford twenty-seven patterns for the distinction of the formations of each period; a number of distinctions which will unquestionably suffice for all practical purposes. The lines of oblique patterns may descend from left to right or from right to left, but the distinction thus afforded shall not be used on any atlas sheet to discriminate patterns otherwise identical.

It is inexpedient to establish in advance definite rules everywhere applicable in the selection of patterns for the representation of formations, but certain desiderata may be indicated. It is of prime importance that the distinctions upon each atlas sheet or map shall be clear and easily recognized. It is desirable that so far as practicable the same devices shall be employed for the representation of the same formations upon contiguous sheets. But it is not necessary to avoid duplication of devices in atlas sheets or maps representing widely separated areas, and especially different geologic provinces. It is also desirable that the patterns be so selected as to form a gradation in tint indicating the stratigraphic succession; and it is preferable that the gradations shall be from darker below to lighter above.

Neither is it expedient to prescribe letter symbols for the formations already defined and yet to be discovered, since the selection must in each case depend in part upon the designations of other formations represented upon the same sheet. Thus the Trenton limestone may be indicated by St, Str, Stl, or Strl, as may be necessary to distinguish its symbol from those of neighboring Silurian formations.

The Pleistocene and other superficial deposits shall be indicated by dots and circles, arranged in irregular order and printed in pale colors. When the subterrane is known, it may be represented by its period color, or the period color with the formation overprint, beneath the Pleistocene pattern device; but when the subterrane is unknown or not to be represented, the Pleistocene pattern shall be printed on a white ground. The Pleistocene formations shall be further distinguished by a letter symbol, in lower case, selected as among the fossiliferous clastics.

Distinction among the superficial deposits shall be secured by varying the colors of patterns, by varying the size of the figures and the closeness of the figures, and by using the two forms of figures separately and in combination. The permutations of the nine colors of the general color scheme, of the two forms of the figure and their combination, of two sizes of figure and of two degrees of closeness, are one hundred and eight in number, and suffice for all practical purposes.

Here also it is inexpedient to establish in advance definite rules for the selection of patterns, but certain desiderata may be recognized. These coincide in the main with those indicated for the delineation of the fossiliferous clastics, but one other should be added. It is desirable that the various elements of graphic discrimination be logically adjusted to the categories of phenomena to be discriminated; that is, the notation should be adapted to the phenomena in a systematic way and not in an indiscriminate way.

The ancient crystalline rocks shall be represented by hachures—short, discrete lines in irregular arrangement—printed in colors of medium tint. For each formation such hachures shall be used in two colors, a pattern in one color being overprinted on a pattern in another color. Within this class of rocks there are four subclasses which it is desirable to discriminate by uniform and prescribed notation. These are (a) rocks of unknown age, (b) rocks determined to be pre-Algonkian, i. e, Archean, (c) metamorphic rocks determined to belong to specific periods of the fossiliferous clastics, (d) metamorphic rocks correlated with specific formations of the fossiliferous clastics.

For the first of these the hachure patterns shall be used without underprint; for Archean rocks they shall be printed over a ground color of pale brown; for a metamorphic formation of known period, one hachure pattern shall be omitted and the other shall be printed over the ground color of the period; for a metamorphic formation or formations of the fossiliferous clastics, one hachure pattern shall be replaced by a parallel-lines pattern of the proper period color. Each formation of the ancient crystalline rocks shall be further indicated by a letter symbol in lower case, the period symbol being added whenever a period color is used.

Distinction among formations shall be secured by varying the colors of the patterns, and by varying the length, width and closeness of the lines of the patterns. By combination of the colors of the general scheme with one another and by the simultaneous combination of the indicated variations of pattern with one another a sufficient number of distinctions are readily obtained.

Subdivisions of the volcanic rocks shall be represented by triangles and rhombs, either solid or open, and these shall be printed in color of deeper tint than other colors used in the maps. They shall be printed on a white ground in case the age is unknown, but printed over the proper ground color and perhaps formation pattern, when the time of extravasation is known.

Distinction in this case also shall be made by variation in color and by variation in pattern. Variation in pattern may be secured by the use of each of the two figures in its two forms, solid and open, in two sizes and in two degrees of closeness. These variations combined with the nine colors of the chronologic system yield a number of distinctions sufficiently large for all practical purposes.

Rules for the choice of colors and patterns to represent the volcanic rocks can not be formulated in the present state of science; but in general the desiderata correspond with those already stated.

In each of the great classes of rocks there occur formations whose outcrops are so narrow that they can not be represented on the scale of the atlas sheets without exaggeration of their width. When platted with greatest approximation to accuracy they appear only as lines. In such cases distinctions by means of pattern fail, as each pattern when reduced to the dimensions of a line assumes the character of a series of dots and dashes. Moreover, there is great practical difficulty in printing a narrow line so as to precisely cover another narrow line, and for this reason the combination of overprint with underprint can not advantageously be employed for the delineation of linear outcrops. It is therefore provided that in all such cases a solid color may be used in place of the overprint. Such solid color shall be pale for the superficial deposits, of medium tint for the fossiliferous clastics and ancient crystalline rocks, and of deep tint for the volcanic rocks. The letter symbol should be associated with each separate outcrop.

A transitional formation may be indicated by the use of either period color for the underprint and alternating pattern devices for formation in the overprint, and in such case the period letter symbols may be either united or omitted.

A formation divisible in one part of a sheet and indivisible in another may be represented by distinct pattern devices for the distinct areas and a combination of these devices in the undifferentiated area, and the formation elements in the letter symbol may be similarly separated and combined in the respective areas.

Normal formation boundaries, when actually determined, shall be indicated by fine dotted lines in black; but when the boundaries are not actually determined the lines shall be omitted and the devices made to blend or fade as the circumstances of the case seem to demand.

Fault lines (particularly when they are formation boundaries) shall be indicated when actually traced by somewhat heavy full lines in black; and when not actually traced, by similar broken lines, toward which the formation devices may blend or fade as circumstances seem to require.

Patterns can be introduced with great economy by the engraver, but their production by hand is laborious and expensive. For this reason it is not desired that geologists, in preparing maps for publication, employ on their manuscript sheets the map notation to be engraved. Instead of indicating the formations by patterns they should use wash colors, and these may be of any tints and tones that are found convenient. The greatest care should be given to the formation boundaries, and the scheme of letter symbols should not only be arranged but should be properly placed upon the formation areas and upon the legend.

These rules for map notation, while framed with special reference to the sheets of the geologic map of the United States, are to be followed, so far as applicable, in the preparation of all maps for publication by the Survey.

THE ILLUSTRATIVE PLATES.

Four plates have been engraved for the purpose of indicating the standard colors to be used in the preparation of geologic maps and to illustrate the various types of color pattern.

The first or left hand column of Pl. II exhibits the nine colors constituting, with the addition of brown, the color scheme of the maps. Each of the nine colors is represented in two tints, of which the paler is that selected for the indication of geologic age. The corresponding period names and period letter symbols are attached to the color blocks.

The second and third columns of the same plate contain illustrations of patterns available for the representation of formations of the Cretaceous period. The same patterns, with variation of color only, serve for the representation of formations of the other periods.

The three columns of Pl. III illustrate the variation of pattern and the combination of pattern with color for the representation of the superficial formations. Of the numerous available patterns, the nine here represented have been selected as preferable for use when a number larger than nine is not required. Of the nine available colors only three are here used, but no preference is expressed.

Pl. IV illustrates the combinations of colors and of patterns available for the representation of ancient crystalline formations. Of thirty-six possible combinations of the standard colors in pairs only three are represented. Other combinations are not prohibited, but it is preferable that two colors standing next each other in the color series be not used together. By this restriction the number of color combinations is reduced to twenty-seven. Of the numerous possible combinations of patterns only nine are represented. These are selected as preferable, and choice should be restricted to them when a greater variety is not necessary.

The first column of Pl. IV illustrates the use of the brown ground color for the indication of Archean age.

Pl. V illustrates the combinations of colors with patterns for the representation of volcanic formations. Of the nine colors only three are represented, and it is not intended to express preference for these. Of the numerous admissible patterns nine have been selected for representation, and choice should be restricted to these when a greater variety is not needed.

CONVENTIONAL SYMBOLS FOR GEOLOGIC SECTIONS.

In the preparation of regional and other sections to accompany sheets of the geologic map of the United States the general system of signs prescribed for the map shall be employed, so that the sections may agree in notation as nearly as practicable with the maps to which they appertain. For serial or columnar sections to be printed with the text of reports of the Survey the notation prescribed in the Second Annual Report, page LIII, shall be used. The characters of that notation are reproduced on the following page.

It will be noted in the above plan that the color scale is used four times: once for each of the four great classes of rocks defined as fossiliferous clastics, superficial deposits, volcanics, and ancient crystallines. But the method of using the several scales is very distinct. For the fossiliferous clastics, pale ground colors are combined with tints of the same tone in parallel lines and medium strength. For the superficial deposits, different tones are combined in pale tints with patterns of dots

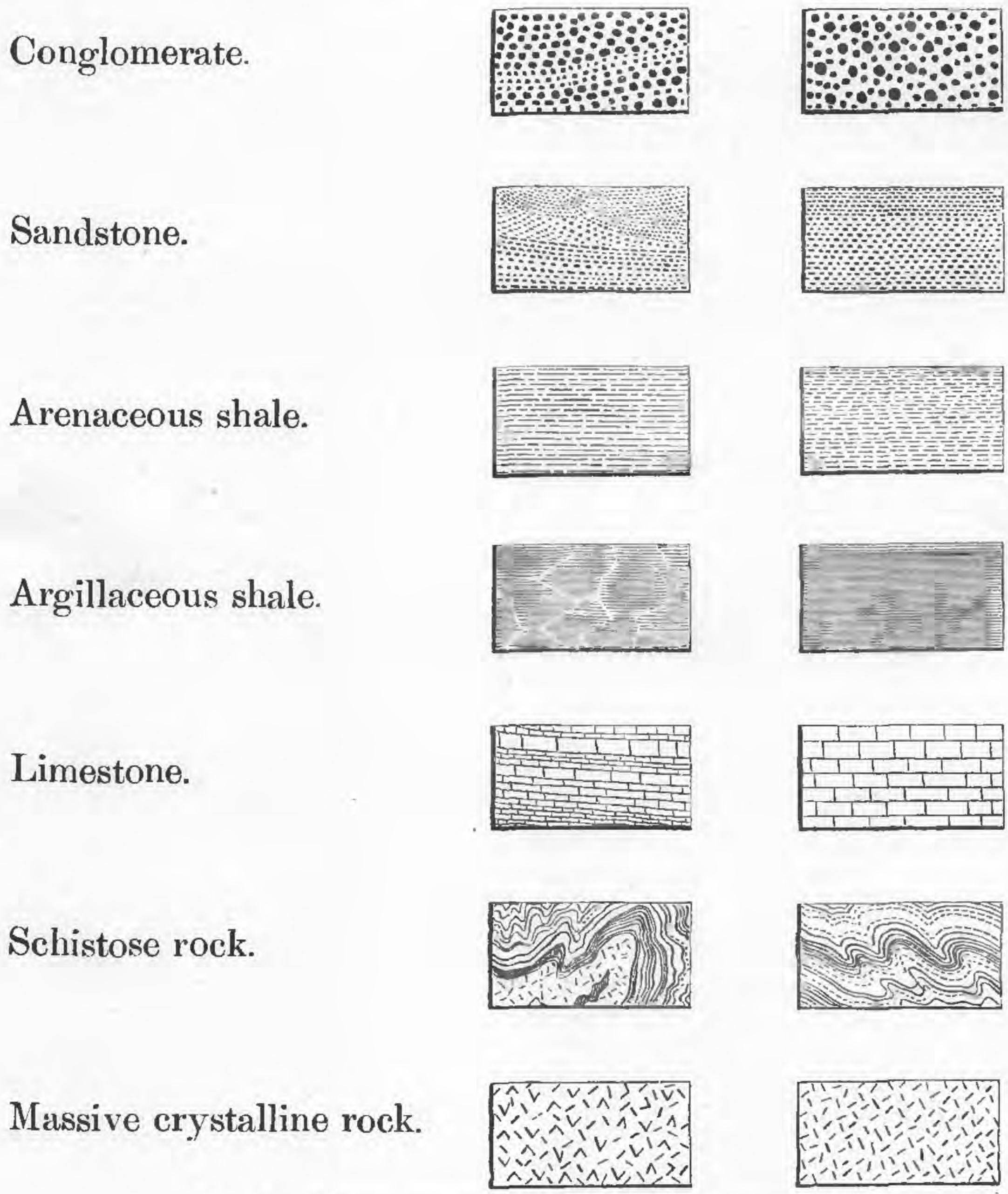
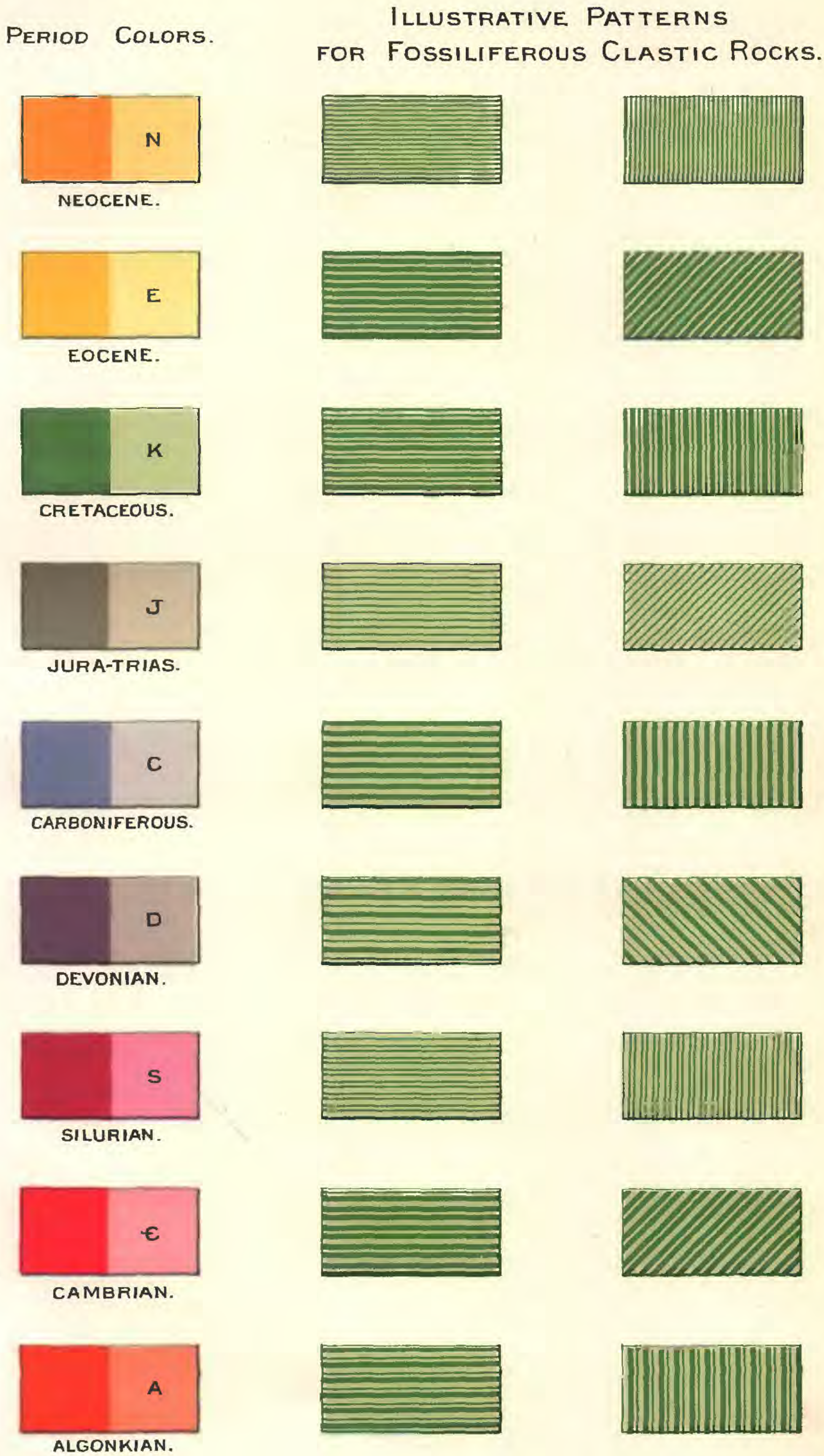


FIG. 1.—Conventional characters for diagrams.

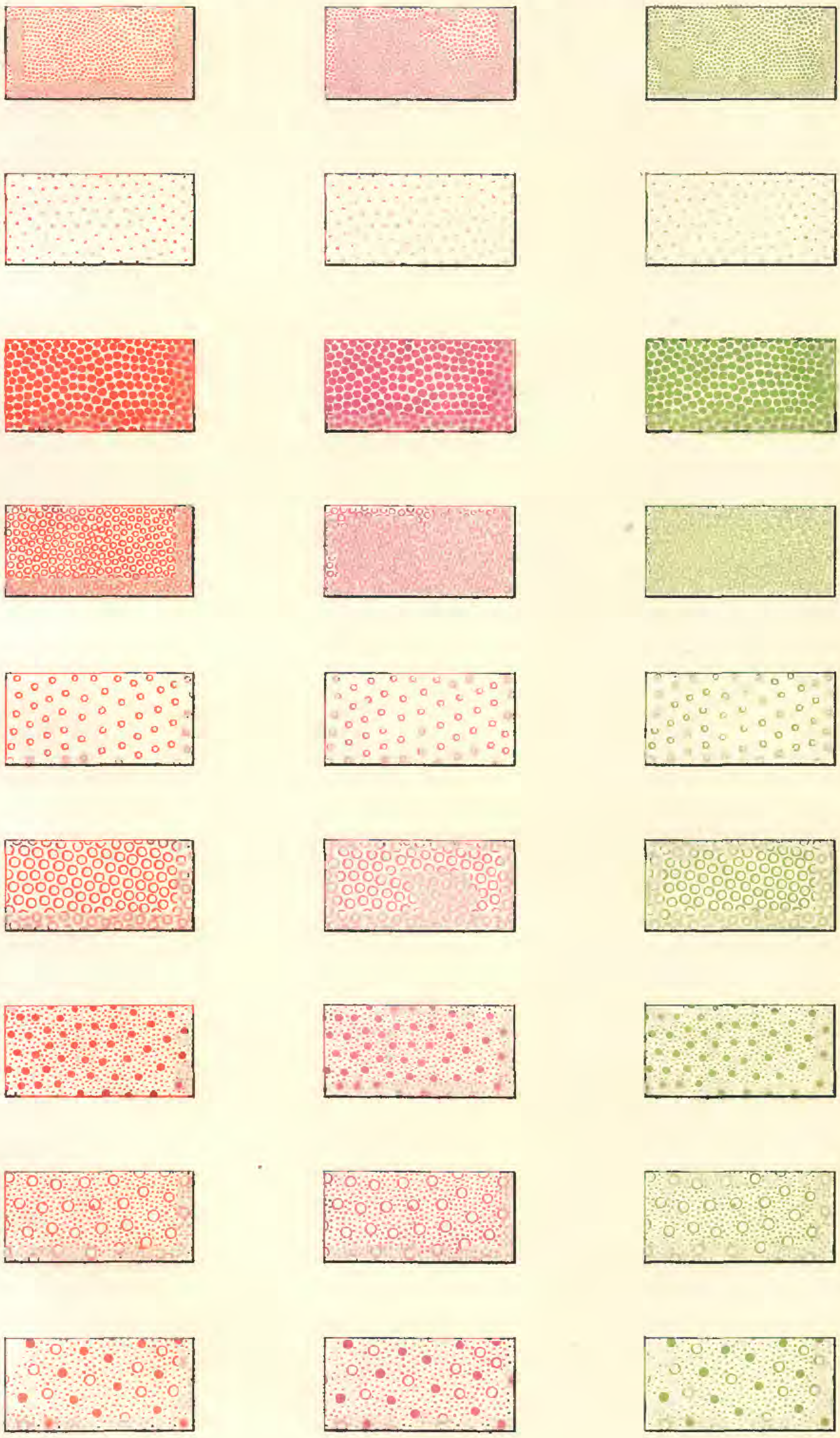
and circles. For the volcanics, tones of contrasting colors are combined in strong or brilliant tints and patterns of angular figures, as triangles and rhombs. For the ancient crystallines or metamorphics, colors are used in two contrasting tones in the overprints, with an underprint of brown for Archean, while

Standards for Geological Cartography.



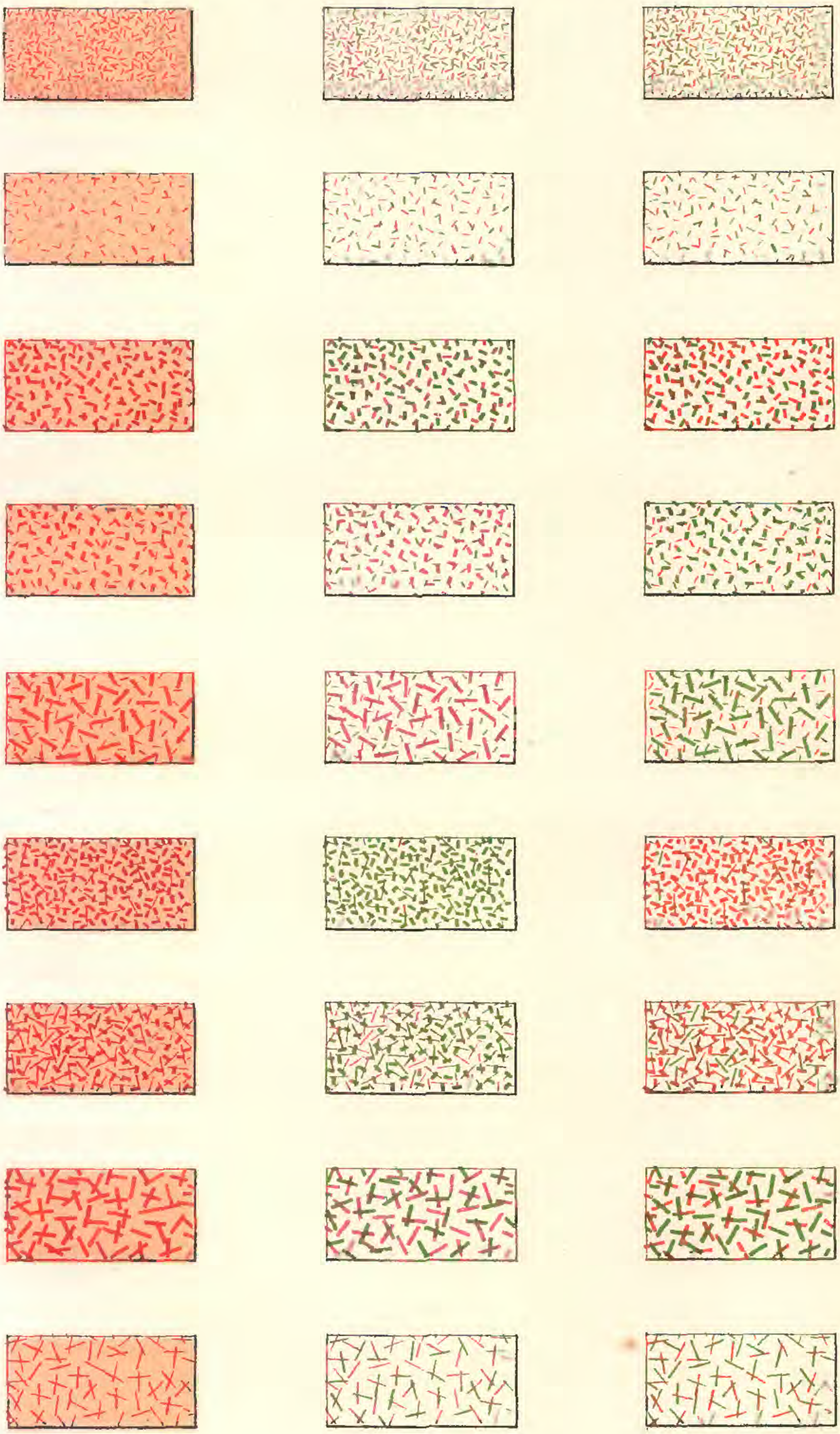
STANDARDS FOR GEOLOGICAL CARTOGRAPHY.

ILLUSTRATIVE PATTERNS FOR SUPERFICIAL DEPOSITS.



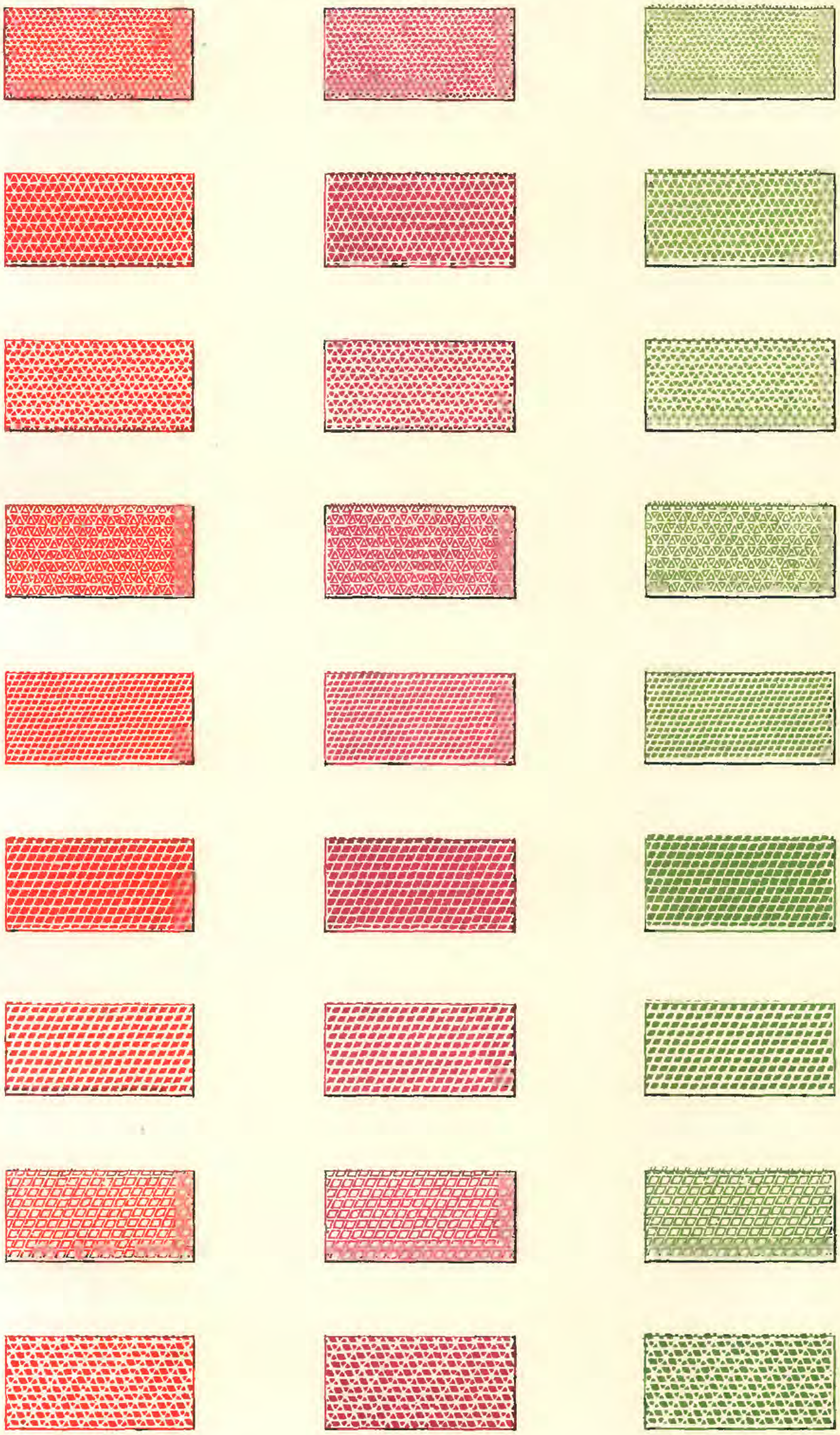
STANDARDS FOR GEOLOGICAL CARTOGRAPHY.

ILLUSTRATIVE PATTERNS FOR ANCIENT CRYSTALLINE ROCKS.



STANDARDS FOR GEOLOGICAL CARTOGRAPHY.

ILLUSTRATIVE PATTERNS FOR VOLCANIC ROCKS.



the patterns are hachures. Wide experiment shows that the distinctions thus summarily outlined serve to clearly differentiate the symbols of the great classes of rocks, so that they are promptly and clearly segregated by the eye when the map is presented.

By the use of the entire color scheme for each of the four classes the device of color distinctions is not made to perform overduty and the eye is not compelled to make many and refined distinctions of tint and tone. By the use of distinct pattern systems color and pattern are combined in such a manner as to aid each other. By the use of a common scale of color for the common scale of time with the four classes of rocks, the time relations to be represented on the maps are expressed by symbols in the clearest and most economical manner.

In this country and in Europe alike usage in relation to geologic map symbols has been greatly diverse, but it is believed that everywhere a tendency in the direction more fully formulated in the above plan is to be observed. In this plan the Director has earnestly endeavored to do the least possible violence to usage, to make the greater categories most distinctive, to make them all reasonably so, and to correlate the different systems of symbols in such a manner as to make time relations clear.

While this subject has been one of constant study by the Director for many years, he is indebted to his colleagues on the Survey for much careful experimentation and many valuable suggestions. He is especially indebted to Messrs. Gilbert and McGee, to whom the subject in all its parts and in all stages of investigation has been referred from time to time. Mr. Gilbert has supervised the experiments and selected the specific patterns in the several classes. Mr. McGee and Mr. Darton have collected from the cartographic literature of geology the symbols used in Europe and America and systematized the same for convenient examination. Mr. Holmes in the earlier years and Mr. Gill in the later have rendered efficient service as experts in the use of color. While drawing on all possible sources and receiving great aid from others, the Director is alone responsible for the final plan.

DISBURSEMENTS.

The accounts of the Survey are in the hands of Mr. Jno. D. McChesney, chief disbursing clerk, who, during the entire existence of the bureau under its present direction, has been responsible for this important service, and who has discharged with unvarying care and fidelity the trusts confided to him.

FINANCIAL STATEMENT.

Amounts appropriated for and expended by the United States Geological Survey for the fiscal year ending June 30, 1889.

		General expenses.	Office salaries.	Total appropriation.
Amounts appropriated		$569,700.00	$35,540.00	$605,240.00
Amounts expended, classified as follows:				
Expenses.				
A. Services	$376,342.92			
B. Traveling expenses	27,443.90			
C. Transportation of property	5,395.41			
D. Field subsistence	18,085.99			
E. Field supplies and expenses	45,276.86			
F. Field material	23,725.41			
G. Instruments	11,007.35			
H. Laboratory material	3,096.42			
I. Photographic material	3,330.91			
K. Books and maps	3,704.15			
L. Stationery and drawing material	1,611.45			
M. Illustrations for report	60.35			
N. Office rents	1,168.30			
O. Office furniture	1,466.34			
P. Office supplies and repairs	2,438.24			
Q. Storage	465.28			
R. Correspondence	543.59			
S. Bonded railroad accounts. Transportation of assistants, $1,919.81. Freight, $318.25	2,238.06	527,400.93		
Salaries.				
A. Salaries			35,007.50	562,408.43
Balance unexpended		42,299.07	532.50	42,831.57
Probable amount required to meet outstanding liabilities.		42,299.07		

In Mr. McChesney's administrative report will be found a statement of the extended details of disbursements of which the above is a concise summation.

DEPARTMENT OF THE INTERIOR, UNITED STATES GEOLOGICAL SURVEY.

ADMINISTRATIVE REPORTS
OF
CHIEFS OF DIVISIONS
AND
HEADS OF INDEPENDENT PARTIES,
ACCOMPANYING THE ANNUAL REPORT OF THE
DIRECTOR OF THE U. S. GEOLOGICAL SURVEY
FOR THE
FISCAL YEAR ENDING JUNE 30, 1889.

ADMINISTRATIVE REPORTS.

REPORT OF MR. HENRY GANNETT.

U. S. Geological Survey,
Branch of Geography,
Washington, D. C., July 1, 1889.

Sir: I have the honor to submit the following report upon the operations of the Geographic Branch of the Survey during the fiscal year 1888–'89:

During the year the work of this branch has been carried on in twenty-three States and Territories, including Maine, New Hampshire, Rhode Island, Connecticut, New York, Pennsylvania, Maryland, Virginia, West Virginia, Kentucky, North Carolina, Tennessee, Georgia, Alabama, Texas, Arkansas, Kansas, Iowa, Wisconsin, New Mexico, Montana, California and Oregon. The entire area surveyed by the Geographic Branch was 43,222 square miles, 6,472 of which was surveyed for the scale of 1 : 62,500, 26,850 for the scale of 1 : 125,000, and 9,900 for that of 1 : 250,000. In addition to the area specified above, the Topographic Division of the Irrigation Survey has surveyed to date 21,000 square miles, which, as a contribution to the general map of the United States, may be added, making a total of 64,222 square miles surveyed by the organizations under your charge and thus completing ninety-nine atlas sheets. The area surveyed by the Geographic Branch is distributed as shown in the following table and in the map which constitutes Plate I:

State.	Scale of field work.	Scale of publication.	Contour interval.	Area surveyed.
			Feet.	*Sq. miles.*
Maine	1 : 45000	1 : 62500	20	320
New Hampshire	1 : 45000	1 : 62500	20	575
Rhode Island	1 : 45000	1 : 62500	20	1,000
Connecticut	1 : 45000	1 : 62500	20	550
New York	1 : 45000	1 : 62500	20	645
Pennsylvania	1 : 45000	1 : 62500	20	842
Maryland	1 : 63360	1 : 125000	50	400
Virginia	1 : 63360	1 : 125000	50 100	5,550
West Virginia	1 : 63360	1 : 125000	100	600
Kentucky	1 : 63360	1 : 125000	100	800
Georgia	1 : 63360	1 : 125000	50	1,500

State.	Scale of field work.	Scale of publication.	Contour interval.	Area surveyed.
			Feet.	*Sq. miles.*
Alabama	1 : 63360	1 : 125000	100	2,300
Texas	1 : 62500	1 : 125000	50	6,250
Arkansas	1 : 62500	1 : 125000	50	3,500
Kansas	1 : 62500	1 : 125000	50	4,200
Iowa	1 : 31680	1 : 62500	20	1,500
Wisconsin	1 : 31680	1 : 62500	20	590
New Mexico	1 : 126720	1 : 250000	200	2,500
Montana	1 : 126720	1 : 250000	200	4,400
California	1 : 63360	1 : 125000	100	2,200
Oregon	1 : 126720	1 : 250000	200	3,000

ORGANIZATION.

During the first three months of the year the general organization remained substantially the same as in former years, and under that organization the parties were sent to the field and commenced work.

As a consequence of the passage in the last days of September of the bill creating an Irrigation Survey, a radical change in organization was made early in October. All that part of the personnel which was engaged in work within the limits of the arid region was constituted a Division of the Irrigation Survey. The change involved the transfer of the work going on in New Mexico, California and Montana. This report, therefore, relates only to work done by these parties up to the close of September. Subsequent to this change the other parties belonging to what was formerly the Western Division, namely, those operating in western Oregon and Texas, reported directly to me during the remainder of the field season.

A further change was made in organization during the spring. A new division, known as the Southern Central Division, was constituted, and to it was assigned all work in the southern portion of the Mississippi Valley and in Texas. This had the effect of transferring from the former Central Division to the Southern Central Division the personnel working in Arkansas. This division was placed in charge of Mr. R. U. Goode. The name of the Central Division was at the same time changed to Northern Central Division.

Numerous transfers of personnel have been made during the year, mainly for the purpose of increasing the force engaged on the Irrigation Survey. These changes will be enumerated in their proper places in this report.

NORTHEASTERN DIVISION.

This division has remained under the direction of Mr. Marcus Baker. It has surveyed an area of 3,932 square miles. Thirty-one atlas sheets, all on a scale of 1: 62,500, and with contour interval of

20 feet, have been prepared, in part by survey and in part by compilation, and completed ready for engraving. The field of work was southern Maine and New Hampshire, Rhode Island, eastern Connecticut, eastern New York and eastern Pennsylvania.

Massachusetts and New Jersey were mapped in previous years, and the energies of the division have this year been devoted mainly to completing atlas sheets along the borders of those States and to mapping Rhode Island. This State was completely mapped during the year under a joint arrangement between its authorities and this organization, whereby the expense of the survey was shared equally.

Nearly all the division was in the field and at work before July 1, 1888, and the field season closed late in November. From that time to the middle of May, 1889, the division was in the office in Washington completing the drawing of the maps surveyed in 1888. The whole division resumed field work in May, 1889, and between that time and June 30, 1889, had surveyed an area of 767 square miles, this area being in southern Maine, western Connecticut, the vicinity of New York City and in the anthracite coal fields of Pennsylvania.

The foregoing brief summary of the work of the division may now be set forth somewhat more fully:

At the beginning of the fiscal year July 1, 1888, several of the parties of this division were in the field at work. These are briefly enumerated as follows: Messrs. R. U. Goode and C. F. Urquhart were engaged under temporary detail in extending the triangulation in Rhode Island for the purpose of furnishing points to the topographers. This work was completed on July 17, 1888, when Messrs. Goode and Urquhart returned to the Western Division.

Messrs. J. H. Jennings, E. B. Clark and William Kramer, each with one assistant, were at work in Rhode Island. Mr. C. C. Bassett, with an assistant, was engaged in extending the triangulation over those portions of the Berlin and Pittsfield sheets which extend beyond the western boundary of Massachusetts into New York, preparatory to mapping the topographic details. Mr. R. D. Cummin, with one assistant, was engaged in the survey of the New York portions of the Ramapo and Greenwood Lake sheets, which lie partly in New Jersey, and Mr. E. W. F. Natter had commenced work upon the Germantown sheet lying north of Philadelphia.

The remaining parties of this division were placed in the field during July. In this month Mr. W. H. Lovell commenced work in southwestern Maine and southeastern New Hampshire, first completing the Newburyport and Haverhill sheets, the Massachusetts portions of which had been surveyed in former years, and subsequently surveying the York and Dover sheets. During most of the season Mr. Lovell had two assistants. The area surveyed by this party during the season was 600 square miles.

In my last report it was stated that the State of Rhode Island had made an appropriation of $5,000 with a view of cooperating with this organization in a survey of the State, that a commission consisting of Messrs. David W. Hoyt, John W. Ellis and Winslow Upton had been appointed by the governor, that articles of agreement between the Geological Survey and the commission had been signed, and that under this agreement work had been commenced.

As the existing triangulation of the U. S. Coast and Geodetic Survey was inadequate for the needs of the topographers, Messrs. Goode and Urquhart were temporarily detailed for the purpose of locating, from bases furnished by the triangulation of the Coast and Geodetic Survey, a number of additional points so distributed as to enable the topographers to work to advantage from them. This work was in progress at the date of my last report, and it was completed about the middle of July.

Owing to the unreliability of the railroad profiles in the State it was evident that it would be necessary to supply the primary basis for the contour work of the map, and Mr. Frank Sutton, with a rodman, was detailed to run a number of level lines across the State, establishing benchmarks suitable for the use of the topographers. This work was finished prior to the date of my last report. As above stated, Messrs. Jennings, Kramer and Clark, each with one assistant, were at work with plane table, transit and stadia, mapping the topography. This work was prosecuted with great energy and good judgment, and the success with which it was attended is due in no small degree to Mr. Jennings, who had, under Mr. Baker, the general supervision of it. The State was completed early in the fall, and in order that the maps of its entire area might be engraved without delay, the Connecticut portions of those sheets which lie partly in that State were also surveyed. In order to effect this, however, it became necessary to put additional force into this field, and consequently Messrs. R. D. Cummin and F. P. Gulliver were transferred from Pennsylvania for a few weeks near the close of the season to assist in finishing it.

During the season Mr. Jennings, in addition to the work of supervision, surveyed an area of 415 square miles, Mr. Kramer surveyed an area of 317 square miles and Mr. Clark 284 square miles.

As was above noted, Mr. Bassett, with Mr. James Longstreet, jr., as assistant, was engaged at the opening of the fiscal year in extending triangulation over the New York parts of the Berlin and Pittsfield sheets. This work, which presented peculiar difficulties, occupied him until the end of July, when he commenced topographic work. He completed the sheets early in November, covering an area of 245 square miles.

The plans for the prosecution of work during the past season included a survey of the sheets comprising New York City and its suburbs, probably the most important group of sheets in the United

States, and in many respects the most difficult to survey, owing to the complex culture contained therein. For this work selection was made of Mr. S. H. Bodfish, and Mr. Sutton and two aids were detailed to assist him. Of the four sheets comprising this area the whole of the northwestern, together with that part of the southwestern sheet which is in the State of New Jersey, had been surveyed by the New Jersey Geological Survey. There remained to be surveyed the two eastern sheets and that part of the southwestern sheet which lies within New York State.

Mr. Bodfish commenced work in July. He devoted most of his time during the season to the compilation of existing surveys of the cities of New York and Brooklyn and in examination of these surveys on the ground, correcting them and bringing the culture up to date. It was found that a large part of this area had been surveyed upon a large scale and was in such shape that it could be profitably used. Mr. Sutton was engaged meantime in surveying such parts of the area as were not covered by these compilations. The close of the season found the work very nearly completed, small areas only being left upon the two eastern sheets. During the past spring the work in these areas has been finished, and with the exception of the office work the sheets are completed.

During the season Mr. Cummin, with one assistant, surveyed the unsurveyed portions of the Ramapo and Greenwood Lake sheets, which lie in New Jersey and New York, and of the Wallpack sheet lying in New Jersey and Pennsylvania. Toward the end of the season he was ordered to eastern Connecticut, where he assisted in the completion of the Moosup sheet. The entire area surveyed by him during the season was 395 square miles.

In July Mr. W. D. Johnson, with Mr. F. P. Gulliver as assistant, took the field, with instructions to complete the Pennsylvania portions of the Delaware Water Gap sheet. On October 1 Mr. Johnson was transferred to the Irrigation Survey and placed in charge of the work in the Arkansas Basin. The Delaware Water Gap sheet was completed by Mr. Gulliver, after which he was ordered to eastern Connecticut, where he assisted in the survey of the Stonington sheet. The entire area surveyed by Messrs. Johnson and Gulliver is estimated at 217 square miles.

To Mr. Natter was assigned the survey and completion of a number of sheets in eastern Pennsylvania, the Germantown sheet entire, and portions of the Philadelphia, Burlington, Lambertville, Easton, Quakertown and Doylestown sheets. He was given a strong party, consisting of Messrs. Atkinson and Ahern with three rodmen. Mr. Natter personally undertook the control, by plane table, of all these sheets, together with the detailed survey of the Germantown sheet and the unfinished part of the Philadelphia sheet. The work projected was completed during the season, and of the area surveyed

Mr. Natter reported as his own personal work 225 square miles, Mr. Atkinson 235 and Mr. Ahern 192 square miles.

The extent of Mr. Lovell's work in Maine being greater than was anticipated, it became necessary that additional triangulation should be executed to control his map. It seemed desirable also to extend the triangulation beyond the immediate needs of the current season in order that the topographers might have points ready for them during the coming season. For the purpose of carrying on this triangulation Mr. S. S. Gannett was temporarily transferred from his Arkansas field of work to Maine early in October. He spent about six weeks in the field in Maine, and in that time located a sufficient number of points to control eight atlas sheets, after which he returned to Arkansas for the purpose of completing the work in that region.

During the spring Messrs. Bassett and Ahern were transferred from this division to the Irrigation Survey.

On the completion of their maps in the spring the parties resumed field work. Mr. Lovell, with Messrs. G. L. Johnson and G. E. Hyde, went on with the work in Maine, and during the months of May and June their output was 295 square miles, making the entire area surveyed by Mr. Lovell's party during the year 895 square miles.

During the spring the legislature of Connecticut passed a bill looking toward cooperation with this organization in making a survey and map of that State. The arrangements for cooperation have not yet been completed, but, assuming that the matter will be arranged, plans have been made for surveying the western half of the State during the field season, parties have been placed in the field and are actively at work. Upon many of the sheets there are a sufficient number of locations from the triangulation of the U. S. Coast and Geodetic Survey for the needs of the topographers, and work has been commenced upon several of them, with the intention of having the triangulation extended over the other sheets as soon as the services of Mr. S. S. Gannett can be spared from the Pennsylvania field for this purpose.

The datum points for the contour work have been supplied by Mr. W. R. Atkinson, who during the months of May and June has run lines of levels over 145 miles in the western part of the State, most of the way on railroads, determining the elevation above mean tide of all road crossings and other points suitable and convenient for datum points.

Three topographic parties were placed in the field during May, the first in charge of Mr. Jennings, with Messrs. Lambert and Ulke as assistants; the second in charge of Mr. Natter, with Mr. Longstreet as assistant; and the third in charge of Mr. Clark, with Mr. J. W. Thom as assistant.

Besides having charge of a party, Mr. Jennings has general charge of the Connecticut work. These parties have thus far been employed mainly in secondary triangulation with the plane table, Mr. Natter only reporting an area completed of 150 square miles.

A party under Mr. Sutton has been occupied during June in completing the Harlem and Brooklyn sheets of the New York area, which is now practically finished.

In response to an urgent request from the Second Geological Survey of the State of Pennsylvania for maps of the anthracite region, work was commenced there in May. Certain of the atlas sheets comprising this region were found to be sufficiently controlled by the triangulation of the U. S. Coast and Geodetic Survey, but in a majority of these sheets it was evidently necessary to extend and supplement this triangulation before the plane tablers could take up the work. Mr. Gannett was therefore detailed to the field for this work early in May. Up to this date he has occupied eight stations and has located points for the control of seven atlas sheets. Three topographic parties have been detailed to this area; the first in charge of Mr. Cummin, with Mr. G. S. Smith as assistant; the second in charge of Mr. Gulliver, with Mr. J. H. Wheat as assistant; the third in charge of Mr. Kramer, with Mr. C. J. Akin as assistant. These parties have been occupied mainly with secondary triangulation with the plane table. Mr. Cummin reports, however, a surveyed area of 100 square miles, making his entire area for the year 495 square miles, and Mr. Gulliver an area of 135 square miles.

SOUTHEASTERN DIVISION.

This division has remained in charge of Mr. Gilbert Thompson. During the past year work has been prosecuted in Virginia, North Carolina, eastern Kentucky, Tennessee, Alabama and Georgia, and an area of 11,150 miles has been surveyed. This small output of work, not more than two thirds the average, is attributable in part to the fact that a number of the most experienced assistants have been engaged upon the revision of earlier work, but in still larger part to the brevity of the field season of 1888, in consequence of the late adjournment of Congress.

During the season of 1888 the division was organized in six surveying parties, in charge respectively of Messrs. E. C. Barnard, Morris Bien, L. C. Fletcher, C. M. Yeates, Merrill Hackett and Louis Nell; besides these parties a number of experienced topographers, Messrs. J. W. Hays, R. O. Gordon, A. E. Murlin, R. C. McKinney, R. M. Towson and D. C. Harrison, were engaged in revising the work of 1882–'83 and in completing partially finished sheets. Several of these men were in the field at work at the beginning of the fiscal year, as was noted in my last annual report. Among them were Mr. Gordon, who was engaged upon a revision of the Greeneville sheet in Tennessee; Mr. Hays, upon the Mount Mitchell sheet in

North Carolina; and Mr. Murlin, upon the Estillville sheet in southwestern Virginia. Mr. Towson, after serving as an assistant in Mr. Barnard's party for a few weeks, commenced a revision of the Saluda and Pisgah sheets in western North Carolina about the middle of August, and Messrs. Harrison and McKinney commenced the revision of the Bristol and Wytheville sheets at about the same time. With the exception of Mr. Hays, all of these men were occupied throughout the season in this work, and the revision of the following sheets was completed:

Wytheville, Abingdon, Bristol, Estillville, Jonesville, Taylorsville, Roan Mountain, Greeneville, Mount Mitchell, Asheville, Pisgah and Saluda. Upon several of these sheets this revision was equivalent to a resurvey of the topographic details, the primary and secondary triangulation of the former survey only being used; while in the case of other sheets it was necessary only to traverse a few lines in order to bring the work up to the standard required by the scale. I am glad to be able to report that the work of revising these early surveys in the Appalachian region is completed.

Early in August Mr. Hays's health became so impaired that he was obliged to retire from field service, and for some weeks he was in a critical condition. Early in October, having partially recovered his health, he was detailed to the Irrigation Survey and was sent to the field in Colorado.

In the latter part of July Mr. Barnard was ordered to the field in charge of a party. Messrs. C. H. Van Hook and L. J. Battle were detailed as assistants to this party, and Mr. R. M. Towson also served there until detailed in August to assist in the revision surveys in North Carolina. In October the party was strengthened by the addition of Mr. W. O. Beall. To this party was assigned the survey of the Goochland, Palmyra and part of the Buckingham sheets in central Virginia; this area was completed, with the exception of a small portion of the Palmyra sheet, the area surveyed by this party during the season being about 2,200 square miles. Owing to the level and forested character of the country Mr. Barnard was obliged to use traverse methods throughout, not only for topographic details but for the primary control of the work.

Late in July Mr. Fletcher was sent to the field in charge of a party consisting of Messrs. W. J. O'Connell, R. J. Breckenridge, H. W. Carpenter and W. L. Miller, under instructions to survey the Natural Bridge, Lexington and Buckingham sheets in western Virginia; Messrs. Clifford Arrick and Charles Bogan were subsequently detailed to this party. Work was prosecuted effectively until late and the assigned area was completed, estimated at 2,050 square miles.

A third party was ordered to the field in charge of Mr. Bien on the 1st of August, and to this party were detailed as assistants Messrs. A. B. Searle, C. E. Cook, Nat. Tyler, jr., Howard Seely and Harry

Irwin. This party was instructed to survey the entire Roanoke sheet and small portions of adjoining atlas sheets. The area assigned to it, amounting to 1,300 square miles, was completed during the season.

At the opening of the fiscal year Mr. Hackett was at work with several assistants upon the Frederick sheet in Maryland, directly north of the District of Columbia. This sheet was completed in the early part of August, when Mr. Hackett was ordered to his old field in Georgia, with Messrs. R. McC. Michler and Hersey Monroe as assistants. Early in October this party was strengthened by the addition of Messrs. G. H. Lamar and E. S. Parker. Mr. Hackett was instructed to survey the Atlanta sheet and the unfinished portions of the Marietta sheet in Georgia, an area of some 1,500 square miles. This area was completed and the party disbanded in November.

On the 14th of August Mr. Louis Nell was ordered to the field in Alabama, and to his party were assigned Messrs. R. L. Longstreet and C. W. Goodlove as assistants, and subsequently Messrs. W. H. Griffin, Duncan Hannegan, F. P. Metzger and B. Peyton Legaré; he was instructed to survey the Bessemer and Talladega sheets, with certain unfinished parts of sheets lying immediately north of them, an area of about 2,300 square miles. Shortly after he had commenced work Mr. Longstreet, his principal assistant, met with a serious accident, breaking his wrist and rendering him incapable of affording further assistance during the season. In spite of this serious loss Mr. Nell succeeded in finishing the area assigned him and disbanded his party in November. Both this party and Mr. Hackett's were obliged to control their areas largely by traverse lines, as the regions in which they were at work contain little relief and are covered with dense forests.

During the early part of the season Mr. F. J. Knight with a small party was engaged in running primary traverses in the territory surveyed by Messrs. Barnard and Fletcher, and later in extending eastward into the Piedmont country the triangulation of the Coast and Geodetic Survey in southern Virginia. In October Mr. Knight was transferred from the Southeastern Division to the Northern Central Division for the purpose of running primary traverses for the control of the work in Iowa.

At the beginning of the fiscal year a party under Mr. C. M. Yeates was at work in Kentucky, engaged in extending northward a triangulation for the control of that area; he was assisted by Messrs. A. E. Wilson and L. D. Brent, and early in October the party was strengthened by several additional assistants. During the season triangulation was extended from the points on the escarpment of the Cumberland plateau, near Cumberland Gap, northward nearly to the Ohio River, connecting with a belt of triangulation made by Mr. F. J. Knight several years previously. In addition to this numerous secondary stations were occupied upon the Manchester sheet in eastern

Kentucky, and the work upon that sheet was nearly completed The area of the topographic work executed by this party is estimated at 300 square miles.

During the winter and spring the parties of this division were busily engaged upon office work. In the spring a number of men were detailed from this division to other parts of the Geographic Branch and to the Irrigation Survey. Messrs. D. C. Harrison and L. D. Brent were detailed to service in Texas early in March. Messrs. Bien and McKinney were detailed to take charge of parties in the Colorado Division of the Irrigation Survey. Mr. Gordon was detailed to take charge of a party in Texas, and Messrs. O'Connell, Cameron and Battle were detailed as assistants in this section. To strengthen the force in Kansas there were detailed Mr. R. M. Towson to take charge of a party, and Messrs. Lamar, Legaré, Griffin and Seely as assistants. Mr. Knight was detailed to take charge of the survey of the iron region of Lake Superior. These details weakened the force of the division to such an extent that many of the men were necessarily retained in the office until late in June to clear up the office work.

Two parties were sent to the field early in May. The first was that of Mr. Fletcher, who, with Messrs. Cooke, Arrick, Miller, Michler and Hannegan as assistants, was directed to survey a strip across West Virginia immediately north of the Kanawha and New Rivers, a very difficult section of country. The party began work about the middle of May and up to the present date has surveyed 600 square miles. The next party to take the field was that of Mr. Barnard, who was detailed to eastern Kentucky. As assistants to Mr. Barnard were detailed Messrs. Van Hook, Goodlove, Tyler, Wilson and Beall. The party got at work very promptly and up to the present date have surveyed a little more than half of the Hazard sheet, an area of about 500 square miles. This region in which Mr. Barnard is engaged is probably the most difficult, considering all the conditions, to be found in the country.

About the middle of June a party under Mr. Nell was sent to the field in central Alabama, with instructions to extend the surveyed area southward toward Montgomery. The party is outfitted and is now at work, but the output to date is inconsiderable. At the same time a party under Mr. Hackett was directed to take the field for the survey of a portion of the drainage basin of the Savannah River in Georgia and South Carolina. This party has also completed outfitting and is now well at work. A fifth party, under Mr. Murlin, was sent to the field at about the same time, with instructions to survey an area upon the Atlantic Plain south and west of Richmond.

CENTRAL DIVISION.

This division has remained in charge of Mr. J. H. Renshawe, and work has been prosecuted in all the fields occupied during the previous season, viz: in Wisconsin, Iowa, Missouri, Kansas and Arkansas.

Arkansas Section.—Work was resumed in Arkansas early in August. Mr. S. S. Gannett remained in charge of the section and of the triangulation party. He was assisted by Messrs. G. T. Hawkins and S. Chester Reid. The topographic party was in charge of Mr. H. B. Blair, who was assisted by Messrs. Basil Duke, W. E. Lackland and M. R. Avery. The triangulation was extended eastward to Little Rock, where a check base was measured on the north side of the Arkansas River in the township of Argenta, expansion effected and connection made with the main belt. Connection was also made with an astronomical station at Little Rock, whose position had been determined by the U. S. Coast and Geodetic Survey. The triangulation of this section completes a belt extending from the eastern border of the Indian Territory eastward across the entire width of the Ozark Hills to Little Rock. This belt consists of strong figures, quadrilaterals and pentagons, and it will serve as a basis for an extension of the work northward and southward. In connection with the triangulation mention should be made of the fact that during the six weeks of Mr. Gannett's absence in New England his assistant, Mr. Hawkins, was left in charge of the work, and most of the angles in the main triangulation were measured by him during this time.

The topographic party, although greatly delayed by illness among its members, surveyed three atlas sheets, those known as the Benton, Dardanelle and Hot Springs, an area of about 3,000 square miles.

Missouri-Kansas Section.—To Mr. H. L. Baldwin was assigned the duty of surveying the two atlas sheets comprising the cities of St. Louis and East St. Louis, upon the scale of 1 : 62,500 in 20-foot contours. Work was commenced early in July, and consisted during that month of the compilation of material from the city and railroad offices and the verification of it. It was not until August 1 that field work commenced. This was pushed with Mr. Baldwin's customary vigor and efficiency, and by the end of September the two sheets were completed. Orders were then given Mr. Baldwin to proceed to Kansas and to survey the Wichita, Abilene and Newton sheets upon the scale of 1 : 125,000 in 50-foot contours. These instructions were carried out and the sheets were completed early in November. The areas surveyed by this party are as follows:

Upon the two St. Louis sheets, 450 square miles; upon the three Kansas sheets, 3,000 square miles.

Iowa Section.—Messrs. W. J. Peters and C. T. Reid, who were assigned to this field of work, arrived on the ground about the middle of July, and spent the next two weeks in an examination of county records and in compilation of railroad plans and profiles, city plans, etc., for subsequent use in the field. Field work was commenced about the end of July, and prosecuted continuously until late in November. The output of the season consists of five atlas sheets upon the scale of 1 : 62,500 in 20-foot contours. These sheets lie north and west of those surveyed during the previous season. The area surveyed is estimated at 1,225 square miles.

In October Mr. F. J. Knight was detailed from the Appalachian Division to Iowa, for the purpose of running primary traverses for control of the areas surveyed by Mr. Peters. In this work Mr. Knight was very successful. Commencing with the astronomical determination at the Rock Island Arsenal, he ran, following the Chicago, Rock Island and Pacific Railroad to Des Moines, a distance of about 175 miles, connecting at that place with an astronomical determination of position. Returning along the Rock Island road to Homestead Station, he ran a line northeast from that point to Sherrill's Mound, a station of the U. S. Coast and Geodetic Survey near Dubuque. Mr. Knight used for directions a six-inch transit reading to 10″, checking his measurements by azimuth observations every 25 miles on an average; for distances he used a 300-foot steel tape under constant tension. These lines serve to control a large area in eastern Iowa.

Wisconsin Section.—As stated in my last report, a considerable area had been surveyed by Mr. I. M. Buell in southern Wisconsin, acting under instructions of Prof. T. C. Chamberlin of the Survey. This area was irregular in shape and its limits did not conform to sheet lines. Last year a little work was done by Mr. Renshawe personally in the direction of completing unfinished atlas sheets. The work of completing the remaining unfinished sheets was undertaken this year, and to it was assigned Mr. Van H. Manning, jr. Field work was commenced by him on September 24 and continued through October. An area of 390 square miles was surveyed during this time, completing, with the aid of the work of Mr. Renshawe during the previous season, six atlas sheets.

During the winter the topographers were engaged in the Washington office, where the work was pushed rapidly and field service was resumed as early as the season would admit.

The survey of the iron region upon the upper peninsula of Michigan having been determined upon, Mr. F. J. Knight, with A. H. Brooks as assistant, was detailed to that field in the early part of May, 1889. The scale adopted for the work is that of 1 : 62,500, and the contour interval 20 feet. The preliminary work consisted in the extension of triangulation from a base furnished by the United States Lake Survey, at Marquette, westward across the area to be surveyed. This has been laid out throughout the entire extent of the work, the angles have been measured over a part of the area, and Mr. Knight has just commenced the mapping of topographic details.

In the latter part of May Mr. Manning was instructed to take the field for the purpose of extending surveys in Wisconsin eastward toward Lake Michigan. His preparations were quickly made and work commenced shortly after his arrival upon the ground. Up to date he has surveyed an area of 200 square miles.

Work was resumed in Iowa shortly after the middle of May by Messrs. Wm. H. Peters and C. T. Reid. They were occupied during the remainder of the month in collecting railroad plans and profiles in the area to be surveyed, and commenced topographic work on the 1st of June. During that month they surveyed 275 square miles, making the entire area for the year in that region 1,500 square miles.

The plans of work for the current season included the survey of fifteen sheets in southern Kansas extending from the meridian of 97° 30′ to 100°, and from the south line of the State northward to the parallel 38° 30′. For the survey of this area the following organization has been provided: A triangulation party, under Mr. H. L. Baldwin, who is in charge of the section, and two topographic parties, in charge, respectively, of Messrs. W. H. Herron and R. M. Towson. These parties have as assistants Messrs. Black, Griffin, Seely, Lamar and Legaré. Messrs. Baldwin and Herron took the field early in May, and were occupied during that month in the compilation of data relating to the area to be surveyed, including the plans and profiles of railroads, town sites, etc. Early in June the remaining members of the section were sent to the field, the topographic parties were organized, and are now at work. Up to this date Mr. Herron's party reports the survey of 500 square miles and Mr. Towson's party of 700 square miles.

SOUTHERN CENTRAL DIVISION.

This division was constituted in May, and is in charge of Mr. R. U. Goode, topographer.

Arkansas Section.—Work in Arkansas was resumed early in May, when Mr. G. T. Hawkins, with S. Chester Reid as assistant, was sent to the field for the purpose of extending triangulation northward over the belt measured during the two preceding years. Although retarded somewhat by sickness and bad weather, Mr. Hawkins has made good progress in the execution of a most difficult piece of work.

A topographic party was organized under Mr. H. B. Blair, with Messrs. Duke, Lackland and Avery as assistants, and commenced work early in June. During that month they surveyed an area of 486 square miles. The entire output of this party during the year was about 3,500 square miles.

Texas Section.—Work in the Texas section was resumed early in April, when Messrs. Goode and Urquhart were sent to the field, under instructions to measure a base line in the vicinity of Albany, Texas, to connect it with the triangulation, and to extend the latter over the area to be surveyed. A base between eight and nine miles long was selected and measured with the steel tape. Connection with the triangulation was made directly without expansion, and triangulation has been extended over four sheets.

The topographic parties were sent to the field early in May. They are in charge, respectively, of Messrs. H. S. Wallace and R. O. Gordon. Mr. Wallace has as assistants Messrs. Battle, Shelley and Martin, while Mr. Gordon is assisted by Messrs. O'Connell and Cameron. Although the weather has been very unfavorable during the months of May and June, each of these parties has succeeded in surveying about 1,000 square miles, Mr. Gordon completing the Albany, and Mr. Wallace the Palo Pinto sheet.

Early in March Mr. E. T. Dumble, State Geologist of Texas, requested the services of topographers for the purpose of mapping the iron region in the northern part of that State, and offered to pay the field expenses of the party. In accordance with this request Messrs. D. C. Harrison and L. D. Brent were ordered to Texas, with directions to survey Cherokee County upon the scale of one mile to an inch in contours 20 feet apart. Although considerably delayed by bad weather and other unfavorable conditions work has progressed fairly well, and at the present time an area of 1,250 square miles has been surveyed.

WESTERN DIVISION.

In this division work was continued in Texas, New Mexico, Montana, California and Oregon. As stated above, a change in organization was made October 1, by which the work in New Mexico, Montana and California was withdrawn from the Geographic Branch and placed in the newly constituted Irrigation Survey. This report will, therefore, detail little more than the organization of these parties.

Up to the time of this change in organization the division remained in charge of Prof. A. H. Thompson, and consisted of five sections, corresponding to the regions of work mentioned above.

Texas Section.—This section has remained in charge of Mr. R. U. Goode, who besides having the executive management of the section has personally carried on triangulation for the control of the topographic work. Two topographic parties, respectively under Messrs. C. H. Fitch and H. S. Wallace, have surveyed topographic details.

These parties were late in reaching the field; indeed no work was done until September. It was continued throughout the fall and even into December, the weather being unusually favorable. The field of work lay north of that surveyed in previous years. Mr. Wallace's party, consisting besides himself of Messrs. Frank E. Gove and E. M. Hasbrouck, surveyed the Eastland and Breckenridge sheets, an area of 2,000 square miles.

Mr. Fitch's party comprised besides himself Messrs. J. E. Shelley, Lincoln Martin and T. D. Haile. During September and October he surveyed the Baird sheet, comprising 1,000 square miles. In the latter part of October Mr. Fitch was taken seriously ill, so that he was obliged to give up field work and return to Washington. The party was placed in the hands of Mr. Urquhart, who had been Mr. Goode's assistant upon the triangulation, but it was then so late in the season that little progress was made, Mr. Urquhart being able to survey only some 250 square miles upon the Albany sheet. The triangulation kept pace with the progress of topographic work. Fifteen new stations were occupied and several more signals were built and sighted upon with the view of future occupation.

Oregon Section.—The plans of work in this section contemplated the completion of the Ashland sheet, and the survey of the two sheets lying west of it to the Pacific. The section was placed in charge of Mr. W. J. Griswold, and was organized in two parties, one in his immediate charge, the other in charge of Mr. E. T. Perkins. Work commenced about the middle of July, and continued until the latter part of October, when the prevalence of bad weather seemed to make it advisable to close field work, although the plans had not been fully carried out. The Ashland sheet was finished, but neither of those lying west of it was completed. The areas surveyed by the two parties were as follows: W. T. Griswold, 1,600 square miles; E. T. Perkins, jr., 1,400 square miles; making a total of 3,000 square miles for the section.

California Section.—The organization of this section was the same as during the previous season. It consisted of three parties which, during the portion of the season under consideration, were all engaged in topographic work. These parties were under the general charge of Mr. H. M. Wilson, who personally conducted one of them, the others being in charge of Messrs. A. F. Dunnington and R. H. McKee. At the beginning of the fiscal year these parties were in the field and had completed the triangulation necessary for the control of the season's work. During the months of July, August and September, they surveyed a total area of 2,200 square miles, of which 925 square miles were surveyed by Mr. Wilson's party, 560 by the party under the charge of Mr. Dunnington and 725 by Mr. McKee's party.

Montana Section.—The organization of this section was similar to that of the season before, there being two parties, respectively in charge of Mr. E. M. Douglas and Mr. Frank Tweedy, Mr. Douglas being in general charge of the section. These parties were in the field prior to the beginning of the fiscal year and had completed, or nearly completed, the triangulation necessary for the control of the season's work. During the months of July, August and September these parties surveyed an area of 4,400 square miles.

New Mexico Section.—This section remained in charge of Mr. A. P. Davis, who personally, as in former years, carried on the triangulation and performed some topographic work. Besides his party there were two topographic parties, in charge, respectively, of Messrs. R. H. Chapman and W. W. Davis. These parties took the field in July and commenced operations on the Albuquerque and Santa Fé sheets. Between that date and the 1st of October they surveyed an area of 2,500 square miles.

METHODS.

The development in topographic methods of the Survey is in the direction of using graphic methods of work, and the changes and modifications in instruments have constantly tended in that direction. The adoption of the plane-table head, invented by Mr. W. D. Johnson, which has been noticed in an earlier report, greatly increased the possibilities in the use of graphic methods. Its steadiness, in which it is exceeded by no known movement, its ease of handling, and the accuracy with which triangulation can be carried on by means of it, leave little to be desired in these respects. It seemed, however, that a simpler and lighter movement could profitably be devised for doing traverse work. As this work is concerned only with the details of topography, and as the traverse line is subject to constant checks by means of points located by intersection, a less degree of accuracy is required than in intersection work; and in a plane table for traversing, much in the way of accuracy, steadiness, etc., can safely be sacrificed for the sake of lightness and facility of handling. With this view the little traverse plane table now in general use in the Survey was devised. This has no clamp or azimuth motion beyond what is afforded by the friction between the board and the tripod head. It has no arrangement for leveling further than is afforded by the tripod legs, as it can be set sufficiently level for taking horizontal angles without sensible error by means of them. The board is fifteen inches square and is made of light pine, and has a compass set in one edge of it, in a narrow box, by means of which it is oriented by reference to the magnetic meridian. The alidade for direction is a simple brass ruler with raised sights at the ends. When vertical angles are required, as upon work in 20-foot contours and for control ines in 50-foot contour work, a small, compact, telescopic alidade is used, and as the zero of the level must be read for each vertical angle, even on the best plane table, the want of level of the board is of little consequence. This traverse plane table became generally used at the beginning of the season and at the present date there are fully one hundred in use in this branch and in the Irrigation Survey. They are also being used by geologists to a considerable extent. The traverse work done by them shows a great improvement, not only in accuracy of the instrumental work, but in the character of the sketching, as it is possible by the use of the plane table in traversing to sketch the contours upon a correct plan.

DRAUGHTING DIVISION.

This division, in charge of Mr. Harry King, has for its function the lettering and completion of original maps, the preparation of map illustrations for publication, the compilation of such base maps as are needed in the office, and other incidental duties for which draughtsmen are needed. The following draughtsmen, besides Mr. King, have been employed during the year: J. H. Klemroth, H. V. Wurdeman, M. A. Cudlipp, H. S. Selden, J. B. Torbert, and H. A. Graham.

The principal items of work upon which they have been engaged during the past year are as follows: The so-called nine-sheet map of the United States, a compilation upon the scale of 26 miles to an inch, which has been completed and is now being engraved; a wall map of Massachusetts, compiled from large atlas sheets, to a scale of 1 : 250,000, in contours of 100 feet, which has also been completed, and is now being engraved; a compilation of the State of New York, still in progress, and a map of a portion of the State of Iowa, besides numerous smaller pieces of work which it is unnecessary to recapitulate.

INSTRUMENTS.

The instrument shop, as heretofore, has been in charge of Mr. Edward Kübel. During most of the year he has had three assistants and for the past three months a fourth assistant.

With the growth of the Geographic Branch of the Survey, and the rapid increase in the number of instruments used by it, the work of the instrument shop has become restricted more and more closely to repairs and adjustments of the instruments in use. Indeed, during the last year Mr. Kübel and his assistants have been able to do little more than keep our supply of instruments in order and perform such experimenting as was called for. The only new work which the shop has been able to turn out consisted of a number of simple plane-table movements for traversing and ruler alidades.

ENGRAVING.

In my last report it was stated that Messrs. Julius Bien & Co. had obtained a contract for engraving one hundred sheets of the general map of the United States, upon which they were at that time at work. This contract is now completed and the plates are at the present time deposited in this office. A small edition of these sheets for the use of this office has been printed. In October, 1888, a contract was entered into by the Public Printer with Messrs. Sinclair & Son, of Philadelphia, for engraving one hundred sheets of the general atlas and upon this contract the firm is now at work. In April, 1889, the Public Printer entered into a contract with Mr.

H. C. Evans, of this city, for engraving thirty sheets, and in June made a contract with Messrs. Harris & Co., of Philadelphia, for engraving twenty-one sheets—contracts which have been made during the year covering in all one hundred and fifty-one sheets. On all these contracts work is progressing rapidly. In addition to the sheets now under contract there are about twenty-five finished sheets in the office awaiting engraving. At the date of my last report one hundred and sixty-six sheets of the general atlas had been engraved, and a table was presented giving the names and locations, scales, etc., of these sheets. Since that date, eighty-three sheets have been engraved. The following table, similar to that published in my last report, gives details with regard to all the sheets published up to the date of this report.

Atlas sheets engraved to July 1, 1889.

State or Territory.	Name of sheet.	Designation of sheet.		Area covered.	Scale.	Contour interval.
		Lat.	Long.			
		° ′	° ′			*Feet.*
Massachusetts and New Hampshire.	Lawrence	42 30	71 00	$\frac{1}{16}$ degree.	1 : 62500	20
	Lowell	42 30	71 15	...do	...do	20
	Groton	42 30	71 30	...do	...do	20
Massachusetts.	Gloucester	42 30	70 30	...do	...do	20
	Salem	42 30	70 45	...do	...do	20
	Greylock	42 30	73 00	...do	...do	40
	Boston Bay	42 15	70 45	...do	...do	20
	Boston	42 15	71 00	...do	...do	20
	Worcester	42 15	71 45	...do	...do	20
	Northampton	42 15	72 30	...do	...do	20
	Chesterfield	42 15	72 45	...do	...do	20
	Becket	42 15	73 00	...do	...do	20
	Provincetown	42 00	70 00	...do	...do	20
	Duxbury	42 00	70 30	...do	...do	20
	Abington	42 00	70 45	...do	...do	20
	Wellfleet	41 45	69 55	...do	...do	20
	Plymouth	41 45	70 30	...do	...do	20
	Middleborough	41 45	70 45	...do	...do	20
	Taunton	41 45	71 00	...do	...do	20
	Chatham	41 30	69 45	...do	...do	20
	Yarmouth	41 30	70 00	...do	...do	20
	Barnstable	41 32	70 15	...do	...do	20
	Falmouth	41 30	70 30	...do	...do	20
	New Bedford	41 30	70 45	...do	...do	20
	Nantucket	41 13	69 57	...do	...do	20
	Muskeget	41 15	70 12	...do	...do	20
	Martha's Vineyard	41 15	70 27	...do	...do	20
	Gay Head	41 15	70 42	...do	...do	20
Massachusetts and Connecticut.	Webster	42 00	71 45	...do	...do	20
	Springfield	42 00	72 30	...do	...do	20
	Granville	42 00	72 45	...do	...do	20
	Sandisfield	42 00	73 00	...do	...do	20

Atlas sheets engraved to July 1, 1889—Continued.

State or Territory.	Name of sheet.	Designation of sheet.				Area covered.	Scale.	Contour interval.
		Lat.		Long.				
		°	′	°	′			Feet.
Massachusetts, Connecticut and New York.	Sheffield	42	00	73	15	1/16 degree	1 : 62500	20
Massachusetts and Rhode Island.	Franklin	42	00	71	15	...do	...do	20
	Providence	41	45	71	15	...do	...do	20
	Fall River	41	30	71	00	...do	...do	20
Rhode Island	Sakonnet	41	15	71	00	...do	...do	20
	Block Island	41	00	71	30	...do	...do	20
New Jersey	Franklin	41	00	74	30	...do	...do	20
	Paterson	40	45	74	00	...do	...do	20
	Morristown	40	45	74	15	...do	...do	20
	Lake Hopatcong	40	45	74	30	...do	...do	20
	Hackettstown	40	45	74	45	...do	...do	20
	Plainfield	40	30	74	15	...do	...do	20
	Sandy Hook	40	15	74	00	...do	...do	10
	New Brunswick	40	15	74	15	...do	...do	10
	Princeton	40	15	74	30	...do	...do	10
	Asbury Park	40	00	74	00	...do	...do	10
	Cassville	40	00	74	15	...do	...do	10
	Bordentown	40	00	74	30	...do	...do	10
	Barnegat	39	45	74	00	...do	...do	10
	Whiting	39	45	74	15	...do	...do	10
	Pemberton	39	45	74	30	...do	...do	10
	Mount Holly	39	45	74	45	...do	...do	10
	Long Beach	39	30	74	00	...do	...do	10
	Little Egg Harbor	39	30	74	15	...do	...do	10
	Atlantic City	39	15	74	15	...do	...do	10
	Sea Isle	39	00	74	30	...do	...do	10
	Dennisville	39	00	74	45	...do	...do	10
	Cape May	38	45	74	45	...do	...do	10
Maryland, District of Columbia and Virginia.	East Washington	38	45	76	45	...do	...do	20
	West Washington	38	45	77	00	...do	...do	20
Maryland, Virginia and West Virginia.	Harper's Ferry	39	00	77	30	¼ degree	1 : 125000	100
	Romney	39	00	78	30	...do	...do	100
Maryland and West Virginia.	Piedmont	89	00	79	00	...do	...do	100
Maryland and Virginia	Fredericksburgh	38	00	77	00	...do	...do	50
Virginia	Luray	38	30	78	00	...do	...do	100
	Spottsylvania	38	00	77	30	...do	...do	50
	Gordonsville	38	00	78	00	...do	...do	100
	Harrisonburg	38	00	78	30	...do	...do	100
	Buckingham	37	30	78	30	...do	...do	100
Virginia and West Virginia	Winchester	39	00	78	00	...do	...do	100
	Woodstock	38	30	78	30	...do	...do	100
	Franklin	38	30	79	00	...do	...do	100
	Staunton	38	00	79	00	...do	...do	100
	Lewisburg	37	30	80	00	...do	...do	100
	Pocahontas	37	00	81	00	...do	...do	100
	Tazewell	37	00	81	30	...do	...do	100

Atlas sheets engraved to July 1, 1889—Continued.

State or Territory.	Name of sheet.	Designation of sheet.				Area covered.	Scale.	Contour interval.
		Lat.		Long.				
		°	′	°	′			*Feet.*
West Virginia	Saint George	39	00	79	30	¼ degree	1 : 125000	100
	Hinton	37	30	80	30	do	do	100
	Raleigh	37	30	81	00	do	do	100
	Oceana	37	30	81	30	do	do	100
West Virginia, Virginia and Kentucky.	Warfield	37	30	82	00	do	do	100
Kentucky	Prestonburg	37	30	82	30	do	do	100
Kentucky and Virginia	Whitesburg	37	00	82	30	do	do	100
	Grundy	37	00	82	00	do	do	100
Kentucky, Virginia and Tennessee.	Estillville	36	30	82	30	do	do	100
	Jonesville	36	30	83	00	do	do	100
	Cumberland Gap	36	30	83	30	do	do	100
Virginia and Tennessee	Bristol	36	30	82	00	do	do	100
Virginia and North Carolina.	Hillsville	36	30	80	30	do	do	100
Virginia, North Carolina and Tennessee.	Abingdon	36	30	81	30	do	do	100
North Carolina	Cowee	35	00	83	00	do	do	100
	Morganton	35	30	81	30	do	do	100
North Carolina and Tennessee.	Roan Mountain	36	00	82	00	do	do	100
	Greeneville	36	00	82	30	do	do	100
	Asheville	35	30	82	30	do	do	100
	Mount Guyot	35	30	83	00	do	do	100
	Knoxville	35	30	83	30	do	do	100
	Nantahalah	35	00	83	30	do	do	100
	Murphy	35	00	84	00	do	do	100
Tennessee	Morristown	36	00	83	00	do	do	100
	Maynardville	36	00	83	30	do	do	100
	Loudon	35	30	84	00	do	do	100
	Kingston	35	30	84	30	do	do	100
	Cleveland	35	00	84	30	do	do	100
	Chattanooga	35	00	85	00	do	do	100
South Carolina	Pickens	34	30	82	30	do	do	100
South Carolina and Georgia.	Walhalla	34	30	83	00	do	do	100
Georgia	Dahlonega	34	30	83	30	do	do	100
	Ellijay	34	30	84	00	do	do	100
	Dalton	34	30	84	30	do	do	100
Georgia and Alabama	Ringgold	34	30	85	00	do	do	100
	Rome	34	00	85	00	do	do	100
	Tallapoosa	33	30	85	00	do	do	100
Alabama	Stevenson	34	30	85	30	do	do	100
	Scottsborough	34	30	86	00	do	do	100
	Huntsville	34	30	86	30	do	do	100
	Fort Payne	34	00	85	30	do	do	100
	Gadsden	34	00	86	00	do	do	100
	Cullman	34	00	86	30	do	do	100
	Anniston	33	30	85	30	do	do	100
	Birmingham	33	30	86	30	do	do	100
Wisconsin	Evansville	42	15	89	15	1/16 degree	1 : 62500	20

Atlas sheets engraved to July 1, 1889—Continued.

State or Territory.	Name of sheet.	Designation of sheet.				Area covered.	Scale.	Contour interval.
		Lat.		Long.				
		°	′	°	′			*Feet.*
Missouri	Lexington	39	00	93	30	¼ degree	1 : 125000	50
	Jefferson City	38	30	92	00	do	do	50
	Boonville	38	30	92	30	do	do	50
	Sedalia	38	30	93	00	do	do	50
	Warrensburg	38	30	93	30	do	do	50
	Harrisonville	38	30	94	00	do	do	50
	Tuscumbia	38	00	92	00	do	do	50
	Versailles	38	00	92	30	do	do	50
	Warsaw	38	00	93	00	do	do	50
	Clinton	38	00	93	30	do	do	50
	Butler	38	00	94	00	do	do	50
	Bolivar	37	30	93	00	do	do	50
	Stockton	37	30	93	30	do	do	50
	Nevada	37	30	94	00	do	do	50
	Springfield	37	00	93	00	do	do	50
	Greenfield	37	00	93	30	do	do	50
	Carthage	37	00	94	00	do	do	50
Missouri and Kansas	Atchison	39	30	95	00	do	do	50
	Olathe	38	30	94	30	do	do	50
	Mound City	38	00	94	30	do	do	50
	Fort Scott	37	30	94	30	do	do	50
	Joplin	37	00	94	30	do	do	50
Kansas	Hiawatha	39	30	95	30	do	do	50
	Seneca	39	30	96	00	do	do	50
	Marysville	39	30	96	30	do	do	50
	Oskaloosa	39	00	95	00	do	do	50
	Topeka	39	00	95	30	do	do	50
	Wamego	39	00	96	00	do	do	50
	Junction City	39	00	96	30	do	do	50
	Lawrence	38	30	95	00	do	do	50
	Burlingame	38	30	95	30	do	do	50
	Eskridge	38	30	96	00	do	do	50
	Parkerville	38	30	96	30	do	do	50
	Garnett	38	00	95	00	do	do	50
	Burlington	38	00	95	30	do	do	50
	Emporia	38	00	96	00	do	do	50
	Cottonwood Falls	38	00	96	30	do	do	50
	Iola	37	30	95	00	do	do	50
	Fredonia	37	30	95	30	do	do	50
	Eureka	37	30	96	00	do	do	50
	El Dorado	37	30	96	30	do	do	50
	Parsons	37	00	95	00	do	do	50
	Independence	37	00	95	30	do	do	50
	Sedan	37	00	96	00	do	do	50
	Burden	37	00	96	30	do	do	50
Texas	Meridian	31	30	97	30	do	do	50
	Hamilton	31	30	98	00	do	do	50
	Brownwood	31	30	98	30	do	do	50
	Coleman	31	30	99	00	do	do	50
	Gatesville	31	00	97	30	do	do	50

Atlas sheets engraved to July 1, 1889—Continued.

State or Territory.	Name of sheet.	Designation of sheet.		Area covered.	Scale.	Contour interval.
		Lat.	Long.			
		° ′	° ′			*Feet.*
Texas	Lampasas	31 00	98 00	¼ degree.	1 : 125000	50
	San Saba	31 00	98 30	...do	...do	50
	Brady	31 00	99 00	...do	...do	50
	Taylor	30 30	97 00	...do	...do	50
	Georgetown	30 30	97 30	...do	...do	50
	Burnett	30 30	98 00	...do	...do	50
	Llano	30 30	98 30	...do	...do	50
	Mason	30 30	99 00	...do	...do	50
	Bastrop	30 00	97 00	...do	...do	50
	Austin	30 00	97 30	...do	...do	50
	Blanco	30 00	98 00	...do	...do	50
	Fredericksburgh	30 00	98 30	...do	...do	50
	Kerrville	30 00	99 00	...do	...do	50
Yellowstone National Park	Cañon	44 30	110 00	...do	...do	100
	Gallatin	44 30	110 30	...do	...do	100
Yellowstone National Park and Wyoming.	Lake	44 00	110 00	...do	...do	100
	Shoshone	44 00	110 30	...do	...do	100
Montana	Great Falls	47 00	111 00	Degree	1 : 250000	200
	Little Belt Mountain	46 00	110 00	...do	...do	200
	Fort Logan	46 00	111 00	...do	...do	200
	Three Forks	45 00	111 00	...do	...do	200
Oregon	Klamath	42 00	121 00	...do	...do	200
Colorado	Crested Butte	38 45	106 45	$\frac{1}{16}$ degree	1 : 62500	100
	Anthracite	38 45	107 00	...do	...do	100
Colorado and Utah	Ashley	40 00	109 00	Degree	1 : 250000	250
	East Tavaputs	39 00	109 00	...do	...do	250
	Sierra La Sal	38 00	109 00	...do	...do	250
	Abajo	37 00	109 00	...do	...do	250
Utah	Uinta	40 00	110 00	...do	...do	250
	Salt Lake	40 00	111 00	...do	...do	250
	Tooele Valley	40 00	112 00	...do	...do	250
	Price River	39 00	110 00	...do	...do	250
	Manti	39 00	111 00	...do	...do	250
	Sevier Desert	39 00	12 00	...do	...do	250
	San Rafael	38 00	110 00	...do	...do	250
	Fish Lake	38 00	111 00	...do	...do	250
	Beaver	38 00	112 00	...do	...do	250
	Henry Mountain	37 00	110 00	...do	...do	250
	Escalante	37 00	111 00	...do	...do	250
	Kanab	37 00	112 00	...do	...do	250
	St. George	37 00	113 00	...do	...do	250
Utah and Nevada	Pioche	37 00	114 00	...do	...do	250
Nevada	Paradise	41 00	117 00	...do	...do	200
	Disaster	41 00	118 00	...do	...do	200
	Long Valley	41 00	119 00	...do	...do	200
	Granite Range	40 00	119 00	...do	...do	200
California	Alturas	41 00	120 00	...do	...do	200
	Modoc Lava Bed	41 00	121 00	...do	...do	200
	Shasta	41 00	122 00	...do	...do	200

Atlas sheets engraved to July 1, 1889—Continued.

State or Territory.	Name of sheet.	Designation of sheet.				Area covered.	Scale.	Contour interval.
		Lat.		Long.				
		°	′	°	′			*Feet.*
California	Honey Lake	40	00	120	00	Degree	1 : 250000	200
	Lassen Peak	40	00	121	00	...do	...do	200
	Red Bluff	40	00	122	00	...do	...do	200
	Nevada City	39	00	121	00	¼ degree	1 : 125000	100
	Marysville	39	00	121	30	...do	...do	100
New Mexico	Largo	36	00	107	00	Degree	1 : 250000	200
	Chaco	36	00	108	00	...do	...do	200
	Mount Taylor	35	00	107	00	...do	...do	200
	Wingate	35	00	108	00	...do	...do	200
New Mexico and Arizona	Cañon de Chelly	36	00	109	00	...do	...do	200
	Fort Defiance	35	00	109	00	...do	...do	200
	St. Johns	34	00	109	00	...do	...do	200
Arizona	Marsh Pass	36	00	110	00	...do	...do	200
	Echo Cliffs	36	00	111	00	...do	...do	250
	Kaibab	36	00	112	00	...do	...do	250
	Mount Trumbull	36	00	113	00	...do	...do	250
	Tusayan	35	00	110	00	...do	...do	200
	San Francisco Mountain.	35	00	111	00	...do	...do	250
	Chino	35	00	112	00	...do	...do	250
	Diamond Creek	35	00	113	00	...do	...do	250
	Holbrook	34	00	110	00	...do	...do	200
	Verde	34	00	111	00	...do	...do	200
	Prescott	34	00	112	00	...do	...do	200
Arizona and Nevada	St. Thomas	36	00	114	00	...do	...do	250
Arizona, Nevada and California.	Camp Mojave	35	00	114	00	...do	...do	250

The above list shows that two hundred and forty-nine sheets have thus far been engraved, comprising sixty-five on the scale 1: 62,500, one hundred and thirty-one on the scale 1: 125,000 and fifty-three on the scale 1: 250,000.

The entire area thus far engraved is about 350,000 square miles, or about one-tenth the area of the country including Alaska. There are in the office awaiting engraving one hundred and forty-seven sheets including those under contract. These sheets comprise an area of about 100,000 square miles.

I have the honor to transmit herewith the report of Mr. R. S. Woodward, Chief Geographer, in charge of the Mathematical Division.

Very respectfully submitted,

HENRY GANNETT,
Chief Topographer.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF MR. R. S. WOODWARD.

U. S. Geological Survey,
Mathematical Division,
Washington, D. C., July 1, 1889.

Sir: I have the honor to submit the following report concerning work done under my immediate supervision during the fiscal year ending June 30, 1889.

Although the work assigned to the Mathematical Division is of a varied character, it may be broadly designated as falling under the following two classes, viz, first, that which is directly auxiliary to the operations of the Division of Geography, and second, that miscellaneous work, of a mathematical character chiefly, which arises in the various branches of the geologic and irrigation work of the Survey. The first class is almost wholly of a purely practical nature, involving applications of determinate principles only; while the second is generally complex, requiring more or less preliminary investigation, if not prolonged research.

Work for the Division of Geography.—The usual attention was given during the year to current computations, consisting principally in the determination of latitudes and longitudes of points in systems of triangulation and in the preparation of mathematical tables designed to meet the needs of the geographers and topographers in field and office work.

The list of geographical positions of points within the United States was kept up to date. About eight hundred new positions were added during the year.

My report on the latitudes and longitudes of points in Missouri, Kansas and New Mexico, determined astronomically by me in 1884 and 1885, was published during the year as Bulletin No. 49 of the Survey publications.

A special series of mathematical formulas and tables, with an accompanying explanatory text, bearing the title "Formulas and Tables to facilitate the Construction and Use of Maps" was published as Bulletin No. 50.

The following tables to be mounted on cardboard were prepared and are now ready for publication:—(1) A 5-place table for facilitating the computation of geodetic differences of latitude, longitude and azimuth in secondary triangulation or in traverse work; (2) A 3-place table of natural sines and cosines, with limiting angles as arguments, for the reduction of traverse work in connection with Crelle's multiplication tables; (3) A 4-place table of logarithms and antilogarithms.

Two new theodolites made in accordance with specifications drawn up by me were furnished to the Survey during the year by Fauth & Co. The main object of these specifications was to secure instruments which would enable observers to attain the requisite efficiency in the angular measures of the triangulation with a minimum of labor. The mechanical construction called for was therefore of a high order, and it was necessary before paying for them to examine the instruments critically to determine whether they fulfilled the requirements. Accordingly, both instruments were carefully examined and tested in actual work, a process requiring many observations and a considerable amount of computation. It is but just to add that the defects of the instruments are well within the limits set in the specifications.

Detailed plans and specifications for a theodolite of the same class as those just mentioned, to be made by the mechanician of the Survey, were also prepared.

As hitherto, much time was occupied during the year with the business of consultation concerning the methods of field and office work and the mathematical theory of instruments, observations, etc. Several members of the Division of Geography shared with me the expense of the erection and equipment of a small observatory, where instruments may be tested and where practice in astronomical work may be had. A number of persons availed themselves of this opportunity and considerable time during evenings was devoted to their assistance.

Miscellaneous Work.—A considerable fraction of the year was spent in the collection and classification of data pertaining to various questions, such as the rainfall in the arid region of the United States, the variation of rainfall with altitude, the sedimentation of streams, the methods and appliances useful in the irrigation work of the Survey, etc. As these questions were all subjects of special reports of a technical character a mere allusion to them suffices here.

The investigations of problems in physical geology mentioned in previous reports were continued during the year, but owing partly to the pressure of other work and partly to the complexity of the problems themselves, less progress than I expected was made. A preliminary mathematical paper on the diffusion of heat in homogeneous rectangular solids was published in the Annals of Mathematics, Vol. IV, No. 4, August, 1888.

Attention was given to the revision of the proofs of my paper on the form and position of the sea level published as Bulletin No. 48, and also to the proofs of Bulletins 49 and 50 mentioned above. As these involved much mathematical and technical matter and as for this reason a few sheets only were issued at a time by the Government Printing Office, they were under consideration during the greater part of the year.

At your request I undertook, in connection with Dr. William Hallock of the Division of Chemistry, the investigation of the laws of transportation and subsidence of sediments. My studies and experiments have thus far been confined to the behavior of coarse sediments, or particles varying from 0.1 to 0.5 inch in diameter. The measurement of the retarding effect of water on bodies falling through it is a matter of great difficulty, and, as was expected, most of my experimental work has thus far been tentative. It has disclosed some of the difficulties, however, and enabled me to devise apparatus and methods of observation which it is hoped may be successfully applied as soon as an opportunity occurs.

The principal results of my survey of Niagara Falls, made in 1886, were made public at the Buffalo meeting of the American Association for the Advancement of Science in that year; and the computations requisite to a more complete exposition of those results were made during the winter of 1886-'87. The exigencies of the other work, however, have delayed the preparation of a report for publication until the present time. During the past month this work has been taken up and a definitive report upon it is now nearly complete.

I was assisted throughout the year by Mr. B. C. Washington, jr. He made the greater part of the calculations involved in the work mentioned above, aided in the preparation of manuscript and in the correction of proofs, and attended to all clerical duties.

Very respectfully, your obedient servant,

R. S. WOODWARD,
Geographer in Charge.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF MR. G. K. GILBERT.

U. S. GEOLOGICAL SURVEY,
DIVISION OF GEOLOGIC CORRELATION,
Washington, D. C., July 1, 1889.

SIR: I have the honor to submit the following report of work in my division during the fiscal year ending yesterday:

INSTITUTION OF THE DIVISION.

In each geologic district a series of stratified formations are found, each representing a portion of geologic time. The outcrops of these are traced on maps by the geologist. The distance to which such tracing can be carried is limited, and as a rule the several formations of one district can not be determined by actual continuity to be the equivalents of the several formations of another district. Where continuity does not determine equivalency recourse is had to resemblances. It may be that the formations are lithologically similar, or are arranged in similar lithologic sequences, or it may be that they contain vestiges of life constituting similar faunas or similar faunal sequences. Lithologic data are not now used for correlating formations widely separated, and are used only with caution where the separation is less. The most important data for correlation are biotic, but the results they afford are not always satisfactory, and geologists are not agreed as to their value.

Differences of opinion as to the precision of paleontologic correlation occasion differences of opinion as to nomenclature. It is believed by some that the system of names adopted for the formations of one district should be applied to formations of neighboring districts, and perhaps to those of all districts. Others hold that each district separated from others by breaks in the horizontal continuity of formations should have its own stratigraphic nomenclature. The practice of geologists has been diverse, ranging between these extremes.

Two things lead the U. S. Geological Survey to give great attention to this question at the present time. First, an attempt has been made, through the International Congress of Geologists, to unify the geologic nomenclature of the entire earth. Second, the time has arrived for beginning the publication of geologic atlas sheets by the Survey, and it is important that the terminology employed in those sheets shall follow well understood rules.

Early in the year 1888 the Director instituted a series of conferences, in which many members of the Survey participated, for the purpose of discussing a variety of questions connected with the subject of nomenclature, and as one result of those conferences it was determined that a series of essays should be prepared in which existing data affecting the problems of American geologic nomenclature should be collected and discussed.[1] To the various paleontologists and geologists selected for the work a circular letter was sent, including the following "Plan for the Discussion of American Geologic Systems."

(1) It is proposed to prepare an essay on each of the following American geologic systems, namely: (1) Quaternary, (2) Plio-Miocene, (3) Oligo-Eocene, (4) Cretaceous, (5) Jura-Trias, (6) Permo-Carboniferous, (7) Devonian, (8) Silurian, (9) Cambrian, (10) x y z, (11) Archean.

The "Congress" committee of the American Association for the Advancement of Science at a recent meeting resolved (in effect) that "systems are determined primarily by fossils, secondarily by structure." This series of essays is planned on the assumption that for purposes of correlation the most important fossils are marine invertebrates. The evidence from vertebrates and that from plants will be discussed each by an appropriate specialist, but this arrangement does not preclude their consideration in the essays on individual systems.

(2) Each essay should show how the system of which it treats has been paleontologically and stratigraphically delimited in North America, and should recite and discuss the facts and principles on which such delimitation is based.

(3) Each essay should show into what series (major subdivisions) the system has been divided in various parts of North America, and on what facts and principles

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[1] See Ninth Annual Report U. S. Geological Survey, pp. 16–17.

the division has been based. If these subdivisions are not uniform in all parts of the continent the various areas of exposure should be classified in provinces, and the essays should show whether and to what extent the series of the several provinces can be correlated with one another.

(4) Each essay should show whether and to what extent the subdivisions of the system in any or all of its American provinces can be correlated with the subdivisions of the system in Europe.

(5) Each essay should be prepared with the aid of a comprehensive review of the pertinent literature, so as to constitute a summary of the material at present available for the major taxonomy of the system.

(6) The names of systems in (1) are provisional. Each essay should consider the question of names for system and series.

The number of systems is likewise provisional, and it may eventually appear that those enumerated in (1) are not coordinate. It was necessary to prepare a scheme in order to apportion the work of assembling the facts, but after these have been assembled, their discussion may lead to an improved scheme. Provision will be made for such discussion after the series of essays has been prepared.

(7) The general purpose of the preparation of the series of essays is threefold: first, to exhibit in a summary way the present state of knowledge of North American geologic systems; second, to formulate the principles of geologic correlation and taxonomy; third, to set forth from the American standpoint the possibility, or the impossibility, of using in all countries the same set of names for stratigraphic divisions smaller than systems.

The above plan having been outlined by the Director, is placed under the general superintendence of Mr. G. K. Gilbert. It is anticipated that the plan will be amplified as the work proceeds and questions arise in connection therewith. Conferences of the gentlemen taking part in the preparation of the above named essays will be called from time to time by Mr. Gilbert, the object of such conferences being to unify the work as regards method and scope.

In January, 1889, the chiefs of division having geologic atlas sheets ready for publication, were called together by the Director for the purpose of discussing plans of map publication, and certain of the determinations reached affect the plan for the correlation essays. It was agreed that the largest classificatory units appearing on the atlas sheets be of the rank of the Cretaceous and the Carboniferous, and that such units be designated periods and be considered and used as units of an arbitrary time scale. A scale of eleven units was adopted, each unit corresponding to one of the "systems" selected as the subjects for essays, and names were chosen for these units. In accordance with these decisions the essays of the series, while discussing the same material, and for the same purposes, will each consider its subject matter as the formations belonging to a time division rather than as the formations belonging to a structure division. The titles of the essays will conform to the period names adopted for the maps, as follows: (1) Pleistocene, (2) Neocene, (3) Eocene, (4) Cretaceous, (5) Jura-Trias, (6) Carboniferous, (7) Devonian, (8) Silurian, (9) Cambrian, (10) Algonkian, (11) Archean.

It was found convenient for administrative purposes to constitute the work of the preparation of these essays a division of the Survey, and it was so organized at the beginning of the fiscal year. The division is somewhat peculiar in that the greater number of its members are likewise members of other divisions and devote only a portion of their time to the work of this. Its personnel and organization may be gleaned from the following paragraphs, which describe briefly the work performed during the year.

THE YEAR'S WORK.

The duty of discussing the taxonomic relations and the nomenclature of the American Pleistocene has been accepted by Dr. T. C. Chamberlin. He has not yet entered specifically upon the work, but will do so soon.

To Dr. William H. Dall has been assigned the duty of discussing the relations of the formations of the Neocene. So far as the western region is concerned his discussion will be based upon the literature, but eastern formations will be studied in the field and in the laboratory. He has been for some years engaged in a revision of the invertebrate paleontology of the Neocene and Eocene formations of the Atlantic and Gulf States, and his work in the preparation of this essay will largely coincide with his general work as chief of the Cenozoic Division of Invertebrate Paleontology. An account of his work in field and office during the fiscal year will be found in the report of his division.

The discussion of the formations of the Eocene has been intrusted to Mr. W. B. Clark, of Johns Hopkins University. During the year he has made field examinations in Maryland, Virginia, and the Carolinas for the purpose of rendering himself personally familiar with the formations and their sequences, and he has also studied their literature. It is proposed that he follow the same method with the equivalent formations at the Far West before beginning the discussion.

Dr. C. A. White is at the head of the Mesozoic Division of Invertebrate Paleontology, and has for many years given special attention to the subject of the Laramie formation. He undertakes the discussion of the Cretaceous, including the Laramie. Such field work as he has performed during the year has been largely planned with reference to the needs of this work, and he has reviewed the literature of the subject. He has also prepared a large body of manuscript as first draft of a portion of his essay. An account of his field operations and other work for the fiscal year will be found in the report of his division.

Work on the Jura-Trias is entrusted to Mr. I. C. Russell, who was transferred for this purpose from the Appalachian Division. In previous years he had examined each of the several areas of outcrop along the Atlantic coast, and the summer of last year was spent in the examination of western localities. The beginning of the fiscal year found him at Canyon City, Colo., from which point he proceeded to Arizona and California. At Sacramento he was joined by Prof. Alpheus Hyatt, who was engaged in the collection of fossil cephalopoda of the Jura-Trias. During August and September they worked together, visiting successively fossiliferous localities near Colfax and Taylorsville, Cal., in the Star Peak Range, Nevada, at Soda Springs, Idaho, at Aurora, Wyoming, and in the Black Hills of Dakota.

Mr. Russell then resumed, in Washington, the preparation of an index to the literature of the Jura-Trias, and this work is so far advanced that little besides clerical labor is needed to complete it.

In May a communication was received from the Superintendent of the U. S. Coast Survey, inviting the Geological Survey to attach one of its geologists to a Coast Survey party organized to survey the boundary of Alaska in the vicinity of the Yukon and Porcupine rivers. The invitation was accepted, and Mr. Russell was selected for the work. It was arranged that he make collections and observations in zoology and ethnology as well as geology, and the supplies and instructions needed for these purposes were furnished by the Smithsonian Institution and the Bureau of Ethnology. He joined the Coast Survey party in San Francisco on the 1st of June, and set sail for St. Michaels, Alaska, on the 14th.

Prof. Henry S. Williams, of Cornell University, accepted the duty of preparing essays on the Carboniferous and Devonian. He has reviewed with care the literature of the two periods, tracing the evolution of the various taxonomic terms in use, and in connection with that work has prepared a portion of his manuscript.

The discussion of the formations of the Silurian and Cambrian has been assigned to Mr. C. D. Walcott, chief of the Paleozoic Division of the Invertebrate Paleontology. He has been occupied for several years with problems affecting the correlation of the Cambrian formations, so that his new duty corresponds in part with work he had already in hand. His chief work with special reference to the discussion, has consisted of a review of the literature, in which he has been aided by Prof. J. F. James. A fuller account of his work, and also of that of Prof. Williams, will be found in the report of his division.

The late Prof. Roland D. Irving devoted himself for many years to the study of the formations underlying the Cambrian strata of the Lake Superior region. On his death, Prof. C. R. Van Hise, who had been his principal assistant, was appointed his successor as chief of the division. The discussion of the correlation and nomenclature of the Algonkian and Archean, at first assigned to Prof. Irving, is now entrusted to Prof. Van Hise. The new duty coincides so closely with the previous course of his studies, that his plans for the year have been little modified. The account of operations contained in his administrative report need not be repeated here.

Most of the gentlemen undertaking the discussion of the nomenclature of periods are students of Invertebrate Paleontology, and it is understood that their discussions will be based upon molluscan fossils in connection with stratigraphy. In order that the evidence supported by vertebrate fossils and by fossil plants might not be neglected, it was arranged that Prof. O. C. Marsh and Mr. Lester F. Ward traverse the subject from the points of view afforded by their special studies. Prof. Marsh has undertaken to consider the correlation of American formations with one another and with foreign formations through vertebrate remains, and Mr. Ward has undertaken to discuss the evidence from remains of plant life. Mr. Ward's work in this connection does not materially depart from his general plan of work as chief of the Division of Paleobotany. He has for years directed the energies of his corps to the thorough classification of the data of American Paleobotany with this end in view. A statement of his progress during the fiscal year would be a mere repetition of the report of his division.

For several years Mr. W. J. McGee has had in preparation a Thesaurus of North American Stratigraphy, his plan including a bibliography, an index to stratigraphic names and a general discussion. This work has been transferred to the Division of Geologic Correlation, and will be carried forward in cooperation with the work of the various assistants upon the nomenclature of the periods assigned to them.

I have heretofore had charge of two other divisions of the Survey, the Appalachian Division and the Division of the Great Basin. During the present fiscal year I have withdrawn, with your consent, from the Appalachian Division, leaving it in charge of Mr. Bailey Willis, and a report of its work has been prepared by him. The field work of the Division of the Great Basin was terminated in 1883, and nothing remained but the preparation of reports. The last of these reports, a Monograph on Lake Bonneville, is now complete in manuscript, and will be transmitted in a few days.

I am, with great respect, your obedient servant,

G. K. GILBERT,
Geologist in Charge.

HON. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF PROF. RAPHAEL PUMPELLY.

U. S. Geological Survey,
Division of Archean Geology,
Dublin, N. H., July 1, 1889.

Sir: I have the honor to present the following statement of the work of my division during the year ending June 30, 1889.

I have directed the efforts of the division in the two directions in which it had been working previously, viz, first, to studying the geological structure of the Green Mountains, second, to coloring the geological map of New England.

In the first of these directions, the study of the Hoosac Mountain and Greylock areas by Messrs. Wolff and Dale, respectively, in northwestern Massachusetts, was practically finished, leaving to be done only some work of a revisionary nature. The most desirable area for study extending across the mountains was found to be in central Vermont, and a topographical survey of about two hundred square miles was about half finished by Mr. Smyth. The geological study of this area was well started by Mr. Wolff and I hope to finish it during the coming season.

The study of the Green Mountain structure, on which I have laid so much stress, is an essential preliminary to the geological survey of New England. While this investigation is yet incomplete, it has shown that these mountains consist of a long range of folds, extending in the direction, and apparently as a continuation, of those of the Appalachian system. In crossing the mountains, as we approach the west side, the folds are compressed and overturned to the west, their axial planes dipping eastward.

Along the western flank of the mountains the Lower Cambrian quartzite and conglomerate, with the overlying Cambrian-Silurian rocks, including the great limestone, and garnetiferous and feldspathic hydromica schists, are involved in this inverted folding. Along the east flank lie quartzite and conglomerate, overlaid by a series of rocks similar to those on the west side, excepting that the limestone has a less development. Between the two, the main body of the mountain range consists of parallel folds with undulating axes, and, in places, dome-shaped arrangements of the strata. The undulation of the axes of the folds brings to the surface along the range the various rocks of which it is formed. To a great extent the surface of the range is formed of a related series of quartzites, conglomerates and white detrital gneisses, which replace each other in the most protean manner, and which appear to pass, on the west side, into the quartzite which Mr. Walcott has determined to be Lower Cambrian, and also into that which underlies the limestone along the eastern flank.

But while the quartzite along the western flank is overlaid by a great thickness of Lower Silurian limestone, the quartzite-conglomerate-gneiss of the main range is directly overlaid only by a great development of garnetiferous and feldspathic hydromica schists, which Mr. Wolff has found to be identical with those overlying the Lower Silurian limestone on Greylock, and with those associated with the limestone on the east.

At several points along the range, where the bottom of the quartzite-gneiss comes to the surface, this is found to be underlaid by a coarse granitoid gneiss. As a rule, in the areas of this coarse gneiss, the large features and the minor details of its position and structure are conformable to those of the overlying quartzite-conglomerate-gneiss beds. But while these latter are essentially detrital throughout in origin, the underlying coarse gneiss shows no trace of clastic origin. And aside from this difference, and notwithstanding the general conformity in position and structure, there are some facts that point to an important time break at this horizon.

Prof. Emerson finds below the coarse granitoid gneiss a chondrodite limestone, and below this again a coarse biotite gneiss.

To the west of the Green Mountain range, and involved in the foldings of its western flank, are Paleozoic rocks of well defined ages. To the eastward lies the great New England area of altered rocks, with only isolated patches of known age.

We have therefore in the Green Mountains a folded range, with a generally hidden pre-Cambrian crystalline core, and a surface of rocks which are apparently the equivalent of the series on the west, from the Lower Cambrian to well up in the Lower Silurian.

The following table shows the succession of strata on the central or Hoosac range, as determined by Messrs. Putnam and Wolff, and myself; on Mount Greylock, to the west of the range, by Mr. Dale; and in the region east of the main Hoosac ridge, by Prof. Emerson; all in Berkshire County, Massachusetts.

West of the Range.	Central Range.	East of the Range.
	The order above this hydromica schist is not yet determined.	
Hydromica schist (albitic). Limestone. Hydromica schist (albitic). Limestone.	= Hydromica schist. Hydromica schist (albitic). Hydromica schist (garnetiferous.)	= Hydromica schist. Hydromica schist. Hydromica schist. Hydromica schist (albitic.) Hydromica schist (garnetiferous.
Quartzite and conglomerate with blue quartz. (Olenellus.)	= Conglomerate quartzite gneiss with blue quartz.	= Conglomerate quartzite gneiss.
Granitoid gneiss blue quartz. Clarksburg Mountain.	= Granitoid gneiss with blue quartz.	= Coarse gneiss, with blue quartz.
		Limestone with chondrodite, phlogopite and graphite.
		Coarse biotite gneiss with allanite.

I have marked the apparent equivalence with the sign =. The range of equivalence above the conglomerate-quartzite-gneiss is at present only conjectural. The question of this equivalence remains however still to be rigidly tested for the whole series. If the equivalence shall be established, we shall have made great progress towards unraveling the geology of the metamorphic areas of New England. I hope to approach the definite solution of this problem during the coming season.

In the direction of areal geology in Massachusetts, the coloring of Berkshire County is about three-quarters finished, Mr. Dale doing the portion west of the Hoosac and Housatonic Rivers, Mr. Wolff the northeastern quarter, and Prof. Emerson the southeastern quarter. Prof. Emerson has completed the western central counties, Franklin, Hampshire and Hampden, and the western half of Worcester County. This finishes about one-half the areal geology of Massachusetts.

In Vermont, during the investigations of the structure of the mountains, a large amount of work has been done in the direction of areal geology, which will greatly facilitate the coloring of the geological map of the State, as soon as a topographical map is provided.

A large number of specimens were collected for study. Mr. Wolff has finished the lithological examinations of the rocks included in the field already surveyed.

There are now ready for publication, and will soon be submitted, the following manuscripts:

I. Report on the Western Central Counties of Massachusetts, Franklin, Hampshire and Hampden, by Prof. B. K. Emerson.

II. Report on the Structure of Hoosac Mountain, by J. E. Wolff.

III. Report on the Structure of Mount Greylock, by T. N. Dale.

IV. Report on the Lithology of the Green Mountains; Part I, by J. E. Wolff.

V. Report on the Bernardston Series, by Prof. B. K. Emerson.

I have the honor to be, sir, your obedient servant,

RAPHAEL PUMPELLY,
Geologist in Charge.

HON. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF MR. N. S. SHALER.

U. S. GEOLOGICAL SURVEY,
ATLANTIC COAST DIVISION,
Cambridge, Mass., July 1, 1889.

SIR: I have the honor to submit the following report on the work done in the division under my charge for the year ending June 30, 1889.

On the 1st of July, 1888, I began the task of mapping the surface deposits of the area included within the States of Massachusetts and a part of Rhode Island and New Hampshire, delineated in the fifty-six atlas sheets which were prepared by the Geological Survey in cooperation with the Commissioners of the Massachusetts Topographical Survey. The details of this project were arranged under your advice. The first aim of the work was accurately to determine the condition of the marine and fresh-water morasses in this interesting field; incidentally to ascertain also the distribution of its glacial and other detrital deposits. As far as possible the map has been made to serve for a delineation of the soils of this field, not from the point of view of their agricultural value, but with reference to the conditions of the underground water. The field work on the fifty-six map sheets is substantially completed. In this work I have been assisted by Messrs. Collier Cobb, C. W. Coman, George E. Ladd, C. T. Quinby, Robert Robertson, C. P. Sinnot, R. S. Tarr and J. B. Woodworth, field assistants in my division; and also by Messrs. L. S. Griswold, J. H. Ropes and J. S. Stone, who have rendered efficient service as volunteer aids.

The evidence obtained in this study of the areal geology of detrital deposits in Massachusetts is in many respects interesting. It is a noteworthy fact that the washed and stratified drift increases in proportion as we pass from the western highlands towards the seaboard district. In the Berkshire hills the washed materials are substantially limited to the lower part of the valleys, occupying probably less than ten per cent of the area. In the region east of the Connecticut, the stratified drift rapidly increases in quantity until near the shore it occupies probably more than three-quarters of the area. Evidence has been obtained to show that in the course of glacial work the drift material has repeatedly passed from the condition of stratified deposits to that of till.

The work has also shown the existence of numerous obscure frontal moraines occupying the interior district east of the Connecticut River. Two marine benches at the height of from 60 to 100 feet above the present level of the sea and another at from 180 to 200 feet have been fairly well proven. Some evidence concerning the origin of drumlins has also been secured. It appears from the work that these peculiar structures grade insensibly into ordinary sheet till.

In certain cases the drumlin form is assumed by ordinary stratified sands.

Other results of this work will be embodied in a memoir which is now in preparation.

Mr. A. F. Foerste has been engaged for the greater part of the year on the geology of the Narragansett Basin. His work has served to determine the distribution of the Carboniferous strata which underlie the coal measures of that basin, on the western, northern and eastern margins of the area.

In connection with his work on the superficial deposits of southeastern Massachusetts Mr. C. W. Coman has determined the distribution of certain preglacial beds, probably of Tertiary or Cretaceous age in the district of Cape Cod. This inquiry affords data for the conclusion that the promontory of Cape Cod from Wellfleet westward consists of a low, irregular ridge, over which is spread a covering of drift deposits. I therefore conclude that the peculiar topography of this section is mainly due to conditions which antedate the Glacial Period. The facts seem to show that this cape is the remnant of a considerable water shed carved in strata laid down before the advent of the Glacial Period.

The work of Messrs. Coman and Sinnott in southeastern Massachusetts, combined with that which I had previously done in the district makes it plain that we have in this district an interesting series of deposits accumulated during the first or advent stages of the Glacial Epoch. These beds apparently afford evidence showing the somewhat gradual approach of the ice sheet to this area. They consist of clays evidently formed with considerable rapidity and much stained with vegetable matter. These deposits have a thickness of a hundred feet or more. Above them lie coarse sands containing small quartz pebbles. These sands are much oxidized, the magnetite which they originally contained having been completely reduced by the action of carbonated waters. Beds of this description constitute a greater part of the mass of the island of Naushon and the neighboring lesser isles of the Elizabeth group. These sands to which I have given the name of the Naushon series extend upward and gradually merge into the ordinary stratified deposits of Glacial age. They have a wide distribution, extending from Massachusetts Bay to Martha's Vineyard. Their western boundary has not yet been ascertained.

During the winter of this fiscal year I was engaged for a time in field work in the Dismal Swamp district of Virgina and North Carolina, completing a report on that region which is submitted herewith. After that work was done I went to the marsh district about the mouth of the Mississippi, to study certain phenomena connected with the inundated lands of that delta region. Some of the results of the work done in this season are embodied in the general account of inundated lands which accompanies the report on the Dismal Swamp.

While engaged on the shore-lines of eastern Florida in the previous fiscal year, I discovered that the reefs of living coral had not their northern limit at Cape Florida, as is commonly supposed, but extended up the coast for many miles north of that point. The reef becomes narrow and relatively inconspicuous, being bared only at the lowest stage of the water, but it exists as a distinct reef as far north as Hillsborough River. It appears to be composed in the main of sea fans and the common species of Manacina among the stone corals. With the assistance of Mr. C. W. Coman, I have traced the distribution of the stone corals toward the north and find from their frequent presence on the shore that the reef probably continues to a point ten or twelve miles north of Jupiter Inlet, beyond which point no fresh specimens of reef-making corals were found.

Very respectfully, your obedient servant,

N. S. SHALER,
Geologist in Charge.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF MR. BAILEY WILLIS.

U. S. GEOLOGICAL SURVEY,
APPALACHIAN DIVISION,
Washington, D. C., July 1, 1889.

SIR: I have the honor to submit herewith the administrative report for the Appalachian Division of Geology for the fiscal year now closed.

ORGANIZATION.

Mr. G. K. Gilbert, who had developed the plan of investigation in the Appalachian province, continued to direct the field and office work until March 1, 1889, when, finding the increasing pressure of executive work onerous, he asked to be relieved; you then instructed me to take charge of the division, and, aided by Mr. Gilbert's counsel, I have planned the work for the coming fiscal year. During the field season of 1888 Mr. Gilbert organized the work of the division as follows:

FIELD WORK.

Mr. H. R. Geiger, assistant geologist, aided by Mr F. W. Geiger, took the field in the vicinity of Harper's Ferry, W. Va., to continue his study of the difficult problem of the relation between the crystalline rocks of the Blue Ridge and the well known strata of the Shenandoah Valley; later in the season he traced out the areal geology of a part of West Virginia and Virginia. Mr. Arthur Keith, assistant geologist, aided by Mr. A. C. Lane and provided with camp outfit and with cook and driver, began in June to plat areal geology and soil distribution upon atlas sheets in that portion of east Tennessee where the measurement of the French Broad section had prepared the way. Mr. C. Willard Hayes, assistant geologist, aided by Mr. A. E. Woodward and fitted out in the same manner as Mr. Keith, was also engaged in preparing maps of areal geology and soil distribution, the base of his work being the detailed section surveyed by Mr. I. C. Russell in Alabama and Georgia. I myself was instructed to direct the work of Messrs. Keith and Hayes and to continue the search for Archean crystallines in the mountains of North Carolina. Mr. I. C. White, who had nearly completed a monograph on the comparative stratigraphy of the bituminous coal rocks, took up the Lewisburg, W. Va., atlas sheet and worked on its areal geology. Mr. N. H. Darton, having continued office work on the bibliography of Appalachian geology until August 8, then made a survey of the Staunton, Va., atlas sheet. When in November the inclemency of the weather rendered further field work unadvisable, the parties were disbanded and the several assistant geologists returned to Washington to put their observations on office record. The force thus employed in office work in Washington consisted of Messrs. H. R. Geiger, Arthur Keith, C. Willard Hayes, N. H. Darton and myself. On February 1, Mr. Hayes was transferred to the Division of Mezosoic Paleontology under Dr. C. A. White, with whom he worked six weeks; he then returned to this division. In the latter part of March a special trip occupying five days was made by Mr. Hayes and myself with Prof. R. Pumpelly over Bluff Mountain, Madison County, N. C., for the purpose of securing Prof. Pumpelly's opinion on difficult problems of the crystalline rocks there exposed.

RESULTS.

The outcome of the work for this fiscal year is the natural growth expected by Mr. Gilbert from the detailed studies made in previous years and, as the character of the work was changed with the season of 1888 from the continuous measurement of specific sections across the strike to the mapping of areal geology, it is appropriate that the results of that earlier work should be summed up.

Mr. Gilbert had caused to be made three sections across the folded strata of the Appalachians; the first from the vicinity of Cumberland, Md., southeast across the Blue Ridge; the second from Cumberland Gap, Tenn., to Asheville, N. C., the third from a district in the plateau of Alabama southeast passing below Rome, Ga. The object of this work was twofold; first, and most important, to ascertain upon what subdivisions of the stratigraphic column areal mapping might be based; second, to make the first steps toward the solution of the problems in mechanics suggested by the structural facts. It was expected that variations would appear in the stratigraphic column from northwest to southeast in the change from marine to shore conditions, but it was thought possible that a number of prominent lithologic subdivisions might be recognized extending continuously from northeast to southwest. A comparison of the three sections showed this last supposition to be true only in a very few marked horizons. The thickness of strata deposited in Virginia was very much greater than that in Alabama, and the changes of character of sediment were there much more frequent; and the passage from the longer Virginia column to the shorter one of Alabama is traced through a great number of stratigraphic variations. The Paleozoic ocean from time to time suffered local changes in depth and in the direction and force of currents, and in consequence of these, marsh or marine deposits followed upon beach formations, while the shales or limestones formed in some earlier marsh or deep sea were covered by sands carried continuously from similar sources of supply. Thus the Paleozoic sediments are a great complex of lenses of every grade of lithologic character, from pure limestone to conglomerate, and lithologic distinctions cease to be of value except when used as guides in small districts or when variations are traced out by continuous detailed study. This generalization being established it was evidently impossible to carry any uniform scheme of taxonomy throughout the Appalachian province, and Mr. Gilbert, therefore, gave instructions that "formations rather than names should be mapped; that is to say, the actual distributions afforded by the stratigraphy of the given area are to be represented on the map in preference to distinctions belonging to the stratigraphic classification of other areas." This principle is carried into the detail of each atlas sheet and it follows that the stratigraphic subdivisions represented on two adjacent atlas sheets will often fail to correspond in minor features. But as the atlas sheet is a small unit of area the stratigraphic variations will be noted at frequent intervals and the many small changes apparent at the boundaries of atlas sheets will conform to the gradual passage of lithologic characters from one phase to another.

The field observations on geologic structure, including the measurement of fault hades by an application of descriptive geometry to the survey of fault outcrops, led to the exercise of much care in drawing lines of structure in sections below the surface; for it becomes apparent that only the major folds could reasonably be supposed to extend through many hundred feet of strata and that all minor crumpling was probably local and confined to the beds in which it was observed. That massive strata do not fold in curves which are concentric with those assumed by adjacent thinner beds was well known; but it was thought desirable to experimentally reproduce the observed forms of structure in layers of varied thickness and consistency, under conditions analogous to those which were supposed to have controlled the Appalachian deformation. The materials used in these experiments were wax, plaster of Paris and Venice turpentine, mixed in various proportions; the layers were placed on a plastic base and were heavily loaded with shot in a box open at the top; they were compressed longitudinally by means of a screw. The experiments have not been completed, but it has been shown that slip of strata on bedding planes is an essential accompaniment of folding, and that at an early stage of flexure overthrust faults may originate in the differences of rigidity of the parts of a heterogeneous mass.

FURTHER WORK.

The Appalachian province is naturally divided into two districts. In the western, which covers the Cumberland plateau and the Appalachian Valley areas, the strata are all Paleozoic sediments; although they are flexed and faulted, the folds are not generally closely appressed, and the problems of stratigraphy and structure can readily be solved by the trained geologist. In this district about 13,000 square miles have been surveyed and the geology has been colored on atlas sheets by the assistant geologists. During the season about to begin the work thus presented will be carefully revised by the geologist in charge and the sheets will then be submitted for publication. Further field work will be carried on by Messrs. Geiger, Keith and Hayes in Virginia and in eastern Tennessee. In the other districts of the Appalachian province, that covering the Blue Ridge and the North Carolina mountains, the rocks are in part Archean eruptives, in part Paleozoic sediments and in part later eruptives. The sedimentary strata are very variable, both in composition and the degree of metamorphism they have suffered, and the determination of their relations is a very difficult task. As the Archean and Lake Superior divisions of the survey are engaged on problems of this nature, it is not deemed desirable that the Appalachian Division should devote a large share of attention to them, but work will be continued in the Blue Ridge near Harper's Ferry and in the vicinity of the Ocoee River, Tennessee.

Instructions for the study of soils were issued by Mr. Gilbert a year ago and preliminary soil maps of seven atlas sheets have been prepared. A large number of soil samples were gathered, and this material now awaits analysis and study. The work of soil mapping and sampling will be carried on this season.

Very respectfully,

BAILEY WILLIS,
Geologist in Charge.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF PROF. C. R. VAN HISE.

U. S. GEOLOGICAL SURVEY,
LAKE SUPERIOR DIVISION,
Madison, Wis., July 1, 1889.

SIR: I beg to submit the following report of the operations of the division of the Survey under my charge for the fiscal year ending June 30:

The plan of operations has not been changed from that of the previous years. This is detailed in the administrative reports of the division in the eighth and ninth annuals. It includes two classes of work, special studies of certain regions of exceptional economic importance or scientific interest, and studies to furnish sheets for the geological atlas of the United States.

FIELD WORK.

The field work of the division has been done by Dr. W. S. Bayley, Prof. C. W. Hall, Prof. Erasmus Haworth, Mr. C. M. Boss and myself.

The first part of the season was occupied by me, with Mr. L. M. Hoskins as a volunteer field assistant, and two Indians, in going over in a general way a wide area in northeastern Minnesota, and in examining in more detail the important localities of the Vermilion and Animikie iron-bearing series. This work involved a canoe trip from Tower, on Vermilion Lake, Minn., to Grand Portage, Lake Superior, along and near the boundary line of the United States and Canada. This distance in an air line is about a hundred miles; but as traveled, so that the important points could be reached, the distance was more than double this amount. At Grand Portage I disbanded my party and joined Dr. W. S. Bayley at Pigeon Point, Minn., in order to examine with him the interesting contact phenomena which are there found between eruptives and eruptive and fragmental rocks. This work was finished August 6, and we then went by steamer to Beaver Bay. From that point, in a small boat, we skirted the northwest shore of Lake Superior as far as Two Harbors, collecting a typical suite of specimens of the Keweenawan rocks there so well exposed. The large collection of rocks of this series once owned by the division was destroyed by fire a few years since, and a type suite was necessary for comparative work. From Two Harbors I accompanied Dr. Bayley's party to the west range line of T. 47 N., R. 35 W., Michigan, on the Duluth, South Shore and Atlantic Railway. We followed this road eastward to Nestoria, where I left Dr. Bayley. I then went to Keweenaw Point, visiting the important localities, both to obtain a more accurate knowledge of the Keweenaw series, and to complete the collection of Keweenawan rocks above mentioned. I also went to Bessemer, Mich., to arrange for field work to fill in a few gaps in our maps of the Penokee series, after which I returned to Madison, which place was reached August 31. This ended my field work until the latter part of June, when I joined, at Marquette, Mr. J. H. Renshawe, in charge of the topographic survey of the Marquette region, the object being to give any information I could which would tend to make his maps more serviceable to us. Later, in company with Prof. Pumpelly, I visited various important points in the Upper Peninsula of Michigan with reference to the field work of the coming fiscal year. I also again joined, before the end of the month, Mr. W. N. Merriam's party for a short time in the vicinity of Champion.

Dr. W. S. Bayley left Waterville, Me., on the 4th of July, and by way of Madison, where he outfitted, proceeded to Pigeon Point, Minn. His party for work here consisted, besides himself, of one woodsman and one packer and cook. He was occupied at this place for about three weeks. The results of this and previous work are given further on. Also a few short excursions were taken to adjacent points in Canada, and several days were consumed in mapping the larger islands of the Lucille group lying south of the point. Dr. Bayley next assisted in making the collection of Keweenawan rocks on the northwest shore of Lake Superior already mentioned, after which he transferred his party to L'Anse, Mich. It was then increased to four in number. The remainder of the season was spent in the region south and west of L'Anse, mapping the areal outline of the Algonkian rocks and determining their relations to the Archean rocks on the east and the Cambrian on the west. This work continued to the 22d of September, when the party was disbanded. During this portion of the field season there was examined 360 square miles of territory with sufficient accuracy for the purposes of the geologic atlas sheets.

Prof. C. W. Hall did a comparatively small amount of field work during the year. This consisted of a few excursions in the autumn months into central eastern Minnesota, in counties Chisago, Kanabec, Pine and Carlton, to define the boundaries of the Archean rocks in that region. This area is heavily drift-covered and the results of the work as to accuracy were necessarily somewhat unsatisfactory.

Prof. Erasmus Haworth joined the division at the beginning of the fiscal year. He was assigned for field work to the pre-Cambrian rocks, which occur in southeastern Missouri. Taking the field July 9, he was occupied, with one interruption, until September 15, in Madison and Iron Counties. The rocks in this part of the State are principally quartz and feldspar porphyries and granites. In the valleys, especially in T. 33 N., R. 4 E., stratified limestones are also found. This limestone is usually in narrow belts extending but a short distance up the hillsides. In many instances fragments of the porphyry are seen in it, showing conclusively that the latter is younger than the porphyry. Again, it is noticed that the limestone invariably has a gentle slope in the direction of the hillsides in such a way as to indicate that their present configuration obtained at the time the limestone was deposited. A very interesting point in connection with this region is the relation between the porphyry and granite. All attempts to determine which was the older proved futile. It was finally concluded that the field relations strongly indicate that the two rocks were originally parts of the same magma and were erupted at the same time. Although this Missouri region is an interesting field, further work will not be done in it until topographic maps are available.

Mr. C. M. Boss did a small amount of work in October on the Penokee Range, in Wisconsin, in order to locate more accurately and continuously the lower formations of that series.

OFFICE WORK.

Aside from the routine work of the office, and a fortnight spent in Washington by your direction, my whole time has been given to the completion of a Monograph upon the Penokee Iron-Bearing Series, by the late Prof. Irving and myself, and also an abstract of it. As the latter is contained in the present volume space will not be here taken to give a summary of its results.

Dr. W. S. Bayley's time has been given to the preparation of a bulletin upon "The Eruptive and Sedimentary Rocks on Pigeon Point, Minnesota, and their Contact Phenomena." This work was completed and transmitted to you in the last days of the year.

Pigeon Point is the extreme northeastern part of the territory of the United States in Minnesota. It is a long arm, which projects into Lake Superior a distance of several miles, its average width being between a quarter and a half of a mile. The area is one of exceeding interest to the geologist, because of the very peculiar contact belts which occur, both between a red eruptive soda-granite and a dark-colored gabbro, and between the eruptives and associated sedimentary rocks. This is the only locality in which intense alteration of sedimentary beds by means of eruptives is known in the Lake Superior region. Some of Dr. Bayley's principal conclusions are given below. Many interesting lithological points are necessarily omitted.

The principal rock of the point is a porphyritic olivine gabbro, with the characteristics of similar rocks occurring in large masses on both sides of Lake Superior. This rock forms a large dyke-like body, which in places has intruded itself between the layers of the fragmental rocks which it cuts. That the portion which is now exposed cooled at some distance beneath the surface of the earth is indicated by its holocrystalline structure. Adjacent to this gabbro is large amount of a bright red rock, whose composition and structure are that of a keratophyre or soda-granite. This occurs principally on the southern border of the gabbro, between the latter and the Animikie quartzites, which cover all the surface of the Point not occupied by the gabbro and the red rock, with the exception of a small portion taken by trap dykes.

This soda-granite has upon one side of it a transition zone into the gabbro, and upon the other, another into the quartzite. At the contacts of the gabbro and the soda-granite is a series of rocks, whose mineralogical and chemical properties are intermediate between these and which grade into the gabbro on the one side, and the soda-granite on the other. The relations indicate that the intermediate rock is composed of mixtures of the magmas of the adjacent rocks, that is, that they are contact rocks in which a portion of the material came from the gabbro and another portion from the granite.

The quartzites present are indurated sandstones, the indurations being due to the enlargements of the quartz-grains.[1] These have undergone metamorphism adjacent to the gabbro and the granite, and have yielded in places a product that is completely crystalline and which at one time was in a plastic condition. The area in which these metamorphic rocks are most prominent is just south of the red rock, bordering it along its entire extent. The altered quartzites form a well defined zone, which may well be designated a "contact belt." Along this belt the quartzites are shattered and reddened. Large pieces of the slightly altered quartzite are imbedded in a rock with some of the peculiarities of the granite, and some characteristics that are peculiar to itself. The contact rocks most remote from the intrusives differ only slightly from the unaltered quartzites. Portions of the contact belt nearer the granite approach nearer the composition of the latter. From the character of the contact rock a portion of it must have been a plastic mass, which acted like an eruptive and included within itself the shattered remains of the unaltered quartzite, dissolving them in part or entirely.

Since the rock between the granite and quartzite is undoubtedly a contact one, the question is raised whether the soda-granite itself may not be a further stage in the alteration of the quartzites. If so, it is interesting as the first described occurrence of the production by contact action of a holocrystalline rock from a fragmental one, where the new rock has all of the characteristics of an eruptive. The red rock fills dikes and veins, cutting the rocks of the contact belt. It intrudes the quartzites, crumpling and altering them, and acts as an eruptive at its contact with the gabbro. It impregnates the quartzites in the outer portion of the contact belt, and in certain localities develops into a porphyritic granophyre. It is present just where it would be expected were it the final member in the alteration of the

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[1] Bull. No. 8, U. S. Geological Survey.

quartzites, and it passes into the quartzites by imperceptible gradations. On the other hand, it is exactly similar to the rocks of undoubted eruptive flows in the Keweenawan series on both sides of Lake Superior, and is always an accompaniment of the gabbro of Pigeon Point, even when no fragmental rocks are near. The genetic relations of the red rock to the gabbro and the quartzites indicate that it is probably a result of the fusion and recrystallization of preexisting quartzites at their contact with a large heated mass of gabbro at some distance beneath the surface of the earth. But even if the granular red rock and its porphyritic phase should prove to be original eruptives, the interesting fact remains that the most altered rock of the contact belt is one which has solidified from a molten magma, resulting largely from the fusion of sediments.

Prof. C. W. Hall has been engaged in the preparation of two bulletins, one "On the Gneisses, Crystalline Schists and Associated Rocks of the Minnesota River Valley," and another on the "Granites and Associated Diabasic Rocks of Central Minnesota." Both of these he reports as well advanced.

Prof. Erasmus Haworth upon returning from the field began work upon the material collected by him in Missouri. At the present time his microscopic study is not complete, so that his results are provisional. There are, however, strong indications that this study will corroborate the conclusion reached in the field concerning the relations of the porphyries and granites—that is, that they are but different forms of crystallization from the same magma, which were simultaneously erupted.

Mr. George E. Luther, who joined the division as stenographer and field assistant October 1, is the only assistant who has given his time wholly to the Survey work. During the year he has been occupied principally in stenographic and typewriter work in connection with the preparation of the publications above mentioned; also, a considerable part of his time has been given to cataloguing and arranging material. This last work he has been able to complete, so that at the present time all records are fully up to date. The residue of time not occupied by these duties has been used by him in assisting in photographic and draughting work.

A large number of thin sections have been prepared at the Washington office for the division and added to its collection; also, sixty-two photographs of thin sections have been taken by Mr. Merriam and Mr. Luther.

PUBLICATIONS.

The most important publication of the division which has appeared during the year is that by Prof. Irving "On the Classification of the Early Cambrian and pre-Cambrian Formations of the Northwestern States." This occupies a place in the Seventh Annual Report.

Aside from this only two papers have been published. Both are found in the American Journal of Science for January. The first is by Dr. Bayley upon "A Quartz-Keratophyre from Pigeon Point and Irving's Augite-Syenite." This paper treats of the characteristics of the peculiar red rock already mentioned as occurring in large quantities at Pigeon Point under such conditions as to give rise to a rock intermediate in properties between those of a soda-granite there found and those of an adjacent olivine gabbro. The second paper, by myself, is upon "The Iron Ores of the Penokee-Gogebic Series of Michigan and Wisconsin." This was an advance announcement of the relations of the iron ores to the surrounding rocks and an explanation of their genesis. This subject is treated in a paper included in the present volume.

Very respectfully,

C. R. VAN HISE,
Geologist in Charge.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF DR. T. C. CHAMBERLIN.

U. S. GEOLOGICAL SURVEY,
GLACIAL DIVISION,
Madison, Wis., July 1, 1889.

SIR: I have the honor to submit herewith a report of the operations of the Glacial Division of the U. S. Geological Survey for the fiscal year ending June 30, 1889:

The larger portion of the time and labors of the division has been occupied in the elaboration and preparation for publication of results of previous field investigations. It may be remarked that for several preceding years field work had occupied the chief place and that a large accumulation of material had been made, which it became desirable to reduce to form and publication.

Assistant Geologist Warren Upham spent the entire year in the elaboration of the data which he had previously accumulated relating to the basin of the Red River of the North, and particularly to the phenomena of the extinct Lake Agassiz and its place and significance in glacial history. It will be remembered that during a portion of the preceding year he had examined the northern extension of that basin in Manitoba by virtue of a joint arrangement between the Geological Survey of Canada and our own. A portion of Mr. Upham's time was occupied in the preparation of a report upon the data thus jointly gathered for the use of both Surveys. Mr. Upham has also given some additional time to the correlation and reduction of elevations of the north border region, which he has conveniently arranged and tabulated for publication as a bulletin. When some additional recent determinations shall have been collected and reduced, it will be submitted for publication. It is planned that Mr. Upham shall spend an additional season in the region adjoining the immediate basin occupied by the ancient Lake Agassiz with the special object of determining the relationship of the several marginal moraines to the beach lines and the lacustrine basin, as these relationships constitute an important factor in fixing the time and determining the significance of the lacustrine occupancy of the basin.

Prof. George H. Stone has continued and practically completed the elaboration of his material relative to the glacial gravels of Maine, and has submitted his manuscript bearing upon that subject. It will be transmitted to you for publication at an early day.

Of the time given to the work of the Survey by Mr. I. M. Buell, special field assistant, a small portion was devoted to additional field observations upon the bowlder trains of south central Wisconsin, particularly those stretching away from the isolated ledges of Montello, Marcellon, Moundville and Observatory Hill. The greater part of this time was occupied in working upon the data previously gathered by field work and the development of more critical methods of work intended to develop more fully the significance of the phenomena of the region.

Prof. R. D. Salisbury having been engaged in work on his own account in Germany during the most of last summer, has given but a very short time to the Survey. In March he spent a few days in field work in north central Illinois in securing some additional data relative to the subjects studied by him two years since. In the last week in June he began field work on the Mississippi River at Chester, Ill., and worked thence southward. The especial object of this investigation was to determine the relationships between the valley deposits of the Lower Mississippi and the glacial deposits of the Upper Mississippi. By examining these deposits at the supposed point of their junctions with the border of northern drift it is hoped to demonstrably establish their time ratios and their genesis.

So much of my own time as has been given to the Survey has been chiefly occupied in administrative work. A few brief reconnaissances in the field in different localities have been made, chiefly in connection with other glacialists, for the purposes of comparison and correlation.

Very respectfully submitted.

T. C. CHAMBERLIN,
Geologist in Charge.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF DR. A. C. PEALE.

U. S. Geological Survey,
Montana Division,
Washington, D. C., July 1,1889.

Sir: I have the honor to submit the following report of operations of the Montana Division of Geology for the year ending June 30, 1889:

FIELD WORK.

Owing to the fact that appropriations for field work were not available until August, the field party was not organized at Bozeman until the first week of that month, and in view of the shortness of the season it was decided to devote it to the investigation of three comparatively small areas whose examination was necessary in order to complete the geological colorings of the northern half of the Three Forks topographic map. It was also thought that at the same time closer search in the beds so well exposed in this region might result in the finding of fossils to close up some of the paleontologic gaps whose existence the study of the collections of previous years had developed.

The actual field work was begun about the middle of August. The first week was devoted to the reexamination of the Paleozoic section as exposed north of the East Gallatin River, and the result was the finding of four fossiliferous horizons in the upper portion of the Cambrian which had hitherto been unknown. Several fossiliferous lines in the upper part of the Carboniferous were also determined. The full value and bearing of the paleontological evidence obtained cannot of course be stated until the collections have been examined and studied by the different paleontologists of the Survey. A preliminary examination of the Cambrian and Carboniferous fossils, however, enables us to state that the Lower, Middle, and Upper divisions of the Cambrian, and the Lower and Upper divisions of the Carboniferous, are all represented within the limits mapped on the Three Forks sheet.

The last week of the month was occupied in tracing the limits of the lake deposits at the upper end of Dry Creek Valley and the north end of the Bridger Range, and in the investigation of the field relations of certain eruptive rocks exposed at the heads of some of the branches of Sixteen Mile Creek.

During the early part of September the Carboniferous and Devonian portions of the section were studied in the area lying between the Gallatin and Missouri Rivers, extending to the Horse Shoe Bend of the Missouri. This area had hitherto not been examined, and large collections were obtained from the Paleozoic rocks exposed here.

About the middle of the month several doubtful points in regard to the geological structure of the Jefferson River Canyon were cleared up by the investigation made at a point some fifteen miles above the Three Forks.

On the 17th of September Mr. F. H. Knowlton of the National Museum, who had spent most of the preceding two months in the examination of the fossil-leaf localities of the Yellowstone National Park with Mr. Hague, joined us for the purpose of studying the field relations of the fossil collections from the borders of the Gallatin Valley. This occupied the remainder of the month, during which also, the locality of fossil wood (wood opal) near Gallatin City was carefully explored and additional collections were secured from it. An interesting collection of fossil bones, among them the remains of a Mastodon, was also made from the lake beds of this vicinity. The field party was disbanded at Bozeman the first week in October, and office work was begun in Washington the middle of the month.

OFFICE WORK.

The office work of the year consisted of the geological coloring of the northern half of the Three Forks topographic map; the preparation of manuscript for a bulletin, and the continuation of the work on the subject of mineral waters. During the year the fourth paper on the statistics of mineral waters (for the year 1887) was published, and a fifth paper on the same subject giving the statistics for the year 1888 has been prepared, and is now ready for publication in the forthcoming volume of the Mineral Resources of the United States.

The work on the manuscript for the bulletin on the "Paleozoic Section in the vicinity of Three Forks, Montana," which was begun during the preceding year has been completed, and nine plates have been prepared for its illustration. Mr. George P. Merrill has furnished eighteen pages of petrographic notes on the eruptive rocks of the section, which with two figures will form an appendix to the bulletin. The Gallatin Paleozoic section as outlined in this paper may be condensed as follows:

	Feet.		*Feet.*
Carboniferous	1,600	Jefferson limestones	350
		Bridger limestones	1,250
Devonian	575	Three Forks shales	135
Devono-Silurian	200	Three Forks limestones	640
Cambrian	1,250	Gallatin limestones	835
		Gallatin sandstones	415
Algonkian	5,000	East Gallatin sandstones (alternations of conglomeritic micaceous sandstone, with bands of siliceous limestones and indurated clay shales)	5,000
Total thickness			8,625

The division is under obligations to the Chemical Laboratory for analyses of rocks furnished; to the Petrographic Laboratory for thin sections of eighty-four specimens of igneous rocks; to Mr. Merrill for microscopic identification of numerous specimens, and to Mr. C. D. Walcott for identifications of fossils. Mr. Charles W. Richmond has rendered efficient service in the field, and also in the preparation of illustrations, in work on the preparation of the paper on the mineral waters, and in other routine office work.

Very respectfully,

A. C. PEALE,
Geologist.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF MR. ARNOLD HAGUE.

U. S. GEOLOGICAL SURVEY,
YELLOWSTONE PARK DIVISION,
Washington, D. C., July 1, 1889.

SIR: I have the honor to submit herewith the following report of field and office work conducted under my charge for the year ending June 30, 1889:

The field work of this division during the past year has been mainly confined to the area of the Yellowstone National Park and the Absaroka Range which lies adjacent to the east.

In accordance with your instructions I authorized Mr. Joseph P. Iddings to leave Washington and proceed to Bozeman, Mont., to make the necessary preparations and outfit the party for the summer of 1888. He left Bozeman for the Park and established the first working camp for the summer in Swan Lake Valley, about four miles from the Mammoth Hot Springs, from which point he completed some investigations undertaken the previous year upon the crystalline rocks of Electric Peak and their relations to the upheaval of the sedimentary beds which form the summit and outlying spurs.

Accompanied by Mr. Walter H. Weed, I joined the party July 19. The field assistants for the summer consisted of Mr. Iddings and Mr. Weed, assistant geologists, permanently attached to the party; Mr. F. H. Knowlton, assistant geologist, of the Smithsonian Institution, who became a member of the party for the season for the special purpose of collecting the plant remains found throughout the volcanic breccias upon the east side of the Park; Mr. Paul J. Dashiell, volunteer assistant, a student of Johns Hopkins University; and Mr. E. H. Shuster, stenographer, disbursing clerk, and storekeeper.

Soon after my arrival in the Park I started upon a trip to the geyser basins, desirous of studying the violent outbursts of Excelsior

Geyser, which, after lying dormant for nearly six years, had broken out afresh but a few weeks before. In the summer of 1882 eruptions were witnessed almost daily, but after a few months of wonderful displays of great power, action ceased altogether until the geyser suddenly again burst forth in the spring of 1888. Since the renewal of the geyser, action has been steadily maintained, and at the time of my visit the interval between eruptions was about one hour and a half. Reports were frequently made to me of great changes taking place in the distribution of the hot waters throughout the Park, resulting from the enormous discharges from the Excelsior, which were steadily drawing upon the underground water supply of other geyser and hot spring areas. In the Midway Basin I found that several hot springs and small streams had ceased to flow and temporarily at least had become extinct, the Excelsior apparently draining the southern end of the basin. In neither the Upper nor the Lower Basins were decided changes observed which could in any way be referred to the renewal of activity in the Excelsior. Indeed, in the Upper Basin several small geysers had recently broken out, indicating rather an increase than a diminution of flow; their action was wholly independent of any changes going on in the Midway Basin. It is impossible to estimate with any degree of accuracy the amount of water thrown out in any single eruption of Excelsior during the few minutes duration of the geyser, but it must reach many thousand barrels. In my observation in the basins I failed to note any diminution in the supply of thermal waters, the enormous amount thrown out by Excelsior apparently being in addition to that which ordinarily reaches the surface. From the geyser basins I proceeded to the junction of the Lamar River with the Yellowstone, going by way of the Grand Canyon and Mount Washburne.

Establishing a permanent camp on Amethyst Creek in the Lamar Valley, the greater part of the season was occupied in a study of the northeast portion of the Park and adjacent country, including the southern end of the Snowy Range, and also extending the surveys eastward to the summit of the Absaroka Range.

In addition to the preparation of a geological map of the region much time was given to investigation of special subjects, such as the glaciation of the Park, the geologic history of the Yellowstone and Lamar Valleys, the relationship between the fossil flora of the region and the vast pile of Tertiary lavas in which they are imbedded, the age of the latest volcanic eruptions found in the broad valley of the Lamar, the geologic structure of a preexisting mountain region before the outpouring of the andesitic breccias and agglomerates which form the present Absaroka Range.

In the autumn I made a geological reconnaissance of the southern end of the Absaroka Range, reaching the summit via Thoroughfare Creek, one of the principal sources of the Upper Yellowstone; thence down the Ishawooa, the north branch of the South Fork of the Stinking Water, following the latter stream out into the broad valley lying between the Absarokas and the Big Horns. I found an exceptionally rough region of country, little traveled except by an occasional hunter or trapper. Returning I followed the canyon of the North Stinking Water, again entering the Park near the north end of Yellowstone Lake. The two trips across the range afforded admirable geological sections of the volcanic rocks—profound canyons, cutting 3,000 or 4,000 feet into the accumulated lavas—but nowhere except along the eastern foot-hills were the underlying sedimentary beds exposed.

To Mr. Knowlton was assigned the duty of collecting in the field the plant remains from the large storehouses of material buried in the Tertiary lavas of the earlier volcanic outbursts of the region. The investigations of previous years conducted under my own direction had not only discovered the principal localities where such material had been preserved, but at the same time had determined within certain limits the geological position of the beds and their relations to the different flows. With this information Mr. Knowlton was enabled to add greatly to our collection, and I shall be much disappointed if his study of this material does not throw additional light upon the history and character of volcanic activity in Tertiary time. Mr. Knowlton remained a member of the party from early in July until September 15, when he was obliged to leave to join Dr. A. C. Peale in the Gallatin Valley for the purpose of examining certain plant beds in connection with important coal deposits in that part of the country.

Mr. Weed devoted several weeks to the annual study of the principal geyser basins of the Park, noting, as in former seasons, the gradual changes taking place from year to year. In the prosecution of this work he has obtained results which could be reached only after assiduous labor and careful observation repeated for a series of years. This past season his studies included not only the more important geyser basins, but those less frequented in the more inaccessible regions of the Park. To Mr. Weed belongs the credit of having explored a new hot spring area, which up to the time of his visit was unknown. It is situated on the east side of the Grand Canyon of the Yellowstone near the head of Wapiti Creek.

During the summer collections of two varieties of rocks characteristically developed in the Park were made for the Educational Series of rocks: One a medium grained typical diorite from the base of Electric Peak, the other a remarkably fine example of a rhyolitic pearlite from the bluff on the east side of the Firehole River, opposite Excelsior Geyser. This pearlite forms a marked lithological feature of the National Reservation.

Field work was brought to a close after an exceptionally successful season in the fourth week of October, and the party finally disbanded October 29 in Bozeman, where the camp equipage was stored for future service.

After the close of the regular field season, accompanied by Mr. Iddings, I visited the well known mining district of Butte, in northern Montana, for the purpose of examining by means of the network of shafts and galleries the granites, granite-porphyries and rhyolites so extensively exposed under ground. The locality affords exceptional facilities for the study of deep seated rock-masses in connection with surface exposures. The three rocks geologically closely allied are well shown here, and their association with the veins of copper and silver ores makes the study of the district desirable from an economic as well as a scientific point of view. The field of investigation is a large one, and the district is in many respects unique.

All the members of the party returned to Washington about November 20, and began arranging in permanent form field notes and observations, preliminary to final publication.

During the winter Mr. Iddings was for the greater part of the time engaged upon a study of the crystalline rocks of the Gallatin Range, and in this connection he prepared descriptions of several hundred microscopical sections of rocks gathered in the field. His study of the intrusive masses of Electric Peak will, I think, be most valuable, and every opportunity has been given him to make it thorough and complete.

Through the investigations of the Geological Survey it is well known that arsenic occurs as a constituent of the thermal waters of the Park. In waters carrying arsenic and more or less sulphureted hydrogen, like those of the geyser basins, it has always seemed to me that sulphide of arsenic must necessarily be deposited under favorable conditions in vents and chambers of many hot springs and solfataras. Diligent search, however, failed to find them until quite recently, when they were detected in the collections made the past season in the Norris Basin. Both orpiment, the yellow sulphide, carrying 61 per cent. of arsenic, and realgar, the brilliant red variety, carrying 70 per cent. of arsenic, were found coating siliceous sinter in the same narrow fissure. It is gratifying, after long seeking, to find these sulphides, feeling sure upon theoretical grounds that the conditions must exist somewhere not only for their deposition but also for their preservation.

During the year several papers have been published, the results of special investigation bearing upon scientific problems connected with the Park. In December there appeared, as Bulletin 47 of the U. S. Geological Survey, a publication entitled: "Analyses of Waters of the Yellowstone National Park, with an account of the methods of analysis employed," by F. A. Gooch and J. E. Whitfield. While, strictly speaking, it is a publication from the chemical laboratory of the Survey, it so closely relates to the labors of this division, that this letter would be incomplete without special mention of the admirable investigations of these well known chemists and the importance of their work, touching, as it does, upon some of the geological problems connected with the Park. The bulletin contains careful analyses of forty-three samples of water collected not only from all the principal geyser basins, but from Yellowstone Lake and other surface waters. There is also a complete analysis of the water furnished to the guests of the hotel at the Mammoth Hot Springs. All these waters were collected under the immediate supervision of the Geological Survey.

A paper entitled: "Obsidian Cliff, Yellowstone National Park," by Joseph P. Iddings, has been published as one of the accompanying papers to the Seventh Annual Report of the Director of the Survey. Mention has already been made of this paper in my previous letters and a brief abstract of its salient features was published in the American Journal of Science, January, 1887. In its present complete form, with accurate illustrations of lithophysæ and spherulties, and artistic views of the famous glass columns, it appears as a valuable contribution to the scientific results of the survey of the Yellowstone Park. Mr. Iddings published in the American Journal of Science, September, 1888, a short article entitled: "On the Origin of Primary Quartz in Basalt," which, although not strictly pertaining to the basalts of this region had a direct bearing upon the constitution of basalts found over wide areas in the northern Cordillera; and the investigation was conducted in connection with his other studies upon the origin of quartz in basic magmas. He showed that these quartz grains are crystallizations from the original fluid magma and bear no definite relation to its chemical composition.

Mr. Walter H. Weed having submitted a paper for the Ninth Annual Report of the Director of the Survey, sent to the American Journal of Science, with the permission of the Director, a brief abstract of his work. Mr. Weed's paper may be found in the May number of the current year and bears the title: "Formation of Siliceous Sinter by the Vegetation of Thermal Springs."

At the New York meeting, February, 1889, of the American Institute of Mining Engineers, I presented a paper entitled: "Soaping Geysers" which, although not strictly a geological publication, is not without interest as bearing upon the phenomena of geyser action and the physical problems connected with superheated waters. In nature superheated waters have scarcely been recognized in other localities, but in the Park caldrons of hot water with a temperature more than two degrees above the accurately determined boiling point, are by no means uncommon. It is in this unstable condition of the water that, under favorable conditions, it is possible to hasten geyser action. I conducted a series of experiments to determine how far geyser action may be stimulated by artificial means, and the article states my conclusions, written in answer to many inquiries upon the subject.

Very respectfully, your obedient servant,

ARNOLD HAGUE,
Geologist in Charge.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF MR. S. F. EMMONS.

U. S. GEOLOGICAL SURVEY,
ROCKY MOUNTAIN DIVISION,
Wood's Holl, Mass., June 30, 1889.

SIR: I have the honor to submit the following report of progress in the Rocky Mountain Division of Mining Geology for the fiscal year 1888-'89:

In accordance with your instructions no new work has been undertaken during the year, but the energies of the entire corps have been devoted to the completion and preparation for publication of the various pieces of work already undertaken.

FIELD WORK.

The months of July, August and September were devoted to field work. This consisted in the completion of the field investigation of the area under survey in the southern Elk Mountains, Gunnison County, Colo., by a combined geological and topographical party under charge of Mr. George H. Eldridge, with which I spent a few weeks in the commencement of the season for the purpose of directing the general plan of work; and in isolated individual investigations by Mr. Whitman Cross and myself in various parts of Colorado, Montana and Wyoming, for the purpose of verifying, elaborating and completing observations already made, and of gathering new data in various mining districts which might furnish correlative data for our generalization upon ore deposits, and at the same time indicate the most promising field for future work.

The Gunnison party consisted of Mr. Eldridge, geologist in charge, Mr. L. G. Eakins, assistant geologist, and Mr. L. L. Thompson, topographical assistant, with two camp men.

The geological investigations were confined to the sedimentary rocks, Mr. Cross having completed his study of eruptives in as great detail as the scale of the map would admit of, during the previous season. They consisted mainly in tracing out the surface outlines of the various subdivisions of the Cretaceous. These are rendered very indistinct by the intense metamorphic action to which the beds have been subjected, and which has produced not only a most remarkable change of lithological characteristics within comparatively short distances, but also an almost complete obliteration of paleontological evidence. These formations cover nearly two-thirds of the area under survey, and are extremely important as carrying not only the various beds of coal which constitute so important a part of the economic wealth of the region, but also a very considerable portion of its valuable deposits of metallic mineral.

Besides this, it was our object to trace as far as possible the relations of these beds with the overlying Tertiaries in the West, and the immense accumulation of breccia materials to the south, beyond the limits of the area mapped.

The necessity for elaboration and modification of various portions of our topographical map was pointed out in my last annual report. Mr. Thompson possessed special qualifications for this work, in that he had served as assistant to Mr. Karl in the original survey of the field, and that to the natural energy and ability he had displayed at that time there had been added the experience acquired during several field seasons in the preparation of the general map of the United States. Working thus with the geologists who were studying the structure of the region, he was enabled by their suggestions to discriminate and to express more fully the mountain forms which characterize different geological conditions; so that by his revision the map has become more expressive in showing how the present mountain sculpture is deduced from the underlying geological structure.

Field work was completed about October 1, but it was not until the end of November that Mr. Thompson had platted his field notes and completed the necessary corrections and additions to the topographical map so as to make it ready for the engravers. He also prepared, under my directions, a more detailed map on a larger scale of the so-called Anthracite Mesa, a ridge which contains the most valuable bed of anthracite coal yet developed west of Pennsylvania.

During the season Mr. Cross visited the mining districts of Silver Cliff and Ten Mile, where he made additional geological observations, and gathered what further data were available in regard to the working mines of the two regions, our material being rather incomplete in the latter respect owing to the fact that the mines have been very intermittently worked. He also gathered various sets of rock specimens in these districts for the Educational Series. In addition to this he investigated further the country in the neighborhood of Salida, Nathrop and Pike's Peak. Near the former locality he discovered an interesting series of beds over ten thousand feet in thickness, which are more recent than the Archean, and older than the Cambrian, as far as could be determined, and which consequently must be classed as Algonkian. Their further investigation promises to be of great interest in tracing the early history of the Rocky Mountains. He also obtained further paleontological material for determining the age of the Denver formation in the Denver region, the report on which is now being made ready for publication.

Under my directions Mr. George L. Cannon, jr., instructor in geology at the Denver High School, spent about two months of his summer vacation in tracing out the Quaternary deposits of the Denver Basin region, and their relations to those of the surrounding plain country, which I regard as of considerable importance for the agricultural interests of the region, as they comprise beds of undoubted loess, a formation to which the lowlands of the Mississippi Valley owe so much of their great fertility. The results of this work will form an important chapter in the forthcoming monograph on this region.

In the summer of 1887, being delayed a part of a day at Canyon City by nonconnection of trains, I discovered some fossils near the base of the Paleozoic exposures which seemed to have a Devonian facies. In October of this year Mr. T. W. Stanton visited the locality by my direction and obtained a large amount of fossiliferous limestones from these exposures, which have been submitted to Mr. Walcott. Upon examination of the larger number of species thus obtained they prove to belong to several stages of the Silurian, but not to the Devonian. They form, however, an important contribution to our knowedge of the Paleozoic life of the Rocky Mountain region.

After having spent such time as I deemed necessary with the Gunnison field party, I proceeded to the San Juan region of Colorado, where I spent a week in geological investigation from the town of Ouray as a center. My principal object was to make a further study of the series of Algonkian beds mentioned in a former report as exposed in a thickness of over ten thousand feet in the canyon of the Uncompahgre River above Ouray, where they stand nearly vertical, with Silurian and Cambrian beds abutting against and overlapping them. I was unable to find any evidence of life in them beyond what appeared to be the casts of fucoids. In the various mining districts in the neighborhood I found many facts in regard to vein formation confirmatory of the views expressed in my paper on the "Structural Relations of Ore Deposits." As regards the general geology of the region I was enabled to determine several hitherto unknown facts, among which may be mentioned, first, that there are three well defined physical breaks or nonconformities in the sedimentary series; second, that there were at least three distinct periods of outpouring of eruptive rocks.

From Ouray, towards the end of August, I proceeded to Butte, Mont., with the intention of making a further study of that interesting mining district, of examining the structure of the famous

Granite Mountain mine and the neighboring country, and of studying the metamorphic processes in the Yellowstone Park in their bearing upon the theory of vein formation. A few days after my arrival at Butte I was taken sick, and the severe illness following prevented my accomplishing more than a small portion of the work which I had planned. Though I was sufficiently recovered to reach Washington early in November, I was unable to devote myself to any continuous labor until February.

OFFICE WORK.

The time not occupied in field work or in making the preliminary studies of field observations necessary for a proper record of the same, has been occupied by the members of my corps in the preparation of the two monographs now in course of preparation, viz, that upon the Ten Mile and Silver Cliff mining districts, and that upon the Denver Basin region. As a new topographical map of the Denver Basin region for purposes of irrigation has been in progress during the year, it has been judged wise to delay the report somewhat in order to take advantage of a more correct topographical basis.

This delay has afforded opportunity for additional field work, with a view to the more satisfactory correlation of the formations of the district. The earlier collections of fossil vertebrates and fossil plants in the region were made in ignorance of certain stratigraphical breaks, and specimens now known to belong to distinct formations have been classed together as parts of the same fauna and flora. Before final conclusions are reached, it is necessary to collate, in a discriminative way, the fauna and flora of these formations, and to this end new collections have been begun, and it is planned to continue this work in the immediate future.

Mr. Cross has briefly set forth the structural facts in a paper recently published in the American Journal of Science, and it is hoped that in the light of these facts the new collections will render possible the correct paleontological separation of the Cretaceous and Tertiary in this region.

Very respectfully, your obedient servant,

S. F. EMMONS,
Geologist in Charge.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF MR. GEORGE F. BECKER.

U. S. GEOLOGICAL SURVEY,
CALIFORNIA DIVISION,
San Francisco, Cal., July 1, 1889.

SIR: Shortly after the commencement of the past fiscal year the proof of my report on the Quicksilver Deposits of the Pacific Slope, Monograph XIII, was completed, and the volume has since appeared.

Since September 1, when I reached San Francisco, my time has been occupied in studying the Gold Belt of California, upon which, as indicated in former annual reports, much preliminary work had already been done by my assistants, Messrs. H. W. Turner and Waldemar Lindgren. Up to the close of the last season the topographical maps of almost exactly one-half of the Gold Belt had been completed, and at the end of the current season the preliminary geological map of the same area will also be done. On this map the sedimentary rocks of Paleozoic and earlier Mesozoic age are not subdivided, and sundry eruptive rocks are grouped together, but the areas demarked are accurately outlined and will require only subdivision. If the topography proceeds at the same rate as hitherto, three more seasons will be needed to complete the topographical basis, and it is believed that by the end of 1893 the final geological map will also be ready.

The massive rocks are much more complex than had been anticipated. There seem to be granites of different ages, as well as gabbros, peridotites, diorites, diabases, andesites, rhyolites and basalts. The order of succession is by no means always that which is most usual elsewhere. The areas are often so intricately interlocked as to make their representation very difficult on a scale of two miles to the inch, and they have often been so profoundly modified by dynamic and chemical action as to make even their identification very difficult, much more so the elucidation of their relations to one another. I shall not feel justified in announcing any definite results of our studies on these rocks until more detailed work has been done.

In passing over granite exposures for hundreds of miles, I have taken occasion to study the dome-shaped masses for which the Sierra Nevada of California is especially noted. Granite domes comparable in size with those of the Yosemite Valley and of other portions of the Sierra are not found in Europe, and I am not aware that they have been described from any part of the world. Those of the Yosemite have been ascribed to internal structure arising from movements in the mass prior to solidification. They have also been cited as colossal examples of conchoidal fracture. There seem to be grave objections to these views. If the talus of one of these domes be examined, it will usually be found that the more ancient fragments have lost their angularity by weathering, and even that they have been reduced to rounded masses similar to the parent dome, although of trifling dimensions.

Again, I have observed domes of large size in which fissures have formed at some not very recent date. The edges and corners thus produced have also rounded, and in some cases it is clear that the dome itself is undergoing a process of resolution into an aggregate of smaller spherical masses. It is also clear that the small blocks are rounded mainly as a result of superficial decomposition or disintegration, not by fracture, and that the changes of form have been controlled by the positions of the original polyhedral surfaces.

If the theory of an original controlling ball structure were correct, it should account for spheroidal weathering of the fragments as well as of the colossal domes, for between the two extremes of size there is every possible gradation. It is not inconceivable that a large mass should be composed of spheroidal elements, themselves arranged in concentric layers, and that the whole mass, as well as the elements, should tend to a spherical form. But were this the case the domes would be bounded by surfaces on which the detailed structure would be apparent, and would on near inspection resemble roches moutonnées. Such surfaces do not occur. The large domes show no indication of a tendency to resolve themselves into smaller spheres excepting when they have first been intersected by fissures. Were the rounding of the masses due to internal structure one would also expect to find the resulting surfaces coincident with other evidences of structure, and in particular with gneissic surfaces, at which ferromagnesian silicates have separated in greater abundance than elsewhere. No such coincidence is observable; on the contrary, gneissic planes often cut squarely across a dome.

In my opinion the great granite domes are simply gigantic cases of exfoliation similar, except in scale, to those often observed in basalt and other rocks, and the regular curvature I believe to be due simply to the fact that, measured per unit of volume, the surface exposed is in an inverse ratio to the radius of curvature, so that the sharply curved surfaces weather fastest.[1] The great size of the domes of the Sierra arises from the distribution of fissures. The peculiar granite is intersected by faults along which intense dynamical action has occurred; but between these belts, which are often separated by miles, the rock is unusually continuous, and it thus affords material for the formation of immense exfoliation nodules.

It has been both asserted and denied by geologists that there is distinct evidence of glaciation in the Yosemite Valley. It may not be amiss to note that on the north wall of the valley, directly north-

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[1] Compare Monograph XIII, p. 68.

west of the Sentinel, at about two hundred and fifty feet above the level of the river, there is an exposure of very well preserved glacial groovings still so smooth that lichens have not been able to gain a foothold. The fact that the walls of the valley are so nearly vertical must evidently facilitate weathering and the scaling off of flakes of rock. These walls would therefore retain evidences of glaciation less tenaciously than most exposures. At the top of the Nevada fall, and therefore just at the edge of the valley, there is well preserved glacial polish, and the post-glacial erosion of the Merced River at this point cannot exceed a foot. The granite is not exceptionally hard, but, on the other hand, the river is for most of the year a very clear stream with little erosive power.

I am not aware that glaciation has been noted so far south as the headwaters of the Kaweah River. At the Mineral King mining district in this region a fine glacier existed some seven or eight miles long and reaching down to an altitude of approximately seven thousand feet above sea level. It passed over granites and slates which at one point are fossiliferous. The glacier had at least three branches and has left perfect polish over large areas of the present drainage. Though the water has continued to flow in the same channels, and in springtime forms roaring, muddy torrents of very high grade, the erosion since the glaciers disappeared is nowhere more than a few feet and in places is insensible.

The older sedimentary rocks of the Sierra have not only been thrown into a highly inclined position, but single groups of beds have also been divided into isolated patches. This lack of continuity renders inferences as to age from structural relations difficult and uncertain, and makes the evidence from fossils the more important. As is well known, however, these are extremely rare on the Gold Belt. Some new fossil localities have been discovered by my parties and I am making every effort to increase the list, but it now appears probable that a satisfactory subdivision of these rocks according to age will be among the last problems to be solved in the investigation.

Other questions, such as serpentinoid and talcose metamorphism, the structure of the range as indicated by numerous nearly parallel belts of granite reduced to a slaty structure by faulting action, and the relation of the ore deposits to the ensemble of geological phenomena have been touched upon only by the way. No complete studies of these problems can be attempted until the map has made further progress.

During the year I have devoted some time, with the assistance of Dr. W. H. Melville, to the study of chemico-physical problems connected with vein formation. While we have made considerable progress in a knowledge of the natural solvents of important metals, we have thus far been baffled in studying decompositions and certain methods of segregation, subjects upon which I hope to render a different report on a future occasion.

Very respectfully, your obedient servant,

G. F. Becker,
Geologist in Charge.

Hon. J. W. Powell,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF MR. J. S. DILLER.

U. S. Geological Survey,
Cascade Division,
Washington, D. C., July 1, 1889.

Sir: Herewith I have the honor to submit a report of operations in the division under my charge for the fiscal year ending June 30, 1889:

The plan of the year's work had for its object: (1) the collection and preparation of a large number of specimens for the Educational Series of rocks and (2) the continuation of the geologic mapping already begun in northern California.

In accordance with your instructions, on July 1 I proceeded with Assistant W. B. Smith to Bozeman, Mont., and organized a party for a short trip into the Crazy Mountains to collect the rare nepheline-bearing eruptive rocks (theralites) described by Mr. J. E. Wolff as occurring in that region. We passed around the western base of the mountains to Gordon's Butte, on the Musselshell River, five miles west of Martinsdale, where we camped for nearly a week preparing specimens of the typical theralite and studying its mode of occurrence. The rocks in the vicinity of Gordon's Butte are well exposed, so that its structure is clearly defined. The main body of the tabular hill is a sheet of theralite two to three hundred feet in thickness forming cliffs on all sides. This is underlaid by fossiliferous sandstones and shales, which form a pedestal lifting the eruptive mass considerably above the general level of the country. Upon the top of the theralite forming the summit of the hill are remnants of metamorphosed sediments, and the whole aspect suggests that Gordon's Butte is a denuded laccolite. Observations at other points also tend to confirm the view that a part, at least, of the Crazy Mountains is made up of intrusive sheets and laccolites, which may remain either in their original position or be highly tilted. On our return we stopped at Elbow Creek, thirteen miles west of Martinsdale, to collect the variety of theralite rich in olivine, and also at other points along the base of the mountains, to examine their structure, reaching Bozeman July 18.

At Rosebery, Oregon, we collected a series of specimens to illustrate spheroidal weathering in an eruptive rock, and near Riddles, Oregon, the peridotite with which the nickel ore genthite is associated. At this locality, upon the west side of Cow Creek Valley, Mr. Will Q. Brown called our attention to a thin limestone containing an abundance of Aucella. The same fossils were found upon the east side of the valley also, in strata which has suffered little if any alteration in either position or structure since their deposition and it is evident that the Aucella beds rest unconformably upon the metamorphic rocks beneath. This is of special importance when we remember that Drs. White and Becker have shown that in California the Aucella beds are involved in the metamorphism.

At Ashland, Oregon, the regular field party was organized and proceeded southward to the Sacramento Valley, continuing the collection of specimens by the way. At the north base of the Siskiyou Mountains a pebbly sandstone was collected and at Cole's a series of faulted pebbles from the Cretaceous Conglomerate. These are noteworthy as demonstrating the enormous pressure to which the conglomerate has been subjected. Some of its hardest pebbles (quartz) were crushed although the mass as a whole has been but little disturbed or changed.

At Mount Shasta specimens of the older and younger hypersthene andesites as well as of the hornblende andesite were collected. A lava stream from Mount Shasta enters the canyon of the Sacramento River, which it follows for about fifty miles. At Delta, over forty miles from its source, the flow furnished good specimens of porphyritic lava.

Near the United States Fishery on the McCloud River excellent specimens of limestone fluted by rain were obtained. They illustrate very well, in a small way, the process of valley-making by solution. At Stillwater we gathered specimens of a waterlaid volcanic tuff which is widely distributed throughout the northern portion of the Sacramento Valley and marks a sharp time horizon in numerous sections.

On Clear Creek in Shasta County were collected two suites of remarkably porphyritic eruptive rocks penetrating auriferous slates. One is especially noteworthy on account of the corroded crystals of porphyritic quartz which it contains. They are so distinctly rounded by the resorbent action of the magma as to be easily mistaken for small pebbles.

Specimens of spheroidal weathering in shales, streaked rhyolitic lava with many inclusions, quartz basalt, yellow and black lapilli, dacite and perlite were all collected about the northern end of the Sacramento Valley and in the Lassen Peak district.

The regular cartographic work of the region west of Lassen Peak was pushed forward in connection with the collection of rocks for the Educational Series. The eastern and northern portions of the Red Bluff district were completed and detailed explorations continued west of the Sacramento River in the Coast Range.

Upon the northwestern border of the Sacramento Valley is a broad belt of Cretaceous sandstones and shales which are inclined to the eastward and their upper edges planed off by a well marked base-level of erosion. The strata are remarkable at a number of points, especially along the North Fork of the Cottonwood and its branches, for the fossil Ammonites they contain and offer a most promising field for paleontological investigation.

A novel feature and one of considerable importance is the presence of a series of sandstone vein rocks which penetrate the slightly tilted shales in a manner exactly analogous to that of an eruptive rock. The sandstone being fine grained and occurring in distinct dike-like masses their igneous character was not seriously questioned until the microscope revealed the fact that they were purely fragmental rocks without any evidence of crystallization from igneous fusion. They occur in considerable numbers with very uniform strike and dip throughout a large tract and offer an interesting problem for study.

October 1 the party disbanded at Red Bluff, Cal., and proceeded to Utah to continue the collection of rocks for the Educational Series. At Peoa, on the Weber River, we obtained a beautifully banded sandstone, and after visiting the Ice Spring craters west of Filmore to obtain specimens of vesicular basalt, fluoidal fragments of fresh lava and a number of photographs, we proceeded to St. George, in southern Utah, where we outfitted for a trip to Mount Trumbull and the Grand Canyon of the Colorado at the foot of the Toroweap.

Encamped at Mount Trumbull we collected olivine nodules from the recent lava flow of that vicinity, as well as small volcanic bombs which are abundant about the numerous cinder cones upon the Uinkaret platform. This camp afforded us an opportunity not only to ascend the principal peaks and thus obtain a comprehensive view of one of the grandest geological panoramas in the world, but also to descend into the Toroweap and to the bottom of the inner gorge of the Grand Canyon itself.

Early in December we returned to Washington, having collected during the field season twenty-six varieties of rocks, two hundred and fifty samples of each kind, aggregating in all about six thousand five hundred specimens. Only a few varieties required no trimming at all. The others were all carefully trimmed before shipment. I desire to heartily commend the work of my assistant, Mr. W. B. Smith, whose efficient aid alone rendered it possible for me to obtain so large a number of specimens in one season.

Other members of the Survey have aided greatly in collecting material. Mr. Whitman Cross collected trachyte, syenite and nevadite in Colorado; Mr. Hague's party diorite and perlite in the National Park; Mr. W. S. Bayley elæolite-syenite at Litchfield, Me., and gabbro at Pigeon Point, Minn.; Mr. McGee loess in Iowa; Mr. Willis crumpled slates at Warm Springs, N. C.; Mr. Hayes bituminous shale at Dug Gap, Ga.; Dr. A. C. Peale volcanic dust in the Gallatin Valley, Mont.; Mr. J. E. Wolff granitoid gneiss, metamorphic conglomerate and albite phyllite, all at the Hoosac Tunnel, Mass., and Mr. H. S. Williams shell marl at Cortland, N. Y. Special arrangements were made with Prof. C. H. Hitchcock, who collected chlorite schist at Lisbon, N. H., quartz porphyry at Pemigawassett, N. H., camptonite at Livermore Falls near Campton, N. H., protogine at Lebanon, N. H., and garnetiferous hornblende-schist at Hanover, N. H., making the total number of specimens collected for the Educational Series during the field season about eleven thousand five hundred. The majority of the specimens collected by other parties than my own were for convenience left either partially or wholly untrimmed.

Since returning from the field I have been engaged in studying the collections made and preparing reports. A bulletin on "A late volcanic eruption in northern California and its peculiar lava" has been completed and submitted for publication.

The geologic map of the Lassen Peak district has been completed, and offered for publication as an atlas sheet with brief notes upon the topography and geology.

Mr. Hermann Ohm and Mr. Fred C. Ohm have worked continuously in the laboratory preparing thin sections of rocks for the Survey. Mr. W. S. Hunnell has been engaged part of the time preparing thin sections and the other portion has been devoted either to trimming or sawing and polishing specimens. Three thousand six hundred and eighty-one thin sections were prepared during the year for the various divisions of the Survey. Four hundred specimens were cut, and of these one hundred and nine were polished.

Very respectfully, your obedient servant,

J. S. DILLER,
Geologist in Charge.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF MR. W J McGEE.

U. S. GEOLOGICAL SURVEY,
POTOMAC DIVISION,
Washington, D. C., July 1, 1889.

SIR: I have the honor to submit the following report of operations in this division during the fiscal year just closing:

THE WORK IN IOWA.

Several years ago an investigation of the glacial and associated deposits and the Pleistocene history of northeastern Iowa was commenced and carried nearly to completion. Circumstances prevented immediate publication of the results of this work, and toward the end of the fiscal year of 1887-'88 the territory was revisited for the purpose of reviewing the early work in the light of recent advances in geologic science; and this resurvey extended into the early months of the present year. The Iowa field work terminated in August, and subsequent months have been spent in preparing for the press an account of that work, in carrying on limited investigations in the more local field of the division in the Middle Atlantic slope, and in superintending the work of the different collaborators mentioned below.

Northeastern Iowa is a part of the vaguely defined region once designated the "Great Plains;" but its extreme eastern portion belongs rather to the rugged and forest covered tract bordering on the Great Lakes. Its indurated rocks include a few limited outliers provisionally referred to the Cretaceous, and a representative series of Paleozoic formations extending from the Coal Measures to the upper Cambrian. The several formations have a gentle inclination away from the central continental nucleus, and are deformed in addition by certain interesting local flexures and a series of especially significant regularly concentric undulations; and by their composition and structure they throw important light on the Paleozoic history of the central part of the continent. The Driftless Area of Wisconsin extends into the territory, and within as well as somewhat beyond its limits the Paleozoic rocks are covered with a thick mantle of residuary materials resulting from their own decomposition. This mantle forms the soil and subsoil in the extreme northeastern part of the State. Within it certain mineral accumulations are found; and it gives a record of some value of Mesozoic and Cenozoic history. The Pleistocene deposits of the territory comprise two sheets of glacial drift, an intercalated forest bed and a superincumbent deposit of loess; the drift sheets coinciding approximately in area and covering the greater part of the territory and the forest bed failing frequently, while the loess is singularly distributed over nearly half of the territory. The topography is significant, particularly in the drift covered area where the prevailing drainage is at right angles to the general slope of the surface, and where, moreover, the rivers frequently diverge from the less elevated surfaces and flow in narrow gorges through plateaus or in the axes of the ridges. The ridges which the rivers thus seek are crowned with loess, while the lowlands which the rivers avoid generally consist of unmodified drift. They are frequently crossed obliquely by lesser loess-crowned ridges and lines of hills. The Pleistocene deposits and the topography of the territory, and particularly the singular distribution of loess and the singular deportment of the rivers, afford a unique record of Pleistocene history. There are in the territory considerable alluvial deposits which sustain an intimate relation to the late Pleistocene terraces and other deposits, and so afford a record of the closing episodes of the Pleistocene and the beginning of the present. In the memoir on the Pleistocene history of northeastern Iowa, which is just completed, the various phenomena are described in some detail and generalized at some length and the several records of the past are interpreted.

THE WORK ON ROCK GAS.

During the last fiscal year Dr. A. J. Phinney was employed to investigate the rock-gas field of Indiana, and toward the end of the year he submitted a report thereon for publication. Within the last lustrum rock gas has become one of the more important among the natural resources of the rocks, particularly in the northeastern-central United States; and pari passu with the development of these resources geologic science has within the past two years taken an enormous stride. Much was indeed known by a few special students of the genesis of the bitumens, including the natural gas now so extensively utilized in half a dozen States; yet this knowledge was not generally disseminated, and the simple laws governing the distribution of gas and oil were not understood, So when the exploitation of rock gas was commenced in Pennsylvania and Ohio the geologist was alike unable to guide efforts or predict results; yet so fully did the systematic student avail himself of the opportunities for observation afforded by prospecting, that within two years the laws governing the accumulation and distribution of the light bitumens were made known, and their presence or absence can now be prognosticated with as great certainty as that attending the prognostication of artesian water. A considerable part of this advance in science resulted from investigations in the great Indiana gas field; and a large part of these investigations were made, carefully recorded and prepared for publication by Dr. Phinney. His report was during the present year returned for revision and the incorporation of new data. An introductory chapter on the origin and the geographic and geologic distribution of the bitumens was prepared in the office of this division, and the entire report is now in press as one of the bulletins of the Survey.

THE WORK IN THE DISTRICT OF COLUMBIA.

Field work within the district has been curtailed somewhat during the fiscal year by reason of the concentration of effort upon the Iowa study; but during the closing months of the year occasional trips have been taken to examine localities especially interesting, to test the recently engraved topographic atlas sheets of the territory by field use, and to examine ephemeral exposures.

During the summer the memorable freshet in the Potomac River of June 1 and 2 was studied. A well known law of river deportment, established by Powell and Gilbert, is that streams of high declivity tend to corrade vertically and thus to flow in deep and narrow channels; but certain Middle Atlantic slope rivers, notably the Susquehanna and somewhat less notably the Potomac, appear to depart from this law in that, despite their high declivity, they flow in broad and shallow channels. A preliminary study of the subject indicates that the apparently anomalous habit of these rivers depends upon behavior during freshets and upon the relation between freshet stage and normal stage. So during the last three years every opportunity to study the Middle Atlantic slope rivers during freshets has been seized. The opportunity mentioned above was without precedent. The river indeed rose no higher in Washington than during certain other recorded freshets depending in part or wholly on ice jams; but above the reach of tidal influence the volume of water and the height of the flood were far beyond those previously recorded. At Cumberland the water rose above the highest previous flood six feet (according to press accounts), at Harper's Ferry six feet eight inches (according to measurements kindly made by Mr. Bailey Willis), at Great Falls eight feet, at Little Falls six feet three inches, and at Chain Bridge between six and seven feet above the level reached by the flood of 1877—the highest hitherto known, at least since the completion of the Chesapeake and Ohio Canal, forty years ago. Lock houses supposed to be far beyond the reach of the highest freshets, and locks supposed to be invulnerable, were swept away; the inner gorge and its bounding hills and precipices at Great Falls were overwhelmed by a turbulent torrent reaching a third of a mile in width and one hundred and fifty feet in depth; over the site of the "Log Dam" near Great Falls, designed to protect the canal from great freshets, the Potomac rushed in a seething stream seven or eight feet deep, and every trace of the wood work and part of the masonry were swept away. The airy iron structure known as Chain Bridge, fifty feet above the ordinary water level, was threatened and a part of its floor was swept by the flood; the tidal estuary opposite Georgetown was transformed into a torrent which endangered and seriously undermined one of the piers of the Free Bridge; which the most powerful steam tugs were unable to stem, and which carried schooners far into the still broader estuary toward Long Bridge despite the aid of tugs and anchors; and the Long Bridge itself, though miles below the head of tide at ordinary water stages, was partially carried away.

With the view of ascertaining the discharge of the Potomac during this unprecedented freshet its velocity was estimated and three cross-sections were carefully measured at different points after the subsidence of the waters—the first a little way below Great Falls, the second at Little Falls, and the third at Chain Bridge—and from these data the discharge has been computed. The results are as follows:

Location of section.	Cross section.	Estimated velocity.		Discharge per second.
		Per hour.	Per second.	
	Sq. feet.	*Miles.*	*Feet.*	*Cubic feet.*
Great Falls	72,664	10	14.7	1,168,000
Little Falls	36,800	12	17.16	631,488
Chain Bridge	42,500	12	17.16	729,200

In these cross sections the surface was assumed horizontal at Great Falls; allowances of one thousand five hundred square feet for convexity were made at Little Falls and Chain Bridge; and allowance was made for the piers at Chain Bridge. The remarkable convexity at Little Falls and Chain Bridge was not accurately measured, but is known to closely approach, if not exceed, three feet vertical at Chain Bridge.

The declivity of the flood from Great Falls to Chain Bridge was something over nine feet per mile; and assuming the declivity slightly under nine feet per mile, Mr. R. S. Woodward has computed the velocities and discharges at the three cross sections by means of Ganguillet & Kutter's formula with the following results:

Location of section.	Cross section.	Coefficient of roughness.	Velocity per second.	Discharge per second.
	Sq. feet.		*Feet.*	*Cubic feet.*
Great Falls	72,644	06	11.6	843,269
Little Falls	35,350	.04	13.8	487,017
Chain Bridge	41,000	.04	15.0	615,000

In this computation all surfaces were assumed horizontal.

The values derived from the sections at Little Falls and Chain Bridge, where the channel is straight and rather smooth, are fairly consistent; but those derived from the Great Falls section, where the channel is exceedingly rugose, are materially inconsistent with the former, and in deducing final values may perhaps be safely neglected. The mean discharge at the two lower sections, with velocity estimated, is 680,344 cubic feet per second, and that computed from the slope and cross section 551,000 cubic feet per second. It seems safe to accept the mean of these, or 615,672 cubic feet per second, as the maximum discharge of the Potomac; for the various results are closely accordant and the mean value is far within that indicated by the somewhat less reliable data derived from the Great Falls section.

This enormous discharge may be realized when it is understood that it is at least one and a third times as great as that of the memorable freshet of 1877; that it is more than three and a half times that of the highest flood recorded by Swain[1] (175,000 cubic feet) in his investigation of the water-power of the eastern United States; that it is more than thirty-eight times the discharge at an average stage for the abnormally wet summer of 1889 as measured in the cross sections (16,081 cubic feet, estimating the velocity at four miles per hour or 5.88 feet per second); and that it is five hundred and seventy-nine times the minimum low water discharge of the same river recorded by Swain[1] (1,063 feet per second). The astounding discharge will be realized too when it is understood that it closely approaches the mean annual discharge of the Mississippi, or 675,000 cubic feet per second,[2] and that it is more than two-fifths of the discharge of the Mississippi during the unprecedented flood of 1858 (or 1,475,000 cubic feet per second)[3] which forms the plane of reference for all great floods in the great river of America.

The freshet channel of the river was also mapped, and several photographs and sketches exhibiting the unusal stage were secured; and some study was made of the erosive effects of the stream above the fall-line, of the sediment transported, and of the erosion above and deposition below the fall-line.

THE WORK ON THE CRYSTALLINE ROCKS OF MARYLAND.

During the past year an investigation of the Piedmont crystallines already commenced by Dr. George H. Williams was carried on in this division, and the following report of purposes, methods and results has been submitted by Dr. Williams:

The district to which attention has been mainly devoted is that occupied by the rocks of uncertain age belonging to the Piedmont region within the limits of the State of Maryland. These cover an area of about 1,700 square miles, embracing the larger parts of Cecil, Harford, Baltimore, Howard, Montgomery, Carroll and Frederick Counties. On the west they disappear beneath the overlying belt of

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[1] Tenth Census of the United States, Vol. 16, p. 10.

[2] Humphreys & Abbott Physics and Hydraulics of the Mississippi, 1876, p. 85.

[3] Op. cit. p. 181.

Triassic red sandstone which stretches along the base of the Catoctin Mountain; and on the east they are buried beneath the Potomac and Columbia formations. Within this district the rocks are for the most part crystalline, and become steadily more so from west to east. The strata are nearly vertical, their metamorphism intense, and their mutual relations extremely complicated. Some of the difficulties in the way of the successful raveling of the problems presented by these rocks are the following: (1) The extensive superficial decay of these rocks; (2) the total absence of exposures over large areas; and (3) the unreliable character of surface dips. These points become of great importance where the relations of the rock masses change so abruptly and so frequently within short distances.

The work upon the Piedmont rocks of Maryland has been carried on during the past year along two distinct lines and with two distinct sets of problems in view. *First.* One object has been to trace out the relations of the slightly crystalline or non-crystalline rocks in the western part of the area to the highly crystalline rocks farther east, and to discover the nature of the transitions by which this crystalline structure appears to be progressively developed. *Second.* It has been an object to map minutely the highly crystalline rocks in the eastern part of the area, particularly about the city of Baltimore (where alone the topographic map is completed) and to work out in detail certain petrographic problems with reference to the eruptive masses which occur there in such abundance. Neither of these two objects can as yet be considered as entirely accomplished, although many results of interest and importance have already been secured. Much still remains to be done upon problems whose distinctness, as well as whose difficulty, increases with the progress of the work.

Relation of the less crystalline to the more crystalline rocks of the Piedmont region.—The first rocks to emerge from the Triassic belt in the district above defined are the slightly crystalline blue limestones of the Frederick Valley. These are lithologically quite identical with the fossiliferous (Trenton) limestones occurring farther west; and, although no organic remains have as yet been identified from them, there seems to be no reason why they may not represent the same horizon. This is a point which is still to be established. On the east of the Frederick limestones succeed perfectly cleaved but comparatively little altered slates, which are capped on Sugar Loaf Mountain by quartzites and sandstones resembling those of the Catoctin and South Mountains. These slates become steadily more and more crystalline toward the east, passing through various grades of phyllite, hydromica-schist, mica-schist and gneiss. For a considerable distance the rocks do not become more crystalline than certain others at other localities (e. g., Bergen, Norway) in which fossils have been found, so that the search for organic remains in Frederick and Carroll counties is by no means hopeless. At the old Dolyhide copper mine near Liberty, in Frederick County, a phyllite was found rich in *ottrelite*—a mineral known only as the product of dynamic metamorphism of argillaceous sediments. In no member of the Piedmont series is the progressive character of the metamorphism more apparent than in the limestones. The character of these intercalated beds remains the same throughout the region except that they become more and more highly crystalline toward the east. They frequently show gradual transitions into adjoining schists and gneisses, which is indicative of a sedimentary origin. In passing from west to east across the Piedmont belt in Maryland no well marked instances of sudden transition from less crystalline to much more crystalline rock has been established. The passage seems at present to be a gradual one throughout and the series a continuous one. The tendency of extreme dislocation and metamorphism to obliterate unconformable contacts and to produce an apparently conformable succession out of originally heterogeneous and discordant materials is, however, well appreciated, and this important point is still under special investigation.

Special investigation of the eastern and more highly crystalline portion of the Piedmont rocks.—One point of particular importance regarding the eastern portion and more crystalline of the Piedmont rocks of Maryland is the presence in them of a very large proportion of ancient eruptives. These masses occupy from a half to one-third of the entire eastern portion of the Piedmont belt; and, in spite of their enormous and extensive metamorphism and alteration, their character and origin can be placed beyond doubt. A sequence of basic, ultra basic and acid eruptions, following each other in accordance with von Richthofen's law, can be made out. Some of these are older, others younger, than the period of greatest crushing and metamorphism, and they themselves may have been active agents in producing the greatly increased crystalline character of the sedimentaries toward the east. West of a line through the center of Baltimore, Howard and Montgomery counties these eruptive rocks are entirely wanting, the only evidence of igneous action there being a few narrow diabase dikes, probably of Triassic age. The areal and genetic importance of these ancient eruptive masses in the East renders them objects of special study, and considerable time has been devoted to their mapping and to the investigation in the laboratory of many petrographic problems which they present.

These problems relate (1) to the nature, origin and sequence of the original eruptive rocks themselves; (2) to the cause of their own metamorphoses and alterations; (3) to their influence upon the inclosing sedimentaries and their connection with the increase of crystalline texture of these.

Aside from the great areas of undoubted eruptives, there is evidence that the rocks of the Piedmont region—even the more crystalline—have originated from the recrystallization of sedimentary beds. This evidence may be summarized as follows:

(1) Presence of intercalated limestones.

(2) Gradual transition from crystalline limestones to adjoining mica-schists and gneisses.

(3) Rapid alternations of narrow parallel beds of very diverse composition.

(4) Presence of conglomerates (rocks of Deer Creek, Harford County).

(5) Presence of many beds, even in the east where most of the members are completely recrystallized, which show evidence of clastic structure.

In the absence of all paleontologic data nothing can be stated with definiteness with regard to the age of the rocks of the Piedmont region in Maryland. Probably they belong to the many different horizons growing older toward the east. The limestone, sandstone and slate on the west side of the belt do not differ from those of the mountains west of the Trias. On account of the evidence of clastic origin, these rocks, in spite of great recrystallization exhibited by rocks on the east side of the region, may perhaps most reasonably be assigned provisionally to the Algonkian formation.

THE SURVEY OF THE FORT RILEY MILITARY RESERVATION.

During the year the survey of the stratigraphy, areal geology and superficial deposits and resources of the Fort Riley Military Reservation in central Kansas, and in the geographic center of the United States, was made by Mr. Robert Hay, of this division. The survey was made in response to a request by the military authorities for special information concerning the water supply and the supply of brick material and building stone within the reservation, these resources being especially important at this time by reason of the considerable enlargement of the post and the construction of new buildings now in progress. The survey was extended not only over the entire reservation of 20,000 acres, but over so much contiguous territory as it became necessary to examine in order to ascertain the stratigraphic and taxonomic relations of the formations developed within the reservation. This survey was completed during May, and a full report, accompanied by maps, diagrams, and other illustrations, was transmitted for publication as a bulletin of the Survey and is now in press.

THE WORK IN THE CAROLINAS.

With the immediate view of correlating the formations developed in the District of Columbia and throughout the Middle Atlantic Slope generally with those of the southern Atlantic and Gulf slopes, and so to elucidate its late Mesozoic and Cenozoic history, and with the remoter view of discovering the resources of the formations throughout this territory, researches have been commenced in the Carolinas. This work was, by your approval, intrusted to Prof. Joseph A. Holmes, of the University of North Carolina. In November a visit was made to Prof. Holmes and a hurried reconnaissance undertaken in the vicinity of Chapel Hill. In carrying out his instructions Prof. Holmes subsequently commenced work on the James and Appomattox Rivers, where he first familiarized himself with the Columbia, Appomattox, and Potomac formations in localities investigated during a trip through southern Virginia, mentioned in a report to you for the fiscal year 1885-'86. Having familiarized himself with the phenomena on these rivers, Prof. Holmes proceeded southward, traversing the Cape Fear, Tar and Neuse Rivers, ascertaining the extent of the Columbia formation over a considerable area in North Carolina, tracing the Appomattox formation through the constantly expanding terrane extending from the Virginia-Carolina boundary southward, and locating exposures of the Potomac formation at various points. Attention was also given to Pleistocene terraces, to the Tertiary deposits, to the phenomena of the fall-line, to the relations between the Mesozoic and Cenozoic clastics of the Coastal Plain, to the Piedmont crystallines and the red sandstones of the Newark system, etc. The formations with which Prof. Holmes was chiefly called upon to deal are deficient in distinctive characteristics, their relations among each other and to other formations, are obscured by puzzling transitions, and fossils are rare or wanting; so his study is one beset with peculiar difficulties. Yet eminently satisfactory progress has been made.

THE WORK ON THE LOWER POTOMAC AND RAPPAHANNOCK RIVERS.

At the end of May Mr. Nelson H. Darton was transferred from the Appalachian Division of Geology to this division, and during the past month outfitted for and set out upon a trip by boat down the Potomac River and thence up the Rappahannock as far Fredericksburg. He was accompanied and assisted by Mr. Frank Marshall Smith, recently graduated from the School of Mines, Columbia College. During the investigation of the geology of the District of Columbia and contiguous territory within the past five years three formations—the Columbia, Appomattox and Potomac—have been defined, their characteristics ascertained, their distribution mapped in so far as base maps were available, and their significance and importance in science and in the arts set forth in general terms, in certain preliminary publications. In the course of the study of these formations it was found necessary to develop new methods of work, new criteria for discrimination, and new bases for classification and interpretation of certain phenomena. One of the innovations which has grown out of the work is the interpretation of geologic history from topographic forms; and in the application of this new geologic method a history of Cenozoic changes in the geography of the Middle Atlantic Slope has been deduced. But this history can not yet be compared with that recorded in the clastic deposits of the Coastal Plain and their contained fossils, for the reason that the latter history has not been adequately set forth. Accordingly it is proposed to investigate the rock masses of the Coastal Plain contiguous to the District of Columbia with respect to their physical relations, their origin, and their testimony as to geographic and other telluric changes, as well as to their resources of economic value. Within the Coastal Plain of the United States there are extensive phosphatic deposits of great importance to the country as fertilizers. In the South the phosphates are usually accumulated in certain layers or beds in nodular form; but in the Middle Atlantic Slope the prevailing form is the silicate of iron and potassium known to mineralogists as "glauconite," and popularly as "greensand" or "greensand marl;" and the volume and purity of the glauconite of the Middle Atlantic Slope are probably such that by its use the tenacious and sometimes barren clays of the contiguous Piedmont zone may be fertilized and renewed and the country enriched. It is for the two purposes of interpreting the history recorded in the clastic deposits of the Coastal Plain and of developing the resources contained within these deposits that the investigation upon which Mr. Darton is engaged was inaugurated. The difficulties in the way of investigating the Tertiary deposits of the Coastal Plain are less than those encountered by Prof. Holmes, for the reason that these formations are more regularly bedded and definitely parted and are charged with fossils. So Mr. Darton has already obtained results of value.

WORK ON THE GULF COAST.

The investigations of Mr. Lawrence C. Johnson in the Lower Mississippi and Gulf regions, with which this division has heretofore had an advisory connection, was during the year finally transferred to the Potomac Division. Mr. Johnson reports that by reason of exceptionally favorable weather during the past winter, and by reason of the lessened demand on the part of public institutions for detailed local surveys, an unusual amount of field work has been accomplished. The greater part of Mr. Johnson's energies were devoted to examinations of the Tertiary formations for the purpose, first, of ascertaining their stratigraphic relations and geographic distribution, to the end that they may be represented in detail upon geologic maps; and second, of ascertaining the contained minerals, the agricultural capabilities, and other natural resources of these formations. In the prosecution of this examination the fossiliferous beds of Newton, Clark, Lauderdale, Lowndes, Tippah, Union, Alcorn, Monroe, Prentiss, Tishomingo, Lamar and Marion Counties in Mississippi, and in adjacent portions of Alabama and Tennessee, were examined in detail, and important data relating to several formations, notably the Claiborne and Tuscaloosa, were gathered. A considerable part of September was occupied in a reconnaissance of the Cretaceous formations of northern Mississippi and adjacent portions of Arkansas in connection with Mr. Robert T. Hill, who was then engaged upon work for the official survey of the latter State. During January a reconnaissance of the Grand Gulf formation and of the well differentiated Miocene strata of the Gulf coast was extended through southern Alabama and into Florida, and important data, which will be set forth in future reports, were secured. During the months of March and April operations were extended into western Tennessee, and special attention was given to the artesian wells at Memphis, Tenn., which have yielded valuable data relating to the stratigraphy of the Mississippi embayment. In May and June these operations were extended eastward and northward over portions of Fayette, Chester, Henderson and Decatur Counties, Tenn.; considerable collections were made from the puzzling Porter's Creek and Flatwoods formations; and much new information concerning the stratigraphic relations and geographic distribution of these and other formations was obtained.

During the past and preceding years Mr. Johnson's investigations have extended over large portions of Louisiana, Mississippi and Alabama, and considerable areas in Texas, Arkansas, Tennessee, Georgia and Florida; much of his work has been of the nature of preliminary reconnaissances, though more detailed surveys have been made in various localities; and by these operations he has familiarized himself with the general structure and the principal mineral resources of the greater part of the Gulf Slope and Coastal Plain. Part of the results of his work have already been published by the Survey or in other public documents, but there remains a large amount of material only awaiting systematic study and final arrangement for publication.

I have the honor to be, sir, very respectfully, your obedient servant,

W J McGee,
Geologist in Charge.

Hon. J. W. Powell,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF PROF. O. C. MARSH.

U. S. Geological Survey,
Division of Vertebrate Paleontology,
New Haven, Conn., July 1, 1889.

Sir: I have the honor to submit the following report of the work of this division during the past year:

In compliance with your letter of general instructions, I have continued the systematic work of collecting vertebrate fossils and investigating those of special interest to science. This work has gone on systematically and with success during the year past, and some of the results are given below.

To make this branch of the Survey of more direct service to geology as a science, a series of investigations has been commenced which is sure to lead to discoveries of interest and later may bring results of considerable importance.

In the series of fossiliferous rocks now known in various parts of the world, there are two profound breaks which paleontology has hitherto failed to bridge over. One of these is between the Paleozoic and the Mesozoic and the other between the Mesozoic and the Tertiary. Theoretically, these breaks should not exist, except in limited areas, but thus far, wherever the junction of these great series of formations has been observed and characteristic fossils secured from each, the dividing line between them has been distinct. Up to the present time this appears to be true in Europe, Asia, Africa and America, and one of the problems in geology as well as paleontology is to account for this as a general fact, or by more careful explorations to find exceptions that will invalidate it.

The Rocky Mountain region offers an inviting field for the solution of these problems, or at least contains much evidence bearing directly upon the questions involved. As these questions lie fairly within the province of this division of the Survey, a systematic effort has been commenced to work out the vertebrate life-history of the periods now so widely separated at the points indicated.

The question where the Cretaceous ends and the Tertiary begins in the Rocky Mountain series of deposits seemed first in importance, and the key to this problem was evidently the great Laramie formation. Here the work was commenced during the past season and is still in progress. The results already attained are encouraging and important to science in themselves, quite apart from their bearing on the questions named. Two discoveries of great interest have been made which deserve mention here, and one of them promises to furnish the material for a new chapter in paleontology.

Hitherto no mammals have been known with certainty from the Cretaceous, although they have been found in the Jurassic below and are the dominant forms of life in the Tertiary above. A comparison of the Jurassic and Tertiary mammals clearly indicated that many intermediate forms must have lived in Cretaceous time, and careful search for these has long been made in various parts of the world, but almost entirely without success.

In the investigation now in progress a fortunate discovery brought to light a horizon in the typical Laramie, in Wyoming, which has already yielded more than one hundred specimens of mammalian remains, including jaws, teeth and various portions of the skeleton, most of them in good preservation. They represent many individuals, all of small size, and not a few new genera and species, the more important of which I have recently described.

Most of these mammals belong to the *Allotheria*, containing the Triassic *Tritylodon* and *Microlestes*, the Jurassic *Stereognathus*, *Plagiaulax* and *Bolodon* in Europe, and *Allodon* and *Ctenacodon* in America, as well as some later forms. Many of the new genera show affinities with Triassic and Jurassic forms. As a whole the mammals found in these deposits are very nearly what was expected from the Cretaceous, but thus far the older types seem to predominate. The investigation will be continued, and it is hoped that the absence of mammalian remains from the known Cretaceous fauna will no longer be a reproach to paleontology.

In the same horizon with the mammals a new family of gigantic horned Dinosaurs has been found, which are by far the strangest reptiles yet discovered. Other vertebrate fossils brought to light are of scarcely less interest and add much to our knowledge of the Laramie fauna.

The other field work in the West has been prosecuted with success, especially in the Miocene of Dakota and the Jurassic of Wyoming and Colorado. The extensive collections thus secured are under investigation at New Haven, and will furnish valuable material for the monographs now in preparation.

Very respectfully,
O. C. MARSH,
Paleontologist in Charge.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF MR. CHARLES D. WALCOTT.

U. S. GEOLOGICAL SURVEY,
DIVISION OF PALEOZOIC INVERTEBRATE PALEONTOLOGY,
Washington, D. C., July 1, 1889.

SIR : I have the honor to present the following report of operations conducted under my charge during the fiscal year ending June 30, 1889 :

FIELD WORK.

The field operations for the year were (1) a preliminary study of the stratigraphy and the succession of the faunas of the Phillipsburgh series of limestones, on the boundary between Canada and Vermont; (2) the study, by Prof. Henry S. Williams, of the Devonian fauna and strata of New York State; (3) the collecting of Cambrian, Silurian, and Devonian fossils by collectors at various localities within the United States.

Early in July I made a preliminary examination of the section near the boundary line between Canada and Vermont for the purpose of determining the stratigraphic succession of the rocks and their contained faunas between the shore of Lake Champlain and the village of St. Armand, Canada.

Prof. Henry S. Williams continued his studies on the Devonian fauna and strata of New York State, and sent Mr. Gilbert van Ingen to Maine for the purpose of collecting fossils from the Oriskany sandstone.

Mr. William P. Rust, of Trenton Falls, N. Y., has been employed as a collector in central and northern New York. He has obtained a large amount of material from the Trenton limestone and the Utica and Lorraine shales that will be of great service in reviewing the faunas of the Ordovician group.

Mr. Ira Sayles was instructed to collect fossils from the Devonian rocks of southern New York; and he is now working under the direction of Prof. Williams.

OFFICE WORK.

Prof. Williams has continued the elaboration of the collections of Devonian fossils, and reports that he has examined the material collected by Mr. Sayles in western New York, and has also made a special study of the fauna of Tully limestone, with special reference to the Cuboides zone. In order to exhibit in genera the relations, modifications, and distribution, and the lapse of time, a number of drawings have been prepared to illustrate these studies. During the year Prof. Williams has made considerable progress in discussing the literature and abstracting and gathering notes upon the American Devonian and Carboniferous geology. He states that the collections of Devonian fossils, made by himself and under his direction, have been so large that he has secured the temporary use of a room in one of the Cornell University buildings as a depository of the U. S. Geological Survey. The material is now stored in over three hundred trays. A heater has been put in the room and connected with the general heating system of the University. We are thus indebted to the kindness of the University authorities for furnishing a place for storage and, during the winter, for supplying the means of heating the room, which is now devoted to the special work of the Survey.

On my return from the field, in November, I began the preparation of a paper on the Fauna of the Olenellus zone. An abstract of this was published in the American Journal of Science for May, and the full paper was submitted, June 29 for publication in the Tenth Annual Report of the U. S. Geological Survey. The preparation of this paper, with the routine work of my office, occupied my time until the close of the fiscal year.

A small collection of Carboniferous and Cambrian fossils collected by Dr. Peale in Montana were identified and a list of the species furnished to him. A small collection of Silurian fossils was examined for Mr. S. F. Emmons, to whom a preliminary report was made.

Mr. Sayles for several months was engaged in assisting Prof. Williams in unpacking and labeling Devonian fossils. He then returned to Washington and attached record labels to specimens until he took the field in May.

During the winter and spring Mr. T. W. Stanton was engaged in working out and arranging fossils from the Potsdam sandstone of the Mississippi Valley. This work was carried up to June 30, and the larger part of the collection prepared for study.

Mr. Joseph F. James was engaged from January 3, one and a half days each week, to February 15, and then full time to June 30, in making abstracts of books and pamphlets containing matter referring to the Cambrian, Ordovician and Silurian groups. In this work he consulted 971 books and pamphlets, made 1,543 abstracts of papers, and rejected as not germane to the subject 424 papers. This work was done for the purpose of securing the data for a review of the literature relating to the groups mentioned.

Mr. J. W. Gentry remained in charge of the office during my absence from the city, and performed various duties. He made a duplicate catalogue from such of Mr. N. H. Darton's cards as related to the geology of the Cambrian, Ordovician and Silurian groups. During the year he attended to the general clerical work of the division.

As honorary curator, in charge of the collections of invertebrate Paleozoic fossils of the U. S. National Museum, I looked after the general collections and the transfer of material from the Geological

Survey to the collections of the Museum. The following material was transferred and credited to the accessions of the National Museum: 67 specimens from the Upper Silurian, collected by Dr. Cooper Curtice, of the Agricultural Department, from one mile below Alexandria, Va.; 32 specimens, collected by George W. Shutt, from the Upper Silurian, in Pendleton County, W. Va.; and the following collections made by myself; 33 specimens from the Lower Cambrian of New York and Vermont; 136 specimens from the Lower Cambrian, Conception Bay, Newfoundland; and 3,340 specimens of the Middle Cambrian, Manuel's Brook, Conception Bay, Newfoundland; making a total of 3,608 specimens transferred from the Survey to the Museum.

During the year I have published four papers growing out of the general studies described in this and preceding reports. "Cambrian Fossils from Mount Stephen, Northwest Territory of Canada", appeared in the American Journal of Science for September, 1888, (Vol. 36, pp. 161–166). "The Stratigraphical Succession of the Cambrian Faunas in North America", was printed in Nature, in October (Vol. 38, p. 551). The "Stratigraphic Position of the Olenellus Fauna in North America and Europe", was printed in the American Journal of Science, occupying pages 374–392 of volume 37, and pages 29–42 of volume 38. The "Description of New Genera and Species of Fossils from the Middle Cambrian", pp. 441–446, and "A Simple Method of Measuring the Thickness of Inclined Strata", pp. 447–448, Proceedings of the U. S. National Museum for 1888.

Very respectfully,

CHARLES D. WALCOTT,
Paleontologist.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF DR. C. A. WHITE.

U. S. GEOLOGICAL SURVEY,
MESOZOIC DIVISION OF INVERTEBRATE PALEONTOLOGY,
Washington, D. C., July 1, 1889.

SIR: The work of my division for the year ending June 30, 1889, has been prosecuted largely with reference to the preparation of a memoir embracing a general summary of our knowledge of the North American Cretaceous; but much labor has also been bestowed upon other subjects pertaining to the general work of the division. The months of July and August were devoted to a preliminary draft of the work upon the Cretaceous formations, in which I was aided by Mr. C. B. Boyle, he having taken in hand the preparation of a catalogue of the published works relating to the subject. This work he has continued until he has prepared upward of a thousand titles, above three hundred of which I have annotated as an aid in the preparation of my manuscript.

On September 7, leaving Mr. Boyle in charge of the office work, I proceeded to Texas for the purpose of making field observations with reference to the work already mentioned; also with reference to the Permian formation of that State.

The latter observations were considered necessary because the general work of my division, embracing as it does the whole of the Mesozoic, makes it desirable to learn as far as practicable the character of its basal delimitation in all parts of the continent. With this object in view as regards the southern portion of the interior region I went directly to Baylor, Archer and Wichita Counties in Texas to examine a series of strata there which had been reported as bearing a commingling of Paleozoic and Mesozoic types of fossils.

These strata were found to constitute an important formation, occupying an area of many thousand square miles in extent, in western Texas and in the Indian Territory. It is the same formation that some geologists have referred to the Permian and some to the "Permo-Carboniferous", and upon some geological maps it is represented as of Triassic age.

The results of that examination and of a study of the fossils then and previously collected are embraced in a bulletin the manuscript of which has already been submitted to you; but they may be briefly stated as follows: Far the larger part of the fossils obtained from that formation, many of which are vertebrate remains, are of Paleozoic types, and many of the invertebrates are of well known Coal-Measure species. A few of the invertebrates are of Mesozoic types, and these are commingled with the Paleozoic forms in such a manner as to leave no doubt that they are all members of one and the same fauna. The commingling of Mesozoic and Paleozoic types in these Texan strata is similar in character to that of the now well known fauna of the Productus limestone of the Salt Range in India.

This series of Texan strata is lithologically distinguishable from, but blends with and is entirely conformable upon, the underlying Coal-Measure series. It appears to have been the result of sedimentation, which was continuous from the Coal Measures, and it passes gradually upward into two hundred or three hundred feet in thickness of gypsum-bearing strata, which are by some geologists regarded as of Triassic age, but they are more probably not separable from the Permian strata upon which they rest.

After summing up the results of these investigations, together with those of other observers, I reached the conclusion that for taxonomic purposes the strata in question are properly referable to the Permian. It is true that other geologists had previously so referred them, but the evidence at that time was, in my opinion, insufficient. For I hold that no close correlations of formations upon one continent with those of another ought to be attempted until much evidence of various kinds has been obtained.

These observations upon the Texan Permian also accord with the view which I have long held, that all the North American strata which have been referred to the Permian ought to be assigned to the Paleozoic rather than to the Mesozoic division. That is, although remains of some Mesozoic forms of life are found beneath the great stratigraphical break between the Paleozoic and Mesozoic which is so conspicuous in large portions of the continent, Paleozoic forms greatly preponderate; while above that break Mesozoic forms not only preponderate, but Paleozoic forms are very rare. Besides this, the stratigraphical relation of all the reputed North American Permian with the Carboniferous beneath it is very intimate.

From the Permian region of Texas I proceeded to the southwestern part of the State to resume the investigation of the Cretaceous formations there which I had prosecuted to a considerable extent the previous year.

These examinations were carried through Comal, Bexar, Medina and Uvalde Counties, and the result, together with that of the examinations made last year in the valley of the Rio Grande, was to confirm my previous belief as to the intimate relation of the Cretaceous formations of the Gulf coast with those of the interior region. So many species of fossils have now been identified in both these regions and in the intervening Texan area that there seems no longer room for doubt that the Ripley group of the Gulf States was not only identical with the eastern Texan formation to which the same name has been applied, but that it was originally, if not even now, a deposit continuous with the Eagle Pass formation in the Rio Grande Valley. It is also just as evident that the latter was a deposit continuous with the Fox Hills-Fort Pierre group of the interior region. Again, it is quite as evident that the "rotten limestone" formation of the Gulf States is represented in Texas by the Austin limestone and the Eagle Ford shales together; and that the latter together represent the Colorado group of the interior region.

The field examinations of the past season in Texas also confirm my previous opinion that the marine formation in the northern part of the State, which I have called the Timber Creek beds, represents the Dakota group of the interior region, and that that whole group, which to the northward is a non-marine deposit, becomes wholly marine to the south, where it loses much of its identity as a separate formation.

On the 5th of October I returned to Washington and resumed office work, devoting the following three months to writing up the results of the field work and preparing them for publication. After this, until the end of the fiscal year, my time was devoted to the work upon the Cretaceous formations, which has already been referred to.

Besides the bibliographical work which Mr. Boyle has done for the memoir upon the Cretaceous formations, he has also done much similar work upon a card catalogue of the publications which treat upon North American Mesozoic invertebrates, which work he has now in an advanced stage of progress. He has also accomplished the ordinary routine work of my division of the Survey and of the National Museum, besides installing a large exhibition series of Mesozoic fossils in the Museum cases. In the latter work he was assisted by Mr. C. W. Hayes, who was detailed from your office for that purpose from February 1 to March 15.

Aside from the work already mentioned, I have examined a conconsiderable number of collections of fossils for members of the Survey and for other parties who desired information concerning them. Among these was a collection of Mesozoic fossils made by the U. S. Fish Commission upon which, at the request of Mr. G. Brown Goode, Assistant Secretary of the Smithsonian Institution, I prepared a brief illustrated report for publication.

During the year a number of paleontologic papers prepared by me have been published. Bulletin No. 51, "On Invertebrate Fossils from the Pacific Coast", consists of five parts, devoted respectively to "New Fossil Mollusca from the Chico-Tejon series of California", to "The occurrence of equivalents of the Chico-Tejon series in Oregon and Washington Territory", to "Cretaceous Fossils from Vancouver Island region", to "The Molluscan Fauna of Puget Group", and to "Mesozoic Mollusca from the southern coast of the Alaskan Peninsula". A paper "On the Genus Aucella, with especial reference to its occurrence in California", occupies pages 226–232 in Dr. Becker's monograph (XIII) on the "Geology of the Quicksilver Deposits of the Pacific Slope". A paper "On the Puget Group of Washington Territory", has also appeared in the American Journal of Science (Vol. 36, pp. 143–150); one on "Hindeastræa, a new generic form of Cretaceous Astreidæ", appeared in the Geological Magazine (Dec., III, vol. V, pp. 362–363); and one on "The Permian formation of Texas", was published by the American Naturalist (vol. 23, pp. 109–128).

Respectfully submitted.

CHARLES A. WHITE,
Geologist in Charge.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF MR. W. H. DALL.

U. S. GEOLOGICAL SURVEY,
DIVISION OF CENOZOIC PALEONTOLOGY,
Washington, D. C., July 1, 1889.

SIR: I have the honor to forward herewith my annual report for the year ending June 30, 1889, concerning the operations of the Division of Cenozoic Paleontology under my direction, for that period.

FORCE.

The personnel of the division during the year ending June 30, 1889, has comprised, besides the writer, Dr. R. E. C. Stearns and Mr. Frank Burns, the latter however being absent a considerable part of the season, while Mr. C. B. Green and, subsequently, Mr. Gilbert D. Harris were temporarily employed for some months. With Prof. R. P. Whitfield and especially Mr. W. B. Clark, of the Johns Hopkins' University, a policy of mutual cooperation has prevailed, and in the last few months of the year Mr. Clark has taken the field, on behalf of this division, in the region of the southern coast Tertiaries. In Mr. Joseph Willcox, of Philadelphia, we have found a zealous volunteer cooperator in the exploration of the Floridian geology, and the satisfactory results of the year's work in that direction are largely due to his active and gratuitous services.

ROUTINE WORK.

The routine work of the division consists partly in identifying material submitted by the geologist of the Survey, or, at the request of the Director, for other persons; and, secondly, of assorting, cleaning, classifying, naming, cataloguing, labeling and arranging for easy reference the fossils collected by members of the Survey from Tertiary deposits or collected in the reference series of the U. S. National Museum, the legal depository of the collections made by the Survey after they have served its purposes. The second part of the work is that which requires the greatest amount of labor, especially on account of the accumulations of material already existing when I took charge of the division. This work has been facilitated by assistance rendered with the permission of the Director of the National Museum by Mr. P. L. Jouy, aid to the Museum in the Department of Mollusks and Cenozoic fossils.

The material referred to the division for report has in all cases been promptly attended to, and there are no arrears of this kind.

The final registration of material during the year 1887-88 amounted to 11,803 entries, equivalent to about 35,400 specimens. During the past year this part of the work was subjected to serious interruption rendered necessary by repairs to the building, which required the temporary evacuation of our quarters. The total registrations for 1888–89 amount to 6,323 entries, corresponding to about 20,000 specimens, which under the circumstances is not unsatisfactory.

FIELD WORK.

Owing to the necessity for utilizing material already collected before adding to it, but little field work has been attempted during the past season. Some two months were spent in Florida by Mr. Willcox, who forwarded large collections from that region, including some very interesting Eocene material from the vicinity of Ocala. Later in the year Mr. Clark visited a large number of localities on the Atlantic coast between Virginia and Georgia with extremely valuable results, an account of which must be deferred until my next report, as Mr. Clark's work has so recently terminated that he has not yet forwarded his detailed account of the results.

The material collected in New Jersey for Prof. Whitfield's monograph of the Miocene of that State has been returned by him named and ready for reference, and his detailed report is now in the hands of the Survey for publication.

In continuation of the policy of rendering assistance to isolated students or persons interested in the general aims of the work the division has replied to inquiries, or rendered assistance in minor matters not involving expenditure, to the following named persons during the year. The requests for such assistance have generally been addressed directly to the writer and the resulting correspondence has been personally attended to by him or by Dr. Stearns:

Prof. Alex. Agassiz, S. Arnheim, H. G. Askew, W. B. Barrows, Dr. Stephen Bowers, Theo. D. A. Cockerell, Dr. A. K. Fisher, S. S. Greeley, General A. W. Greely, Dr. W. B. Hartman, Henry Hemphill, Captain E. P. Herendeen, Prof. A. Heilprin, C. S. Hill, Dr. W. Kobelt, George F. Kunz, J. B. Lapenotière, Colonel Marshall McDonald, W. G. Mazyck, Thomas Morgan, Lieut. J. F. Moser, Hon. J. B. Moore, Charles R. Orcutt, Prof. A. S. Packard, jr., F. M. Phillips, H. A. Pilsbry, G. H. Ragsdale, W. J. Raymond, J. M. Rogers, I. C. Russell, Prof. N. S. Shaler, Dr. R. W. Shufeldt, C. T. Simpson, E. A. Smith, Dr. V. Sterki, George J. Streator, M. A. Suchetet, Prof. J. B. Tilton, G. W. Webster, W. W. Westgate, James J. White, Prof. R. P. Whitfield, Joseph Willcox; a total of forty-five individuals.

SPECIAL RESEARCHES.

The part of this division in the general scheme of geological correlation, under the supervision of Mr. G. K. Gilbert, has been specially reported on to that gentleman. But it may be well to indicate in a general way what is being attempted and how far the work has been carried out.

The Plio-Miocene section, intrusted to the writer, was at the time our work was undertaken in a much confused condition. It was evident that to do anything creditable the work must be started de novo and the existing information utilized after the main lines of the structure were definitely worked out. The plan undertaken by me included the determination stratigraphically of a series of typical sections—one near the northeast termination of the Atlantic Tertiary series in New Jersey, one in Maryland and perhaps in Virginia, one in the Carolinas, one in Florida, and one or two in the Gulf region. The fauna of the subdivisions of these sections being thoroughly determined, they would serve as benchmarks to bring the scattered observations of the older writers into some real parallelism. The Gulf section has been practically determined and its fauna largely recorded in Bulletin No. 43 of the Survey, recently published. I determined the relative stratigraphy of the New Jersey beds over a year ago and turned over the data and fossils to Prof. R. P. Whitfield, who was working on that division of the New Jersey Paleontology. His report has been received at the office and he has sent me a list of the species contained in these beds. In cooperation with Prof. W. B. Clark good progress has been made on the Maryland section, though the fauna remains to be revised. The work of the same gentleman in the Carolinas, together with that previously done under my direction by Mr. Frank Burns, will go far toward settling that section and its fauna. I have been personally at work on the Floridian fauna and section for several years, and the work, with the assistance of Mr. Joseph Willcox, has made good progress and is now in an advanced state. I hope to complete the work on the fauna during the present autumn and the stratigraphy during the next winter, unless unforeseen interruptions prevent. Later it will be necessary, probably, to take up the Texas district and make a section there, in which work a rich fauna is likely to be developed. It will be seen from the above review that fair progress has been made in this branch of the work.

The connection of our recent marine fauna with that of the Atlantic and especially of the Floridian Tertiaries is very intimate. As a foundation for accurate work on the latter it is absolutely essential to have a fair understanding of the former. I have therefore not considered it a deviation from the strict line of my work to devote part of my time to an enumeration and description of this fauna. This work, founded on the collections of the party on the U. S. Coast Survey steamer *Blake*, under the direction of Prof. Alex. Agassiz, has occupied a part of my leisure for the last eight years, and is now finally published as one of the bulletins of the Cambridge Museum, forming a volume of some five hundred pages, with thirty-one plates, and comprising the most extensive contribution to a knowledge of our Southern mollusk fauna which has ever appeared in print.

Following upon this I have, with the cooperation of the National Museum, prepared an illustrated check-list of our Southern marine shell-bearing mollusks and brachiopods, exhibiting their geographical and hydrological distribution and the geologic age to which the several species are known to attain. Like all such lists, this is doubtless imperfect, and serves to exhibit its own imperfections on account of the semigraphic manner in which the data are arranged. But the exhibition of the gaps is a strong stimulus toward getting them filled, and such, I believe, will be the general effect of this publication. It will comprise about 1,500 species, illustrated by 74 plates, and form a volume of the Museum bulletins (No. 37), containing about 150 pages of text. It is now in process of printing. A report on the Tertiary fossils and mollusks collected by the U. S. Fish Commission steamer *Albatross* on her late voyage from the Atlantic to the Pacific coast of the United States has been promised to the U. S. Commissioner of Fisheries, and is in a fair state of advancement.

The work on the Floridian Miocene and Pliocene faunas, so often referred to, is progressing well, and will be in a state for publication in the autumn through the cooperation of the Wagner Free Institute of Science of Philadelphia. It will comprise between four and five hundred well illustrated species, and will, I hope, materially assist in putting the fauna on a secure foundation, previous work upon it having been more or less partial and fragmentary.

From this outline it will be seen that the work of the division has not been confined to that of routine, and that its labors are beginning to bear fruit worthy of the opportunities.

I have the honor to be, very respectfully, yours,

WM. H. DALL,
Paleontologist in Charge.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF MR. LESTER F. WARD.

U. S. GEOLOGICAL SURVEY,
DIVISION OF PALEOBOTANY,
Washington, D. C., July 1, 1889.

SIR: I have the honor to submit the following report of the operations in the Division of Paleobotany during the fiscal year:

FIELD WORK.

As stated in my last administrative report, Prof. F. H. Knowlton was in the field ready to commence operations in the Yellowstone Park on the 1st of July. He remained until October 6 and made a very thorough study of the park from a paleobotanical point of view, visiting many localities not seen by us the previous year and making careful collections of both vegetable impressions and silicified wood. His notes are very complete, giving altitudes, sketches and geological sections which will be of great value when the work of elaborating the material shall be undertaken. Besides a thorough re-examination of the Amethyst Mountain region, he was successful in obtaining good material on Mount Evarts, near the mouth of Elk Creek, on Crescent Hill, along Lost Creek, on Mount Norris and the Thunderer, on Bison Peak, at the head of Hell Roaring Creek, on Pelican Creek, Cache Creek, Calfee Creek and Miller Creek, discovering several new fossil forests of great extent.

With the exception of the operations of Prof. Fontaine and Dr. Newberry, as reported below, the only other field work done by the division during the year was a short reconnaissance made by myself and Mr. David White on the coasts of Martha's Vineyard and Nantucket, Massachusetts, from the 18th to the 22d of June, and some excavation at Gay Head by Mr. White since that time which is still going on. The section at Gay Head and one in Chilmark on the north side of Martha's Vineyard give some promise of yielding a few plant remains which may throw light upon the age of the deposits. A few leaf prints and much lignitized wood have already been discovered and it is hoped that a thorough investigation may reveal more and better material. Mr. White is now at work in this field and will continue as long as there is any promise of success. It will be convenient to report upon the whole work at once, and this will therefore be deferred until a future occasion after it has been completed.

OFFICE WORK.

The force of the division has consisted of Mr. David White, assistant paleontologist, Mr. F. von Dachenhausen, draughtsman, and Miss L. M. Schmidt, copyist and general assistant, who have remained throughout the year; Mr. D. W. Cronin, draughtsman, from July 1 to October 15; Mr. A. D. Duganne, laborer, from October 10, 1888, to February 16, 1889; Mr. Charles S. Prosser, assistant paleontologist, from November 1, 1888, to June 30, 1889; Mr. A. P. Dudley, clerk, from May 1 to May 20, 1889; Dr. George Latimer, clerk, and Mr. Charles Bogan, laborer, from May 1 to June 30, 1889; Mrs. A. W. Todd, copyist, from June 7 to June 30, 1889; Mrs. J. A. Luce, copyist, from June 17 to June 30, 1889; and Prof. F. H. Knowlton, assistant paleontologist, from June 25 to June 30, 1889. Besides the above, employed for the most part in office work in Washington, Prof. Leo Lesquereux at Columbus, Ohio; Dr. J. S. Newberry at the School of Mines, Columbia College, New York; and Prof. William M. Fontaine at the University of Virginia, have, as heretofore, been attached to the division, and have conducted special investigations which will be reported upon in the proper place.

The work performed during the year may be classified as follows: (1) The preparation of illustrations of fossil plants; (2) the identification of fossil plants; (3) the preparation of manuscript; (4) proof-correction; (5) bibliographic work; (6) catalogue work. These several branches of work may be conveniently mentioned in the above order.

(1) *The preparation of illustrations.*—It will be observed from the above statement of the force of the division that only one draughtsman has been at work since October 15, 1888. The statement made in my last administrative report that "with the present force continued the work on the Laramie flora will be completed before the end of the next fiscal year" was a safe one, as shown by the fact that with only half that force during the greater part of the year this work is already nearly completed, not more than forty drawings remaining to be done on the original type series. Most of the drawings made have been photographed and mounted for study, as described in my last report.

(2) *Identification.*—Owing to the pressure of work in the other departments, I have found scarcely any time to devote to the determination of fossil plants. On September 18, 1888, I began the study of the dicotyledonous forms from the Laramie group, first making a careful comparison to ascertain what types had not been drawn and placing such in the hands of the draughtsman, next taking the necessary steps to complete three study series of photographs, one in large groups mounted and swung in frames attached to a Museum exhibition pillar, one mounted singly on cards of uniform size and arranged in the numercal order of the types as originally selected, and a third mounted like the second, but arranged in systematic order as far as known or presumed, the system to become more definite and exact as the work of determination advances. For some months I devoted a part of each day to this work and made a small beginning on the actual work of identification, but this had to be discontinued entirely when the pressure of proof-correction began towards the end of January.

Under the head of identification may properly be included most of the work of Prof. Lesquereux. A large collection of fossil plants made by Mr. Charles H. Sternberg from the Dakota group of Kansas was shipped to him by the latter on September 29 and a second in November, to be examined with a view to the selection of such specimens as might be deemed valuable for purchase by the Survey. Still a third collection of Dakota group plants was placed in Prof. Lesquereux's hands by Prof. F. H. Snow, and he has passed all this material in review, describing and figuring what was new for his monograph of the flora of the Dakota group, into which it will be incorporated, the manuscript, once submitted for publication, having been withdrawn for the purpose.

(3) *Preparation of manuscript.*—On July 12, having previously prepared tables of distribution of the Cambrian, Silurian and Devonian floras of the United States, I commenced a paper on the correlation of American plant-bearing strata. By August 9 I had finished the rough draft of the pre-Carboniferous. The work of tabulating the Carboniferous species was carried on during the summer, upon which I had the assistance of Mr. David White. That system was subdivided into three parts, the Lower Carboniferous, the Coal Measures proper, and the Upper Barren Measures or supposed Permian. The outline of the first of these divisions was completed on November 30, that of the second on December 11, and that of the third on December 20. Four elaborate tables of distribution of the Carboniferous species of the United States were prepared during January and February from the data previously compiled. These will form a part of the paper and be followed by a thorough discussion of the data they embrace in their most general aspects. To render this discussion thorough and complete a large amount of labor had to be expended in extracting and combining the correlated facts. In this I was assisted by Mr. Prosser, who completed it on June 27. The discussion of the tables from the data thus supplied will be commenced soon, and will complete the first part of my paper, viz, that embracing the Paleozoic flora of the United States. It will be entitled: "The Homotactic Correlation of American Paleozoic Plant-bearing Strata", and will probably be published by the Survey. The remainder of the series is reserved for a second paper and the two combined will be available for use in the proposed collection of essays on correlation for the next meeting of the International Congress of Geologists.

Considerable time (February 13 to March 2) was devoted to recasting a number of rough tables of distribution of the flora of the Potomac formation made a year before, with Prof. Fontaine's approval, from his manuscript of that flora. These have been put into good condition for publication and have been appended to Prof. Fontaine's monograph now in press. In his introduction he has acknowledged the value of this work. It was performed for the most part by Mr. Prosser.

On June 13 work was begun on the index to my paper on the Geographical Distribution of Fossil Plants from the page proofs. It is proposed to give this paper a special index, containing the names of all the geographical localities too numerous for the general index of the volume. From this special index such heads will be selected as are thought sufficiently important to be introduced into the general index also. The work on this index is still going on, and on account of its urgency four persons have been engaged upon it for the past week.

(4) *Correction of proofs.*—The proofs of my paper for the Eighth Annual Report on the Geographical Distribution of Fossil Plants began to arrive on the 22d of January and were not finally disposed of until the middle of June. This paper is essentially bibliographic in character and its value depends largely upon its completeness. The manuscript had already been twice withdrawn since it was submitted in July, 1887, and the matter brought down to date, but still a long period had elapsed since its last revision and this had happened to be one of unusual activity in the publication of works relating to this subject. It also happened that a large number of older works which could not be consulted at the time the paper was written, but which were ordered at that time in the hope that they might be introduced later, arrived in this interval. It was considered well worth while to embody both these classes of matter in the paper, which required considerable additions to be made in the galley proof. To do this carefully and properly also required much time and labor, which, however, will be well repaid, as will also the expense, by the increased value of the paper.

Prof. Fontaine's monograph of the Flora of the Potomac Formation was put in type during the months of April, May and June, and one proof of this also passed through my hands. The botanical names and the bibliographic references were very thoroughly verified and the text carefully read, special attention being given to harmonizing the references to plates and figures, and the various lists, tables, etc., with the general descriptive text.

(5) *Bibliographic work.*—This, as heretofore, has been in the hands of Mr. David White, and has progressed as rapidly as could be expected, in view of the numerous demands in other directions upon his time. He spent the greater part of the month of August in Cambridge and Boston in search of rare works not to be consulted at Washington. A number of orders for the purchase of such works from the various houses in Europe that deal in this class of literature and send out catalogues have been prepared and sent in, and several large invoices have arrived. Much attention has been given to the proper form of cards to be adopted for the final card catalogue and to making this conform to that of the other bibliographies in progress by the Survey, also to the general character of the work which will soon be begun for publication on the bibliography of fossil plants.

(6) *Catalogue work.*—This relates to the cataloguing of species of fossil plants. The importance of shifting the burden of this work from my shoulders and its assignment to some competent person who could give his attention chiefly to it has long been felt, and it was therefore greatly to my satisfaction that Mr. Charles S. Prosser, of Cornell University, was appointed for this purpose on November 1, 1888. He found the first requisite to be the completion of the cataloguing of a large mass of literature that had accumulated throug

purchase and in other ways, but this has not prevented him from giving much thought and study to the subject of organization in this branch. Owing to serious delays in obtaining greatly needed clerical aid the ground covered was less than had been hoped, but considerable progress has been made, and matters are in excellent shape for future operations.

WORK OF PROF. FONTAINE.

Prof. William M. Fontaine submits the following report of work done by him during the fiscal year 1888–'89:

During the present fiscal year, in the months of August and September last, I made an examination of certain points in North Carolina. The object was to see if any new localities of the fossil plants of the Older Mesozoic or Rhetic flora could be discovered; to examine the localities given by Dr. E. Emmons, with the purpose of making additional collections if possible; and, lastly, to see if any Potomac strata exist in that State. I examined the eastern margin of the Older Mesozoic, the so-called Trias, between Greensborough and Raleigh, and, proceeding along this same margin southward nearly to the southern borders of the State, I examined several localities, for it is here that it is most probable that the Potomac exists, if anywhere in North Carolina.

My examinations did not disclose any new localities of fossil plants. Dr. Emmons gives the region adjoining the Deep and Haw Rivers, as at Haywood, etc., as one affording a number of his most interesting specimens. My investigation of some of these localities showed that there are now no exposures yielding fossils, and I am convinced that it will be difficult to find them. As far as I could learn, Dr. Emmons collected his plants from spots which had been temporarily exposed in search for coal.

At Haywood I found eight to ten feet of unequivocal Potomac, similar in lithological character to that of Virginia, and showing also exactly the same geographical and geological relations. There is also in this vicinity a great deal of gravel and cobblestones exactly like those of the Virginian Potomac. This material seems to represent Potomac strata now removed by erosion.

All along the eastern margin of the older Mesozoic there is an extensive display of the Appomattox formation, which usually hides everything else.

In the same months I collected in Alabama from the Tuscaloosa formation a considerable quantity of fossil plants. In most cases the fossils are poorly preserved and the matrix not favorable for securing good specimens. Material was obtained from localities as much as fifty miles apart. Some good impressions were found, mostly near Tuscaloosa. An examination of these plants indicates that the flora is decidedly younger than the Older or Lower Potomac of Virginia. This more extensive collection shows that the number of fossils common to this formation and the Virginia Potomac is not so large as I was led to suppose from a former preliminary examination and a smaller collection. Since making this collection I have been occupied with the preparation and study of the plants.

WORK OF DR. J. S. NEWBERRY IN PALEOBOTANY.

Dr. J. S. Newberry reports the following work during the year relating to fossil plants:

I beg leave to submit the following brief report of the work I have done for the U. S. Geological Survey during the year ending June 30, 1889:

(1) I have read the proofs of text and plates of my monograph (XIV) on "The Fossil Fishes and Fossil Plants of the Trias of New Jersey and the Connecticut Valley", recently published.

(2) I have finished text and plates of my monograph (XVI) on "The Paleozoic

Fishes of North America" and have read the proofs of the first hundred pages of the text. This will form a volume of about 300 pages, 4°, with 53 plates.

(3) I have begun a revision of my memoir, so long in hand, on "The Fossil Plants of the Cretaceous and Tertiary Rocks of the Far West". It will form a volume of 200 to 300 pages text, with 150 plates. In the continuation of my studies of the flora of the Laramie group during the past summer I made a visit to Colorado at my own expense, examined the most interesting outcrops of the formation before unvisited by me and had large collections of fossil plants made at the most interesting localities by a competent man employed for the purpose. Through the courtesy of Mr. George E. Hadden, of Florence, and Mr. R. C. Hills, of Denver, I was given the use of large collections of fossil plants obtained by them from the Laramie of eastern Colorado. These have been drawn and in part described, so that I hope to have this memoir ready for publication within a few weeks.

(4) In order to give greater completeness and value to the report I have in hand on "The Flora of the Amboy Clays of New Jersey", I improved the opportunity offered by a visit to England in September to examine all the collections of fossil plants from the Upper Cretaceous and Eocene in England and on the Continent. This investigation included a visit to Aachen (Aix-la-Chapelle) and an examination of the large amount of material collected there by the late Dr. Debey, of which only a small portion has been as yet described. The observations made on this excursion contributed much to my knowledge of the parallelism of our Cretaceous and Tertiary rocks with those of Europe, and will add considerably to the value of my reports. The flora of the Amboy clay has been proved by our collections and studies to be unexpectedly rich and interesting. For want of funds I have been unable to continue collections in this formation during the past season; but in my judgment no richer field is within reach of American geologists, and none in which the expenditure of a little money would produce more important scientific results. My work on this flora has been temporarily suspended on account of the time necessarily given to the completion of the other memoirs enumerated above. I have already identified in this flora about one hundred and thirty species of plants, of which most are new to science, but quite a number have been described from collections made in our Dakota group and in the Upper Cretaceous rocks of Greenland and Aachen. About fifty plates have been already prepared to illustrate the Amboy flora, but as no description of it has been given to the public, except in a few preliminary notes by myself, and as the extensive workings of the Amboy clays afford exceptional facilities for obtaining more material, it has seemed to me eminently desirable that a little more time and money should be devoted to the accumulation and study of material from a formation so easily accessible and of so much botanical and geological interest. I hope to have my first contribution to the knowledge of the Amboy flora ready for presentation before the close of the present year.

(5) I have long had in my possession a group of fossil plants from the Devonian and Lower Carboniferous rocks of Ohio and Kentucky which it seems to me ought to be made known to the public. Among these are several tree ferns, *Lepidodendra*, *Sphenophyllum* and conifers (*Dadoxylon*) from the Coniferous Limestone and Huron shale (Middle and Upper Devonian), which represent the first forests known to us on the American continent. The specimens seem to have been floated off from islands along the Cincinnati arch and are remarkable for their good preservation, and considering their antiquity, for their high botanical rank. Of these plants I have prepared figures and descriptions, and if desired would submit them for publication as a bulletin of the Survey.

Very respectfully, your obedient servant,

LESTER F. WARD,
Geologist in Charge.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF MR. S. H. SCUDDER.

U. S GEOLOGICAL SURVEY,
DIVISION OF FOSSIL INSECTS,
In the field, Florissant, Colo., July 1, 1889.

SIR: As I had leave of absence from the Survey for one-half of the past official year, the present report deals with only six months' work. In this my time has been given partly to a study of some of our older fossil insects, partly to the Tertiary insects of Florissant, Colo.

The former included especially a large series of cockroaches from the younger Carboniferous or Permo-Carboniferous rocks of West Virginia, and a very interesting *Lithosialis* from the Coal Measures of Alabama, the first recognition of the genus in America. The latter embraced a part of the *Elateridæ* and *Buprestidæ* among the *Coleoptera,* and latterly the *Hemiptera,* in which some unfinished work undertaken before my connection with the Survey was taken up, and which will now be pushed forward to publication.

In addition, a good deal of time had to be given to the revision of the drawings of *Hymenoptera* made during my absence from material prepared beforehand. The catalogue of described fossil insects mentioned in a previous report has made steady progress, but the portion completed still requires verification.

The drawings made during the year by Mr. Blake have been mainly confined to the same class of subjects as last year. One hundred and sixteen drawings of Tertiary *Hymenoptera* have been made, but of these, owing to my long absence from work, only about one-half have yet been finished in ink. Besides forty-six drawings of Carboniferous cockroaches have been finished, some in ink and some in pencil.

Shortly before the close of the year I entered on a season's field work in the west, with two assistants, beginning at Florissant, Colo. This locality, an ancient lake basin near the southeast limit of the South Park, has proved the most productive of fossil insects of any yet discovered in any part of the world, excepting those stations where amber is found. Probably twenty thousand specimens have already been obtained from it, by various collectors, and the easiest reached and most productive beds only have been worked. Our examination so far shows that plenty more are obtainable, but that they must be secured in the future at much greater cost by the removal of a large amount of overlying material, not to mention the obstacles which may sometimes arise from private ownership of localities.

Respectfully yours,

SAMUEL H. SCUDDER,
Paleontologist in Charge.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF PROF. F. W. CLARKE.

U. S. GEOLOGICAL SURVEY,
DIVISION OF CHEMISTRY,
Washington, D. C., July 1, 1889.

SIR: I have the honor to submit the following report of work done in the Division of Chemistry and Physics in the fiscal year 1888-'89:

During the first half of the year I was engaged for a considerable portion of the time in duties connected with the Exposition in Cincinnati, at which I represented the Geological Survey, and later the Department of the Interior. In these capacities I visited that city twice: first in July, during the installation of the exhibits; later, in October and November, for the purpose of repacking and returning the collections. The display made by this Bureau consisted of maps, diagrams, illustrations, photographs, transparencies, relief models, rocks, geyser products, etc., and attracted much attention.

For the rest of the year my time was necessarily much occupied with routine administrative duties, but one or two minor investigations were completed, and others were carried far along. In February, jointly with Mr. Catlett, I described a remarkable nickel ore from the Algoma District in Canada, which proved to be the rare and little known species, polydymite. Its most noteworthy feature was its appreciable content in platinum, a metal not hitherto discovered in a true metalliferous vein. I have also examined a remarkable association of gyrolite and apophyllite from the New Almaden quicksilver mine, in which the former mineral was evidently the parent of the latter. In addition to these researches I have reinvestigated the theory of the mica group, and have succeeded in reducing all micas to one general type of formula. I have also begun and nearly finished a rediscussion of certain atomic weights by the method of least squares, and have done some work upon the chemical relations of serpentine. In August and September I found time for a short field expedition, in which I visited localities in western Maine and northern New Hampshire, making collections of mineral specimens.

During my absences from Washington the laboratory was left in charge of Dr. W. F. Hillebrand, who has continued his investigation upon the composition of uraninite, which now approaches completion. He has also described two remarkable descloizites, one from Georgetown, N. Mex., the other from Tombstone, Ariz. In the autumn of 1888 he took the field for two months; visiting the cryolite localities of Pike's Peak, the Tintic District in Utah, Lake Valley, Georgetown and Las Cruces, N. Mex., and Tombstone and Bisbee, Ariz. From these localities he brought back large and valuable collections, especially of the cryolite group, the rare copper arseniates from the Tintic, the vanadates of Georgetown, the wulfenite of Las Cruces, the turquoise of Los Cerillos and the superb azurites and malachites from the Copper Queen mine.

The long investigation of Dr. T. M. Chatard upon the natural soda of Owen's and Mono Lakes and the development of chemical industries in connection therewith, has at last been brought to a close, and his report has been presented for publication. Dr. Chatard has also done a considerable amount of routine work during the year, and has made analyses of an interesting chrome tourmaline and associated fuchsite mica from Maryland.

By Mr. J. E. Whitfield there has been described dumortierite from Arizona, and a new meteoric iron from La Bella Roca, in the State of San Lüis Potosi, Mexico. The greater part of Mr. Whitfield's time, however, has been occupied with the Yellowstone Park collections of Mr. Hague. Of these, thirty-eight rocks, salts and incrustations, and three waters were analyzed during the year. For comparative purposes three geyserites from New Zealand were also analyzed. On May 15 Mr. Whitfield resigned from the Survey to accept a position in Philadelphia, and the vacancy so created was filled by the promotion of Mr. L. G. Eakins.

From July until nearly November Mr. Eakins was absent in the field with Mr. Emmons's division. Since his return he has made analyses of two rare minerals, astrophyllite from Colorado and gadolinite from Texas, of four specimens relating to the serpentine investigation, and of eight rocks, two fossil bones, five samples of loess, and thirty-four coals from Colorado and Wyoming. The coal analyses represent Mr. Eldridge's study of the Crested Butte region in Colorado.

To Mr. Charles Catlett many routine analyses were referred, including many assays for gold and silver. Among the analyses were twelve coals, six ores of manganese, twelve iron ores, and eleven samples of serpentine and its associated micas and pyroxenes from Montville, N. J., Moriah, N. Y., and Easton, Pa. He also shared in the study of the platiniferous nickel ores from Canada, already mentioned. On April 1 he resigned to take a position elsewhere, and on June 14 Mr. E. A. Schneider was appointed to the vacancy.

In all three hundred and twenty-six analyses were reported from the Washington laboratory in the course of the year. They include, in addition to the cases already named, nine rocks collected by Dr. G. H. Williams in Maryland, seven rocks from Prof. Van Hise's collections, eight rocks from Mr. Diller, seven spring waters, four building stones, four clays, four samples of adobe soil, a specimen of steel from the stem piece of the United States cruiser *Maine*, and a stereotype metal submitted for examination by the Public Printer.

IN THE PHYSICAL LABORATORY.

During the early part of the year Dr. Barus endeavored to verify the outline of a physical theory of solid viscosity due to Maxwell, by showing its sufficiency in accounting for all the phenomena thus far observed. The behavior of steel in all states of temperature and of temper was found to be particularly suggestive; but the experiments were extended so as to include metals carrying permanent flexure, tension, drawn strain and torsion. Lag and fatigue in metals (hysteresis), the occurrences of accommodation and of motional annealing, the secular changes particularly observed in glasshard steel, and other allied phenomena, were discussed in detail and coordinated. Finally, corresponding features in the magnetic behavior of iron were adduced and an attempt was made to utilize the temporary increase of rigidity due to the action of a magnetic field for telephonic purposes. It was shown that the behavior of filamentary wires is such that it may be made available for the construction of electric dynamometers.

In a second part of the work on solid viscosity, Dr. Barus endeavors to throw light on the nature of the changes of molecular structure by which viscous motion in solids is promoted. For this purpose the changes of carburation, of hydroelectric qualities, and the rates of solution of given samples of steel and other metals, in all states of strain, were examined in detail. Measurements were also made on the absolute amount of energy potentialized in given permanent increments of strain. With similar ends in view, the conductivity of stressed glass and the viscosity of electrolyzing glass were carefully measured and compared with the corresponding constants of unstressed glass. The results of this work will be published in two bulletins of the Survey, of which the first is now in the hands of the printer; the other is nearly ready for publication.

Experiments are in progress on the absolute measurement of extremely high degrees of viscosity, such, for instance, as are shown by solid paraffines and similar substances.

Pursuing an open point of inquiry of an earlier bulletin (No. 35), relating to the computed sizes of very fine solid particles subsiding in liquids under different conditions, Dr. Barus made a further series of experiments with the object of clearly exhibiting the present aspects of the physics of sedimentation.

The methods of high temperature measurement detailed in Bulletin 54, have since been further developed and a standard form of high temperature air thermometer has been devised. It will be shown that a practically efficient and accurate method of absolute measurement consists in standardizing a reentrant porcelain air thermometer by aid of a reentrant air thermometer of glass, using a suitable platinum-platinum-iridium thermocouple as a means of coordination in the way shown in the bulletin. In addition to the standard form of manometer which accompanies this apparatus, a torsion galvanometer has been devised with special reference to temperature work. Its chief feature is the enormous range within which thermo-electric forces are measurable. Without special adjustment any temperature from zero to the extreme of white heat may be at once obtained. This apparatus was tested and its efficiency demonstrated by a detailed research on the pressure variations of high temperature boiling points. The results obtained with mercury, sulphur, cadmium, zinc, bismuth, etc., when boiling under different constant pressures between 0 atmosphere and 1 atmosphere are such as establish the probable truth of the principle of Groshans. They thus suggest another new method of high temperature measurement, the practical availability of which compares favorably with the transpiration pyrometer discussed in the last report.

With this work Dr. Barus has carried forward the researches on viscosity and temperature to a point of progress at which their bearing on outstanding problems in dynamic geology becomes evident when the application is made under conditions of high pressure. One of the problems in question is the case of fusion under pressure. Another relates to the change of compressibility, under varying conditions of pressure and of temperature. It will be shown that these two problems are closely related and that they contain within themselves the simplest case of a lag or viscous phenomenon.

Substances of exceptionally low degrees of compressibility (such for instance as are possessed by liquid metals) admit of special treatment when they are electrical conductors. Dr. Barus shows that both the melting point and pressure problem, and the problem relating to compressibility may be practically worked out by expressing specific volume in terms of specific resistance. It is believed that the continuity of change from solid to liquid may actually be demonstrated in this way. Substances which are more compressible than metals, whether conductors or not, are open to research by using either the change of viscosity, or of compressibility at the melting point as a criterion of fusion. Experiments are now in progress and have been made in some number on the fusion and compressibility of substances melting between 40° and 200°, conditions by which the practical work is very decidedly facilitated. It is gratifying to find that the results lead to certain general deductions, the important geologic application of which is already obvious.

Continuing his experiments upon the thermal expansion of rocks, Dr. Hallock has found that the immersion method is entirely impracticable when a rock is appreciably porous. This was clearly manifested in experiments upon the Berea sandstone, and other experiments on marble and obsidian opened the question whether the difficulties of the method do not overbalance its advantages. It is hoped that tests which are now under way may settle this point. Early in January work was begun upon linear expansions. The bath, comparator, etc., have been adjusted, and a series of comparisons has been made between a standard metre and a standard brass rod, at varying temperatures. The rock samples will be compared with the rod so standardized, and the work will go on as rapidly as specimens can be obtained.

In the autumn Dr. Hallock prepared two papers bearing upon the general question of contact action between solids. He shows that some alloys at least are analogous to freezing mixtures, and that although chemical action between solids is in some cases possible, Prof. Spring's test experiments are not conclusive. In the latter's researches vapors play an all-important part. Dr. Hallock has also been somewhat occupied with Mr. Woodward in experiments upon the rapidity of sedimentation in rivers, as related to corrasion.

From the branch laboratory at San Francisco, Dr. Melville, the chemist in charge, submits the following statement:

> At the outset a series of rocks from Mount Diablo, embracing four spec mens, was studied and the rocks were analyzed. Then came a period of investigation of the osmosis of various liquids through septa of different material, the ultimate object being its application to geology. A long and tedious investigation followed which comprised an extended study of solubilities of sulphides of heavy metals in many different reagents at ordinary temperatures and pressures. All of these experiments were repeated in sealed tubes at high pressures, more than sixty tubes being opened and their contents analyzed. Other experiments in sealed tubes were made as to the changes which solutions of gases and salts would produce on the mineral constituents of amphibolites, andesites and diabases. I then studied reactions to account for the association of certain minerals, and contemporaneously six analyses of rocks were made, three partial and three complete. The mineral livingstonite was analyzed, principally for identification. Most recently some work upon the synthesis of silicates has been done, and experiments have been made upon the decomposition of natural silicates which may lead to some explanation of the structure of these bodies.
>
> For two years past much time has been spent on rock specimens which were collected at Mount Diablo, California, by Mr. H. W. Turner, assistant geologist and myself. A great many of these have been analyzed and other analyses of different series of rocks from the same locality will soon follow.

I remain, very respectfully,

F. W. CLARKE,
Chief Chemist.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washinnton, D. C.

REPORT OF DR. D. T. DAY.

U. S. GEOLOGICAL SURVEY,
DIVISION OF MINING STATISTICS AND TECHNOLOGY,
Washington, D. C., July 1, 1889.

SIR: I have the honor to report that the work of the Division of Mining Statistics and Technology during the fiscal year was executed in accordance with the plan laid out for previous years. The fifth report of the series "Mineral Resources of the United States" was submitted to you in August, and by your direction a summary of the principal statistics was published through the press. The following month was sufficient for typesetting and correction of the proofs, and the entire volume was distributed in December.

In addition to the usual quantitative information regarding mineral products and their uses, this report contained a statement prepared by Mr. Albert Williams, jr., showing the localities in each State and Territory where useful deposits of minerals have been found and distinguishing the productive deposits from our reserves. This work is remarkable as showing the great development of known mineral deposits, and incidentally the discovery of some new fields since a similar report was published in 1883.

The report "Mineral Resources of the United States, 1888," was begun in October and continued to the end of the year. On June 10 the totals for the principal mineral products were published through the daily and technical press as follows:

METALS.

Iron and steel.—The principal statistics for 1888 were: Domestic iron ore consumed, about 12,060,000 long tons; value at mines, $28,944,000. This is an increase over 1887 in quantity of 760,000 tons, but a decrease in value of $4,956,000. Imported iron ore consumed, 587,470 long tons; total iron ore consumed in 1888, about 12,650,000 long tons, or 150,000 tons more than in 1887. Pig iron made in 1888, 6,489,738 long tons; value at furnace, $107,000,000. This is an increase over 1887 of 72,590 tons in quantity, but a decrease of $14,925,800 in value. Steel of all kinds produced in 1888, 2,899,440 long tons; value at works, $89,000,000. This is a decrease from 1887 of 439,631 tons in quantity and of $14,811,000 in value. Total spot value of all iron and steel made in 1888, in the first stage of manufacture, excluding all duplications, $145,000,000, a decrease of $26,103,000 as compared with 1887. Limestone used as a flux in the manufacture of pig iron in 1888, about 5,438,000 long tons; value at quarry, about $2,719,000.

Gold and silver.—According to the Director of the Mint, the gold product was 1,604,927 fine ounces, valued at $33,175,000. This is about the same as in 1887, being an excess of only $75,000. The silver product was 45,783,632 fine ounces, of the commercial value of about $43,000,000 and of the coining value of $59,195,000. This is an increase of 4,515,327 ounces over the product in 1887. In addition to the product of our own mines, some 10,000,000 ounces of silver were extracted in the United States from foreign ores and bullion.

Copper.—The total product, including the yield of imported ores, increased to 231,270,622 pounds, or 115,635 short tons, during 1888, which is 46,053,291 pounds more than the product of 1887. During the first quarter of 1889 the production was increasing at even a more rapid rate. The prices received by American producers averaged 15½ cents per pound for Lake copper, 14½ for Arizona and 14 for other districts, making the total value $33,833,954. Montana led in the production, making 97,897,968 pounds. Consumption was somewhat reduced by the high prices.

Lead.—The product increased to 180,555 short tons from 160,700 tons in 1887. The increase was due principally to the heavier receipts of lead in Mexican silver-lead ores from 15,000 tons in 1887 to over 27,000 tons in 1888. The average price in New York was 4.41 cents per pound. The production of white lead, chiefly from pig lead, was 89,000 short tons, valued at $10,680,000.

Zinc.—The erection of new works and the extension of old ones led to a further notable increase in the production of zinc in 1888. The additional capacity was distributed pretty uniformly in the West, East and South. Production in 1888, 55,903 short tons, with a total value of $5,500,855; in 1887, 50,340 tons, worth $4,782,300. The production of zinc white in 1888, directly from ores, was 20,000 short tons, worth $1,600,000.

Quicksilver.—The product was 33,250 flasks (of 76½ pounds each) from California, a decline in that State of 510 flasks from 1887, in spite of a very satisfactory price, which averaged $42.50 per flask, making the total value $1,413,125. No new valuable deposits were discovered in 1888, and without them it is not probable that the yield of quicksilver will increase.

Nickel.—The industry remains unchanged except for indications of further development at Lovelock in Nevada, and Riddle, Oregon. The product includes 190,637 pounds of metallic nickel, valued at $114,382 at 60 cents per pound, and 4,545 pounds, worth $1,136, exported in ores and matte. Total value, $115,518. The corresponding value in 1887 was $133,200.

Cobalt oxide.—The total product, including the contents of the exported ores and matte, was 12,266 pounds, worth $18,441. In 1887 the total was 18,340 pounds, worth $18,774, the lower rate of value in that year resulting from a larger proportion of exported nickel in matte and ore. The price of cobalt oxide remained at $2 per pound.

Chromium.—The product declined from 3,000 tons in 1887 to 1,500 tons in 1888. The average price in San Francisco remained at $15 per ton. Increased operations are probable in 1889.

Manganese.—The product of manganese and manganiferous iron ores in the United States in 1888 was 239,460 tons, valued at $876,215. Of this amount some 25,500 tons would be classed as manganese ores; the remainder as manganiferous iron ores. Of the manganiferous iron ores 11,462 tons, averaging 11 per cent. of manganese, and 189,574 tons, averaging 4 per cent. of manganese, were from the Colby mine, Michigan. In addition to the above, some 60,000 tons of argentiferous manganese ores, valued at $10 a ton, chiefly for the silver contained in them, were produced in the Rocky Mountain region.

Aluminum.—The past year was more promising than ever before for the production of cheap aluminum. The production of metallic aluminum as an industry distinct from the production of alloys began toward the close of the year, and 500 pounds had been made up to December 31; the production of 3,000 pounds since then indicates that the industry may continue. The exact amount of alloys produced by the Cowles process has not been furnished, but was not markedly different from the product of 1887, when 18,000 pounds of aluminum contained in bronze and ferro-aluminum were produced. The price for metallic aluminum declined to as low as $4.50 per pound for less favored brands.

Platinum.—Including the platinum and iridium separated from gold by the assay office and that saved in placer gold mining, the product was about 500 ounces, valued at $2,000.

FUELS.

Coal.—The total production of all kinds of commercial coal in 1888 was 142,037,735 short tons (increase over 1887, 18,022,480 tons), valued at the mines at $204,221,990 (increase, $30,625,994). This may be divided into Pennsylvania anthracite, 43,922,897 short tons (increase, 4,416,642 short tons), or 39,216,872 long tons, including 38,145,718 long tons shipped by the railroads and canals and reported by their statistician, Mr. John H. Jones, and 1,071,154 long tons sold to the local trade at the mines (increase 3,943,430 long tons), valued at $85,649,649 (increase, $6,284,405); all other coals, including bituminous, brown coal, lignite, small lots of anthracite produced in Colorado and Arkansas, and 4,000 tons of graphitic coal mined in Rhode Island, amounting in the aggregate to 98,114,838 short tons (increase, 13,605,838 tons), valued at $118,572,341 (increase $24,341,589).

The colliery consumption at the individual mines varies from nothing to 8 per cent. of the total output of the mines, being greatest at special Pennsylvania anthracite mines and lowest at those bituminous mines where the coal bed lies nearly horizontal, and where no steam-power or ventilating furnaces are used. The averages for the different States vary from 2 to 6.4 per cent., the minimum average being in the Pennsylvania bituminous and the maximum average in the Pennsylvania anthracite region.

The total output of the mines, including colliery consumption, was: Pennsylvania anthracite 41,624,610 long tons (increase over 1887, 4,045,863 long tons), or 46,619,564 short tons (increase 4,531,367 short tons); all other coals, 102,039,838 short tons (increase 14,152,478 tons), making the total output of all coals from mines in the United States, exclusive of slack coal thrown on the dumps, 148,659,402 short tons (increase 18,683,845 tons), valued as follows: Anthracite, $89,020,483 (increase $4,468,302); bituminous, $122,497,341 (increase, $24,492,685); total value $211,517,824 (increase, $28,960,987). The above figures show a notable increase in 1888 over 1887 in the aggregate output and value of both anthracite and bituminous coal, although not so great an increase as occurred in 1887 over 1886 in the value of the anthracite, or in the total tonnage of the bituminous coal.

Coke.—The production of coke in the United States in 1888 was 8,527,560 tons, valued at about $14,000,000. Pennsylvania produced by far the largest amount, the Connellsville region alone producing 4,955,553 tons; West Virginia, 528,533 tons; Alabama, 518,511 tons; Tennessee, 385,693 tons, and Virginia, 149,099 tons.

Petroleum.—The product of petroleum in the United States in 1888 was 27,346,018 barrels (of 42 gallons each), valued at about $24,598,559. Of this amount Pennsylvania produced 16,491,083 barrels; Ohio, 10,010,868 barrels; West Virginia, 119,448 barrels; California, 704,619 barrels; and other States 20,000 barrels.

Natural gas.—The amount of natural gas consumed is given in coal displacement; that is, the amount of coal displaced by the use of natural gas. It is estimated that the amount of coal displaced by natural gas in the United States in 1888 was 14,163,830 tons, valued at $22,662,128. Of this amount 12,543,830 tons were displaced in Pennsylvania; 750,000 in Ohio, and 660,000 in Indiana.

STRUCTURAL MATERIALS.

Building stone.—Direct returns from producers of the various kinds of building stone show that there was but a small gain in value over the figures of 1887. The value of the stone produced in 1888 is $25,500,000, or $500,000 more than in the preceding year.

Brick and tile.—Value, $48,213,000. This figure represents only a small gain over 1887, and the gain is due rather to increase in the number of manufacturing plants than to increased production at the older and more important sources of supply. In fact, many of the latter show a falling off in production. Prices also were generally somewhat lower than in 1887.

Lime.—The production is estimated at 49,087,000 barrels, with an average value of 50 cents per barrel, making a total of $24,543,500 as the value of the year's product. These figures are not largely in advance of those for 1887, and the gains are not so much the results of increased production in the leading lime regions as in localities of minor importance.

Cement.—The amount of cement produced in 1888 is less than for 1887, being 6,253,295 barrels for 1888, valued at 72½ cents per barrel, making $4,533,639 as the value of the year's product.

ABRASIVE MATERIALS.

Buhrstones.—The product which is used for grinding cement, plaster, paints, feed, etc., comes from New York, Pennsylvania, and North Carolina, and is valued at $150,000.

Grindstones.—Ohio and Michigan furnish practically all the sandstone from which grindstones are made. The product in 1888 increased slightly, 41,000 long tons, worth $281,800, being produced against 37,400, worth $224,400, in 1887. The price varied from $6.50 to $10 per ton at the quarries before being finished into grindstones.

Corundum.—Production is limited to the old mines in North Carolina and Georgia; 589 short tons, valued at $91,620, were produced in 1888, against 600 tons in 1887.

Oil-stones and whetstones.—The production of novaculite from Arkansas increased slightly, making the total, including Labrador oil-stone, etc., 1,500,000 pounds, valued at $18,000 in the rough state.

MISCELLANEOUS.

Precious stones.—No systematic mining in search of gems was carried on in 1888. But in mining for other substances and in chance discoveries, gems worth $64,850 in the rough state, and gold quartz, worth $75,000, were found.

Phosphate rock.—The production declined to 433,705 long tons, but the total value increased slightly to $1,951,673 on account of better prices. The trade in manufactured fertilizers was very prosperous.

Marls.—The production in the Southern States, particularly in Virginia, North Carolina, Alabama, Mississippi, and Florida, is increasing, while the product of New Jersey did not vary from that of 1887. About 600,000 tons, valued at $300,000, were produced.

Salt.—The industry shows only slight changes; in 1888 the production was 8,055,881 barrels of 280 pounds, valued at $4,377,204. In 1887 the product was 8,003,962 barrels, worth $4,093,846. Kansas became a commercial source of salt in 1888, producing 155,000 barrels, with a prospect of increase in 1889.

Bromine.—The product was 307,386 pounds, worth $95,290, an increase from 199,087 pounds, worth $61,717, in 1887. The price remained at 31 cents per pound.

Borax.—The production was restricted to 7,589,000 pounds, worth $455,340, at 6 cents per pound for the average quality. In 1887 the product was 11,000,000 pounds, worth 5 cents per pound.

Sulphur.—The sulphur refinery in Utah was partially burned. This and litigation over the property prevented any production in 1888. The supply came principally from Sicily, with small importations from Japan. It was practically all made into sulphuric acid.

Pyrites.—Production, 54,331 long tons, valued at the mines at $167,658; a slight increase in quantity over the previous year.

Barytes.—The production from Missouri, Virginia, and New York increased to 20,000 long tons, worth at the mines $110,000. In 1887 the product was 15,000 long tons, worth $75,000.

Gypsum.—The domestic supply comes principally from Ohio and Michigan, with smaller amounts from New York, Virginia, Kansas, Colorado, California, Dakota and Utah. The product in 1888 was 96,000 short tons of crude gypsum, valued at $430,000. A large portion of the supply is imported from Nova Scotia, where 126,118 tons, worth $121,579, were produced in 1888.

Ozocerite.—From the region of Soldier's Summit, Utah, about 20,000 pounds of crude mineral wax were produced, worth $1,000 in New York, where the material was sold. An increase is probable in 1889.

Soapstone.—Production about 15,000 tons, worth $50,000 before shipment.

Asphaltum.—The product of 1888 includes 700 tons of gilsonite mined in Utah; 3,100 tons of ordinary asphaltum, principally from California, and 50,000 tons of bituminous rock quarried in California for pavements in competition with asphaltum; total value, $331,500.

Feldspar.—The consumption for potters' use declined to 8,700 long tons, worth, in Trenton, New Jersey, $50,000. In 1887, 10,200 long tons were produced, worth $56,100.

Flint.—For potters' use the consumption was 16,250 long tons; including that for sandpaper and for glass, the consumption was about 30,000 tons, worth, unground, $175,000.

Potters' clay.—The consumption included 18,000 long tons of kaolin or china clay, 5,250 tons of ball clay, and 13,500 tons of fire clay, worth altogether $300,000.

Mica.—Owing principally to the use of smaller sizes in stoves the production of sheet mica decreased from 70,500 pounds in 1887 to 48,000 in 1888, valued at $70,000. There is increased demand for mica waste.

Mineral paints.—The product, including ocher, metallic paints, and small amounts of umber and sienna, increased to 24,000 long tons, valued at $380,000.

Graphite.—The production of pure graphite was limited to Ticonderoga, New York, and is reported as unchanged. The total production of pure material was 400,000 pounds, worth $33,000. Small amounts of less pure material for foundry facings, etc., were produced in North Carolina and at Cranston, Rhode Island.

Fluorspar.—The production, limited to the neighborhood of Roseclaire, Ill., and Evansville, Ind., is reported at 6,000 tons, worth $30,000, an increase of 1,000 tons over 1887.

Infusorial earth.—The product came principally from Maryland, and amounted to 2,500 short tons, worth, before shipment, $12,500.

Zircon.—During 1887 and 1888, 25 tons of zircon were mined, principally in Henderson County, N. C., and sold for $10,000, for the manufacture of incandescent gas burners. About 4 tons of monazite, 1 ton of allanite, 600 pounds of samarskite, and $500 worth of yttrium minerals were produced for the same purpose. About 6 tons of monazite and 5 tons of cerite were also imported.

Mineral waters.—Amount sold in 1888, 9,628,568 gallons, valued at $1,709,302. In 1887 the product was 8,259,609 gallons, worth $1,261,473.

Totals.—The total value of the minerals produced in 1888 was $591,659,931. It is recognized that this is the sum of the value of substances taken in various stages of manufacture, and hence not strictly comparable with each other; still it is the most valuable means of comparing the total products of different years. The result is an increase of nearly $50,000,000 beyond the value of the product in 1887. In that year nearly every mineral industry showed an increase, and hence an increased total was evident. But the fact that the increase was so very large was due to rather exceptional conditions in a few important industries, and it could not reasonably be expected that a similar combination of circumstances would result in even a larger total value for 1888. Nevertheless the unprecedented stimulus given to the production of copper by an artificial price increased the total value of that product by nearly $13,000,000, or nearly enough to offset the decline in the total value of pig iron. The other important factors in the increase were coal and the other fuels which followed the increased quantity of metals. With the anticipated decline of copper to the normal demand, a decline in the total value of the product in 1889 will not be inconsistent with the natural development of our mineral resources.

In addition to myself the office force consisted of Mr. William A. Raborg, Mr. Albert Williams, jr., and Mr. Jefferson Middleton, who have aided with increased zeal and efficiency the administration of the office work.

Very respectfully, your obedient servant,

DAVID T. DAY,
Geologist in Charge.

HON. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF MR. W. A. CROFFUT.

U. S. Geological Survey,
Editorial Division,
Washington, D. C., July 1, 1889.

Sir: During the fiscal year just closed this division has been fully occupied in editing manuscripts officially accepted for reports, papers, bulletins and monographs, and in reading and revising proofs of these from the Government Printing Office. In this I have been assisted by Mr. George M. Wood and Mr. J. H. Blodgett, and through their intelligent cooperation the effort made during the year to bring up to date the publication of the annual reports of the Survey has been reasonably successful. The following statement indicates what progress has been made in this and other respects, but it furnishes no adequate measure of the amount of editorial work which the publications actually represent:

Manuscripts read.	Proof read twice to four times.	Received from Public Printer.
Eighth Annual.	Seventh Annual.	Seventh Annual.
Ninth Annual.	Eighth Annual.	Monographs XIII and XIV.
Monographs I, XIII, XIV, XV, XVI.	Ninth Annual in part.	Bulletins 43, 45, 46, 47, 48, 49, 50, 51, 52.
Bulletins 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59.	Monographs XIII, XIV, XV, XVI.	Mineral Resources, fifth volume.
Mineral Resources, fifth volume.	Bulletins 46, 47, 48, 49, 50, 51, 52, 53.	

Very respectfully submitted,

W. A. Croffut,
Executive Officer in Charge.

REPORT OF MR. W. H. HOLMES.

U. S. Geological Survey,
Division of Illustrations,
Washington, D. C., July 1, 1889.

Sir: During the year the work of this division has been conducted on the plan adopted for preceding years, and no change in personnel has taken place.

During the year illustrations have been transmitted through this office for four bulletins, three monographs, and one annual report. These illustrations fall technically within the following classes:

Five plates by chromo-lithography.
Five plates by photo-lithography.
One hundred and sixty-six plates by photo-tint.
One hundred and seventy-six plates by photo-engraving.
Nine plates by wood engraving.
Ninety-nine figures by photo-tint.
One hundred and thirty-five figures by photo-engraving.
Five figures by wood engraving.

A small portion of the illustrations included in this list were prepared during preceding years. The following list shows approximately the drawings executed since June 30, 1888:

Fossil mollusca	335	Mineralogic specimens	25
Fossil vertebrates	300	Microscopic subjects	15
Fossil insects	208	Geologic landscapes	45
Fossil plants	322	Sections and diagrams	120
Miscellaneous	250		

The photographic work remains in charge of Mr. J. K. Hillers. The following is a list of the negatives, prints and transparencies made during the year:

Negatives.		Prints.		Transparencies.	
Size.	No.	Size.	No.	Size.	No.
28 by 34	173	28 by 34	602	28 by 34	39
20 by 24	391	20 by 24	3,606	20 by 24	18
14 by 17	141	14 by 17	533		
11 by 14	144	11 by 14	1,910		
8 by 10	284	8 by 10	1,649		
5 by 8	284	5 by 8	610		

Very respectfully, your obedient servant,

W. H. Holmes,
Geologist in Charge.

Hon. J. W. Powell,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF MR. CHAS. C. DARWIN.

U. S. Geological Survey,
Division of Library and Documents,
Washington, D. C., July 1, 1889.

Sir: I have the honor to submit the following report concerning the work of this division in the fiscal year ended June 30, 1889:

That work is becoming more and more every year the work of a bureau of information, and no statistics can be given of the numberless researches made in finding and verifying references, in identifying authors, in answering the innumerable requests for facts which come to the library from every other division of the Survey. It is therefore in every part of the Survey that the results of most of the work of this division must be sought, and not in this report, which can deal only with that regular routine work accomplished in the fractional time left for it. That routine work is carried on as formerly in three distinct lines—that which relates to the library, that which belongs to the distribution of documents, and that of correspondence.

LIBRARY.

The library has far outgrown its housing. The beginning of the year found us embarassed by the difficulty of properly administering a fast growing and constantly consulted mass of books within limits already overcrowded. A temporary relief from this state of things was secured by encroaching for three feet ten inches upon the width of the area heretofore reserved for the tables of readers and lengthening by that much the three central book-racks. The 161 feet of additional shelving thus obtained enabled us to properly arrange the generous selection from the library of the late Dr. F. V. Hayden, which was presented to the library by Mrs. Hayden at the end of the last fiscal year. But the accessions of the present year have come to shelves already filled, and great inconvenience has resulted. Among these accessions two deserve special mention.

On September 28, 1888, 2,369 books and pamphlets were received from Paris, being the greater part of the geological portion of the library of M. Jules Pierre François Stanislas Desnoyers, French academician, for years secretary of the Société d'histoire naturelle de Paris, secretary of the Société géologique de France, and librarian of the Muséum d'histoire naturelle from 1834 to 1887. This remarkable library was dissipated by an auction sale at Paris, to which my assistant, Mr. Charles A. Burnett, was accredited as the agent of the Survey. Mr. Burnett secured everything which we desired at far more reasonable prices than we had any reason to expect; and at a cost of 3,183.30 francs, or $614.38, the Survey came into the possession of a carefully collected library of 2,369 books and pamphlets especially rich in dynamic geology and the older geologic brochures not now to be found in the market. The acquisition of this collection at so small a cost is the most advantageous transaction in the history of the library.

On May 7, 1889, as the result of a partition between the Smithsonian Institution and the Geological Survey of a donation from Miss Frances Lea, the library received through Prof. W. H. Dall 576 books and pamphlets from the library of the late Isaac Lea of Philadelphia. The early prominence of Dr. Lea in American science and his wide range of exchanges made this collection of unusual value in the earlier and rarer American geologic literature.

Irrigation.—The irrigation engineering undertaken by the Survey has created a demand for the standard works upon the subject, and so enlarged the legitimate scope of the library as to make it include not only works upon irrigation proper, but the ministering subjects of meteorology, hydraulics, engineering, and so much of agriculture as relates to the enriching of the soil. The most important works on these subjects have so far been produced in foreign countries, and during the last half of the year there have been secured from England, France, Spain, Germany, Italy and India a valuable collection of works which will be of very material service to the topographer, the engineer, and the economist in the study of irrigation.

All these accessions have been catalogued and put into circulation, save such as were already upon the shelves of the library. The two gifts of Mrs. Hayden and Miss Lea and the Desnoyers collection, purchased in lots, necessarily duplicated many books already in our possession. These with those already in the duplicate room form a library of about 2,000 volumes available to replace losses, to multiply copies to field parties, or to exchange. This collection of duplicates—which are not really duplicates, because the Survey sometimes needs eight to sixteen copies of a work—is not included in the following table, which comprises only books and pamphlets regularly entered in the library:

Contents of the library, June 30, 1889.

BOOKS.			
On hand June 30, 1888:			
Received by exchange	16,410		
Received by purchase	5,053		
		21,463	
Received during the past year:			
By exchange	1,543		
By purchase	1,294	2,837	
			24,300
PAMPHLETS.			
On hand June 30, 1888:			
Received by exchange	28,450		
Received by purchase	1,650		
		30,100	
Received during the past year:			
By exchange	2,400		
By purchase	1,600	4,000	
			34,100
Total number of books and pamphlets			58,400

The average of circulation continued during this year to be as high as ever and demanded almost the whole time of one person. A thousand books were consulted every month.

We have been able to send only 656 books to the bindery, owing to the crowded condition of that establishment, and of these 547 are still there. As all of the exchanges and most of the books imported are unbound, we need to have at least 2,000 volumes bound every year. Prevented in that, as in this year, many important books are restricted to a limited use.

PUBLICATIONS.

Monographs XIII and XIV, Bulletins 43, 45, 46, 47, 48, 49, 50, 51 and 52, the Seventh Annual Report, and the fifth volume of Mineral Resources have been published during the year. The list of publications of the Survey corrected to June 30, 1889, is as follows:

ANNUAL REPORTS.

I. First Annual Report of the United States Geological Survey, by Clarence King. 1880. 8°. 79 pp. 1 map. A preliminary report describing plan of organization and publications.

II. Second Annual Report of the United States Geological Survey, 1880-'81, by J. W. Powell. 1882. 8°. lv, 588 pp. 61 pl. 1 map.

III. Third Annual Report of the United States Geological Survey, 1881-'82, by J. W. Powell. 1883. 8°. xviii, 564 pp. 67 pl. and maps.

IV. Fourth Annual Report of the United States Geological Survey, 1882-'83, by J. W. Powell. 1884. 8° xxxii, 473 pp. 85 pl. and maps.

V. Fifth Annual Report of the United States Geological Survey, 1883-'84, by J. W. Powell. 1885. 8°. xxxvi, 469 pp. 58 pl. and maps.

VI. Sixth Annual Report of the United States Geological Survey, 1884-'85, by J. W. Powell. 1886. 8°. xxix, 570 pp. 65 pl. and maps.

VII. Seventh Annual Report of the United States Geological Survey, 1885-'86, by J. W. Powell. 1888. 8°. xx, 656 pp. 72 pl. and maps.

MONOGRAPHS.

II. Tertiary History of the Grand Cañon District, with atlas, by Clarence E. Dutton, Capt. U. S. Army. 1882. 4°. xiv, 264 pp. 42 pl. and atlas of 24 sheets folio. Price $10.12.

III. Geology of the Comstock Lode and the Washoe District, with atlas, by George F. Becker. 1882. 4°. xv, 422 pp. 7 pl. and atlas of 21 sheets folio. Price $11.00.

IV. Comstock Mining and Miners, by Eliot Lord. 1883. 4°. xiv, 451 pp. 3 pl. Price $1.50.

V. The Copper-Bearing Rocks of Lake Superior, by Roland Duer Irving. 1883. 4°. xvi, 464 pp. 15 l. 29 pl. and maps. Price $1.85.

VI. Contributions to the Knowledge of the Older Mesozoic Flora of Virginia, by William Morris Fontaine. 1883. 4°. xi, 144 pp. 54 l. 54 pl. Price $1.05.

VII. Silver-Lead Deposits of Eureka, Nevada, by Joseph Story Curtis. 1884. 4°. xiii, 200 pp. 16 pl. Price $1.20.

VIII. Paleontology of the Eureka District, by Charles Doolittle Walcott. 1884. 4°. xiii, 298 pp. 24 l. 24 pl. Price $1.10.

IX. Brachiopoda and Lamellibranchiata of the Raritan Clays and Greensand Marls of New Jersey, by Robert P. Whitfield. 1885. 4°. xx, 338 pp. 35 pl. 1 map. Price $1.15.

X. Dinocerata. A Monograph of an Extinct Order of Gigantic Mammals, by Othniel Charles Marsh. 1886. 4°. xviii, 243 pp. 56 l. 56 pl. Price $2.70.

XI. Geological History of Lake Lahontan, a Quaternary Lake of Northwestern Nevada, by Israel Cook Russell. 1885. 4°. xiv, 288 pp. 46 pl. and maps. Price $1.75.

XII. Geology and Mining Industry of Leadville, Colorado, with atlas, by Samuel Franklin Emmons. 1886. 4°. xxix, 770 pp. 45 pl. and atlas of 35 sheets folio. Price $8.40.

XIII. Geology of the Quicksilver Deposits of the Pacific Slope, with atlas, by George F. Becker. 1888. 4°. xix, 486 pp. 7 pl. and atlas of 14 sheets folio. Price $2.00.

XIV. Fossil Fishes and Fossil Plants of the Triassic Rocks of New Jersey and the Connecticut Valley, by John S. Newberry. 1888. 4°. xiv, 152 pp. 26 pl. Price $1.00.

BULLETINS.

1. On Hypersthene-Andesite and on Triclinic Pyroxene in Augitic Rocks, by Whitman Cross, with a Geological Sketch of Buffalo Peaks, Colorado, by S. F. Emmons. 1883. 8° 42 pp. 2 pl. Price 10 cents.

2. Gold and Silver Conversion Tables, giving the coining values of troy ounces of fine metal, etc., computed by Albert Williams, jr. 1883. 8°. 8 pp. Price 5 cents.

3. On the Fossil Faunas of the Upper Devonian along the meridian of 76° 30′, from Tompkins County, N. Y., to Bradford County, Pa., by Henry S. Williams. 1884. 8°. 36 pp. Price 5 cents.

4. On Mesozoic Fossils, by Charles A. White. 1884. 8°. 36 pp. 9 pl. Price 5 cents.

5. A Dictionary of Altitudes in the United States, compiled by Henry Gannett. 1884. 8°. 325 pp. Price 20 cents.

6. Elevations in the Dominion of Canada, by J. W. Spencer. 1884. 8°. 43 pp. Price 5 cents.

7. Mapoteca Geologica Americana. A Catalogue of Geological Maps of America (North and South), 1752–1881, in geographic and chronologic order, by Jules Marcou and John Belknap Marcou. 1884. 8°. 184 pp. Price 10 cents.

8. On Secondary Enlargements of Mineral Fragments in Certain Rocks, by R. D. Irving and C. R. Van Hise. 1884. 8°. 56 pp. 6 pl. Price 10 cents.

9. A Report of work done in the Washington Laboratory during the fiscal year 1883–'84. F. W. Clarke, chief chemist; T. M. Chatard, assistant chemist. 1884. 8°. 40 pp. Price 5 cents.

10. On the Cambrian Faunas of North America. Preliminary studies, by Charles Doolittle Walcott. 1884. 8°. 74 pp. 10 pl. Price 5 cents.

11. On the Quaternary and Recent Mollusca of the Great Basin; with Descriptions of New Forms, by R. Ellsworth Call. Introduced by a sketch of the Quaternary Lakes of the Great Basin, by G. K. Gilbert. 1884. 8°. 66 pp. 6 pl. Price 5 cents.

12. A Crystallographic Study of the Thinolite of Lake Lahontan, by Edward S. Dana. 1884. 8°. 34 pp. 3 pl. Price 5 cents.

13. Boundaries of the United States and of the several States and Territories, with a Historical Sketch of the Territorial Changes, by Henry Gannett. 1885. 8°. 135 pp. Price 10 cents.

14. The Electrical and Magnetic Properties of the Iron-Carburets, by Carl Barus and Vincent Strouhal. 1885. 8°. 238 pp. Price 15 cents.

15. On the Mesozoic and Cenozoic Paleontology of California, by Charles A. White. 1885. 8°. 33 pp. Price 5 cents.

16. On the Higher Devonian Faunas of Ontario County, New York, by John M. Clarke. 1885. 8°. 86 pp. 3 pl. Price 5 cents.

17. On the Development of Crystallization in the Igneous Rocks of Washoe, Nevada, with Notes on the Geology of the District, by Arnold Hague and Joseph P. Iddings. 1885. 8°. 44 pp. Price 5 cents.

18. On Marine Eocene, Fresh-water Miocene, and other Fossil Mollusca of Western North America, by Charles A. White. 1885. 8°. 26 pp. 3 pl. Price 5 cents.

19. Notes on the Stratigraphy of California, by George F. Becker. 1885. 8°. 28 pp. Price 5 cents.

20. Contributions to the Mineralogy of the Rocky Mountains, by Whitman Cross and W. F. Hillebrand. 1885. 8°. 114 pp. 1 pl. Price 10 cents.

21. The Lignites of the Great Sioux Reservation. A Report on the Region between the Grand and Moreau Rivers, Dakota, by Bailey Willis. 1885. 8°. 16 pp. 5 pl. Price 5 cents.

22. On New Cretaceous Fossils from California, by Charles A. White. 1885. 8°. 25 pp. 5 pl. Price 5 cents.

23. Observations on the Junction between the Eastern Sandstone and the Keweenaw Series on Keweenaw Point, Lake Superior, by R. D. Irving and T. C. Chamberlin. 1885. 8°. 124 pp. 17 pl. Price 15 cents.

24. List of Marine Mollusca, comprising the Quaternary Fossils and recent forms from American Localities between Cape Hatteras and Cape Roque, including the Bermudas, by William Healey Dall. 1885. 8°. 336 pp. Price 25 cents.

25. The present Technical Condition of the Steel Industry of the United States, by Phineas Barnes. 1885. 8°. 85 pp. Price 10 cents.

26. Copper Smelting, by Henry M. Howe. 1885. 8°. 107 pp. Price 10 cents.

27. Report of work done in the Division of Chemistry and Physics, mainly during the fiscal year 1884–'85. 1886. 8°. 80 pp. Price 10 cents.

28. The Gabbros and Associated Hornblende Rocks occurring in the Neighborhood of Baltimore, Md., by George Huntington Williams. 1886. 8°. 78 pp. 4 pl. Price 10 cents.

29. On the Fresh-water Invertebrates of the North American Jurassic, by Charles A. White. 1886. 8°. 41 pp. 4 pl. Price 5 cents.

30. Second Contribution to the Studies on the Cambrian Faunas of North America, by Charles Doolittle Walcott. 1886. 8°. 369 pp. 33 pl. Price 25 cents.

31. Systematic Review of our Present Knowledge of Fossil Insects, including Myriapods and Arachnids, by Samuel Hubbard Scudder. 1886. 8°. 128 pp. Price 15 cents.

32. List and Analyses of the Mineral Springs of the United States; a Preliminary Study, by Albert C. Peale. 1886. 8°. 235 pp. Price 20 cents.

33. Notes on the Geology of Northern California, by J. S. Diller. 1886. 8°. 23 pp. Price 5 cents.

34. On the relation of the Laramie Molluscan Fauna to that of the succeeding Fresh-water Eocene and other groups, by Charles A. White. 1886. 8°. 54 pp. 5 pl. Price 10 cents.

35. Physical Properties of the Iron-Carburets, by Carl Barus and Vincent Strouhal. 1886. 8°. 62 pp. Price 10 cents.

36. Subsidence of Fine Solid Particles in Liquids, by Carl Barus. 1886. 8°. 58 pp. Price 10 cents.

37. Types of the Laramie Flora, by Lester F. Ward. 1887. 8°. 354 pp. 57 pl. Price 25 cents.

38. Peridotite of Elliott County, Kentucky, by J. S. Diller. 1887. 8°. 31 pp. 1 pl. Price 5 cents.

39. The Upper Beaches and Deltas of the Glacial Lake Agassiz, by Warren Upham. 1887. 8°. 84 pp. 1 pl. Price 10 cents.

40. Changes in River Courses in Washington Territory due to Glaciation, by Bailey Willis. 1887. 8°. 10 pp. 4 pl. Price 5 cents.

41. On the Fossil Faunas of the Upper Devonian—the Genesee Section, New York, by Henry S. Williams. 1887. 8°. 121 pp. 4 pl. Price 15 cents.

42. Report of work done in the Division of Chemistry and Physics, mainly during the fiscal year 1885–'86. F. W. Clarke, chief chemist. 1887. 8°. 152 pp. 1 pl. Price 15 cents.

43. Tertiary and Cretaceous Strata of the Tuscaloosa, Tombigbee, and Alabama Rivers, by Eugene A. Smith and Lawrence C. Johnson. 1887. 8°. 189 pp. 21 pl. Price 15 cents.

44. Bibliography of North American Geology for 1886, by Nelson H. Darton. 1887. 8°. 35 pp. Price 5 cents.

45. The Present Condition of Knowledge of the Geology of Texas, by Robert T. Hill. 1887. 8°. 94 pp. Price 10 cents.

46. Nature and Origin of Deposits of Phosphate of Lime, by R. A. F. Penrose, jr., with an Introduction by N. S. Shaler. 1888. 8°. 143 pp. Price 15 cents.

47. Analyses of Waters of the Yellowstone National Park, with an Account of the Methods of Analysis employed, by Frank Austin Gooch and James Edward Whitfield. 1888. 8°. 84 pp. Price 10 cents.

48. On the Form and Position of the Sea Level, by Robert Simpson Woodward. 1888. 8°. 88 pp. Price 10 cents.

49. Latitudes and Longitudes of Certain Points in Missouri, Kansas, and New Mexico, by Robert Simpson Woodward. 1889. 8°. 133 pp. Price 15 cents.

50. Formulas and Tables to facilitate the Construction and Use of Maps, by Robert Simpson Woodward. 1889. 8°. 124 pp. Price 15 cents.

51. On Invertebrate Fossils from the Pacific Coast, by Charles Abiathar White. 1889. 8°. 102 pp. 14 pl. Price 15 cents.

52. Subaërial Decay of Rocks and Origin of the Red Color of Certain Formations, by Israel Cook Russell. 1889. 8°. 65 pp. 5 pl. Price 10 cents.

STATISTICAL PAPERS.

Mineral Resources of the United States [1882], by Albert Williams, jr. 1883. 8°. xvii, 813 pp. Price 50 cents.

Mineral Resources of the United States, 1883 and 1884, by Albert Williams, jr. 1885. 8°. xiv, 1016 pp. Price 60 cents.

Mineral Resources of the United States, 1885. Division of Mining Statistics and Technology, 1886. 8°. vii, 576 pp. Price 40 cents.

Mineral Resources of the United States, 1886, by David T. Day. 1887. 8°. viii, 813 pp. Price 50 cents.

Mineral Resources of the United States, 1887, by David T. Day. 1888. 8°. vii, 832 pp. Price 50 cents.

Exchange.—Three thousand nine hundred and forty-three books and pamphlets have been received during the year from exchange; the Seventh Annual Report has been sent to all correspondents in the United States, Canada, and Mexico; Bulletins 40 to 47, and the volume of Mineral Resources for 1887 have been distributed to all entitled to complete exchange; and the distribution of Monograph XII has been completed.

The distribution during the year is in detail as follows:

Exchange distribution.

Seventh Annual Report	447
Bulletin 40	715
Bulletin 41	715
Bulletin 42	715
Bulletin 43	715
Bulletin 44	715
Bulletin 45	715
Bulletin 46	715
Bulletin 47	715
Monograph II (text)	463
Monograph II (atlas)	644
Mineral Resources, 1887	712
Total	8,016

Sale.—The sales show a continued growth of interest in the publications of the Survey. The table below exhibits the moneys received by years and quarters since such sales were begun:

Moneys received from the sale of publications and paid into the United States Treasury, by quarters, from 1883 *to* 1889 :

Year.	Quarter.	Amount.	Yearly sales.	Year.	Quarter.	Amount.	Yearly sales.
1883	First	$253.00	$643.24	1886	Second	$186.10	$813.28
	Second	82.26			Third	159.89	
	Third	60.82			Fourth	141.89	
	Fourth	247.16		1887	First	384.82	1,265.06
1884	First	196.44	438.94		Second	231.07	
	Second	107.28			Third	123.25	
	Third	82.65			Fourth	525.92	
	Fourth	52.57		1888	First	702.57	1,399.32
1885	First	115.10	460.92		Second	840.51	
	Second	90.00			Third	185.12	
	Third	68.05			Fourth	171.12	
	Fourth	187.77		1889	First	450.32	
1886	First	325.40			Second	239.80	

The sale account for 1888–'89 is shown in detail in the following table:

Sale of publications, 1888–'89.

Title of work.	Price.	No. sold.	Amount.	Title of work.	Price.	No. sold.	Amount.
Monograph II	$10.12	3	$30.36	Bulletin 13	$0.10	31	$3.10
Monograph III	11.00	7	77.00	Bulletin 14	.15	17	2.55
Monograph IV	1.50	10	15.00	Bulletin 15	.05	24	1.20
Monograph V	1.85	24	44.40	Bulletin 16	.05	21	1.05
Monograph VI	1.05	5	5.25	Bulletin 17	.05	21	1.05
Monograph VII	1.20	14	16.80	Bulletin 18	.05	29	1.45
Monograph VIII	1.10	6	6.60	Bulletin 19	.05	25	1.25
Monograph IX	1.15	2	2.30	Bulletin 20	.10	84	3.40
Monograph X	2.70	5	13.50	Bulletin 21	.05	26	1.30
Monograph XI	1.75	6	10.50	Bulletin 22	.05	29	1.45
Monograph XII	8.40	20	168.00	Bulletin 23	.15	20	3.00
Monograph XIII	2.00	13	26.00	Bulletin 24	.25	18	4.50
Monograph XIV	1.00	24	24.00	Bulletin 25	.10	67	6.70
Bulletin 1	.10	21	2.10	Bulletin 26	.10	66	6.60
Bulletin 2	.05	23	1.15	Bulletin 27	.10	29	2.90
Bulletin 3	.05	24	1.20	Bulletin 28	.10	27	2.70
Bulletin 4	.05	27	1.35	Bulletin 29	.05	47	2.35
Bulletin 5	.20	64	12.80	Bulletin 30	.25	30	7.50
Bulletin 6	.05	21	1.05	Bulletin 31	.15	24	3.60
Bulletin 7	.10	17	1.70	Bulletin 32	.20	58	11.60
Bulletin 8	.10	21	2.10	Bulletin 33	.05	45	2.25
Bulletin 9	.05	23	1.40	Bulletin 84	.10	19	1.90
Bulletin 10	.05	34	1.70	Bulletin 35	.10	19	1.90
Bulletin 11	.05	34	1.70	Bulletin 36	.10	21	2.10
Bulletin 12	.05	19	.95	Bulletin 37	.25	30	7.50

Sale of publications, 1888–'89—Continued.

Title of work.	Price.	No. sold.	Amount.
Bulletin 38	$0.05	14	$0.70
Bulletin 39	.10	37	3.70
Bulletin 40	.05	35	1.75
Bulletin 41	.15	56	8.40
Bulletin 42	.15	54	8.10
Bulletin 43	.15	50	7.50
Bulletin 44	.05	32	1.60
Bulletin 45	.10	74	7.40
Bulletin 46	.15	317	47.55
Bulletin 47	.10	111	21.10
Bulletin 48	.10	109	10.90
Bulletin 49	.15	42	6.30
Bulletin 50	$0.15	16	$2.40
Bulletin 51	.15	1	.15
Bulletin 52	.10	2	.20
Mineral Resources, 1882	.50	88	44.00
Mineral Resources, 1883–'84	.60	93	55.80
Mineral Resources, 1885	.40	95	38.00
Mineral Resources, 1886	.50	146	73.00
Mineral Resources, 1887	.50	308	154.00
Total		3,029	1,046.36

Free distribution.—Besides the larger distribution by sale and exchange, the growing popular demand for such publications as can be supplied upon application has been met by the gratuitous distribution of 18,577 volumes. This number includes 225 complete sets furnished to the Department of the Interior for distribution under the "Joint resolution to distribute copies of special memoirs and reports of the United States Geological Survey."

The work of the year in this branch of the division is therefore shown by the following table of

Publications distributed in 1888–'89.

Publications sent out by way of exchange	8,016
Publications sold	3,029
Publications distributed gratuitously	18,577
Proofs of atlas sheets	5,092
Total number of books and maps distributed	34,714

CORRESPONDENCE.

This division carries on all the correspondence relating to exchange, sale, and distribution of publications, and to purchases for the library. It has been a little larger this year than last; 14,367 letters were sent and 16,335 were received during the year; an average of 46+ sent and 53+ received daily. These are all filed and indexed in a simple manner which admits of ready reference.

I am, sir, very respectfully,

CHARLES C. DARWIN,
Librarian.

HON. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF MR. JNO. D. McCHESNEY.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., June 30, 1889.

SIR: I have the honor to submit herewith a detailed statement of the expenditures from the appropriation for the U. S. Geological Survey for the fiscal year ending June 30, 1889, amounting to $562,408.43.

Very respectfully,

JNO. D. McCHESNEY,
Chief Disbursing Clerk.

To the DIRECTOR,
U. S. Geological Survey.

Abstract of disbursements made by Jno. D. McChesney, Chief Disbursing Clerk U. S. Geological Survey, during the first quarter of 1889.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1888.				
July 16	1	A. S. Marye	Salary, July 1 to 11, 1888	$22.50
19	2	Chas. S. Cudlip	Photographic supplies	72.20
21	3	G. K. Gilbert	Traveling expenses	44.79
21	4	David T. Day	do	21.15
24	5	J. W. Powell	do	44.50
25	6	C. H. Pond	Topographic supplies	1.90
25	7	W. D. Olark & Co	Laboratory supplies	7.00
25	8	Robert T. Hill	Traveling expenses	114.84
25	9	Bailey Willis	do	85.56
30	10	Jno. D. McChesney	do	19.00
31	11	W. A. Croffut	Services, July 5 to 31, 1888	184.00
31	12	Geo. W. Shutt	Services, July, 1888	252.70
31	13	A. H. Thompson	do	227.40
31	14	R. H. Chapman	do	84.20
31	15	N. S. Shaler	do	260.00
31	16	A. B. Rennehan	do	30.00
31	17	Ira Sayles	do	117.90
31	18	Leo Lesquereux	do	75.00
31	19	Lawrence C. Johnson	do	117.90
31	20	J. Henry Blake	do	151.60
31	21	Sam. H. Scudder	do	210.60
31	22	W. J. McGee	do	202.20
31	23	H. R. Geiger	do	126.40
31	24	F. W. Geiger	do	60.00
31	25	A. F. Dunnington	do	134.80
31	26	Chas. D. Walcott	do	202.20
31	27	O. C. Marsh	do	337.00
31	28	F. Berge	do	80.00
31	29	L. P. Bush	do	50.00
31	30	H. Gibb	do	60.00
31	31	G. Baur	do	150.00
31	32	O. A. Peterson	do	55.00
31	33	J. B. Hatcher	do	200.00
31	34	W. H. Burwell	do	55.00
31	35	Pay-roll of employés	do	672.80
31	36	do	do	694.20
31	37	do	do	442.73
31	38	do	do	3,622.50
31	39	do	do	769.67
31	40	do	do	2,863.30
31	41	do	do	1,508.80
31	42	L. G. Stevenson	do	60.00
31	43	R. T. Hill	do	101.10
31	44	Wm. Hallock	do	134.80
Aug. 2	45	Louisville, Evansville and St. Louis R. R.	Transportation of assistants	11.00
2	46	J. Bishop & Co	Repairs to laboratory	10.30

Abstract of disbursements made by Jno. D. McChesney, etc.—Continued.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1888. Aug. 2	47	N. Y. Central and Hudson River R. R.	Transportation of assistants	$51.50
2	48	John F. Stephenson	Freight	1.69
2	49	Chas. Oley	Services, July, 1888	62.90
July 31	50	L. G. Eakins	do	101.10
31	51	I. C. Russell	do	168.50
31	52	C. R. Van Hise	do	130.00
31	53	Robert Robertson	do	60.00
31	54	R. S. Tarr	do	50.00
31	55	Bailey Willis	do	202.20
31	56	Geo. H. Eldridge	Traveling expenses	274.30
Aug. 3	57	C. H. Oppie & Sons	Subsistence, etc	33.89
3	58	Clark & Matter	do	23.92
3	59	do	do	33.65
3	60	A. Lamme & Co	do	29.12
3	61	Quartermaster's Department	Topographic supplies	92.96
3	62	F. A. True	Publications	15.00
3	63	Pay-roll of employés	Services, July, 1888	210.80
3	64	do	do	195.80
4	65	A. B. Renneham	Services, August 1 to 4, 1888	4.00
4	66	Chesapeake and Ohio R. R	Transportation of assistants	21.25
4	67	Bailey Willis	Traveling expenses	68.59
4	68	August T. Foerste	Services, July, 1888	30.00
4	69	Clarke & Matter	Subsistence, etc	13.74
4	70	H. Rosendale	Instruments	10.50
6	71	Wyckoff, Seamans & Benedict	Repairs to type-writer	16.00
6	72	Richard E. Edes	Traveling expenses	18.25
6	73	I. C. White	Services, July, 1888	168.50
6	74	Arthur Keith	Geological supplies, etc	104.34
7	75	John F. Paret	Supplies	3.00
7	76	Fred. A. Schmidt	do	14.40
7	77	Lawrence C. Johnson	Traveling expenses	49.05
8	78	H. R. Geiger	do	83.02
11	79	C. Willard Hayes	Cash paid field expenses	103.14
11	80	Hume, Cleary & Co	Supplies	1.75
11	81	J. B. Woodworth	Services, July, 1888	50.00
11	82	R. S. Tarr	Traveling expenses	60.28
11	83	Pay-roll of employés	Services, July, 1888	392.22
11	84	W. D. Clarke & Co	Supplies	25.88
13	85	Chas. S. Cudlip	Photographic supplies	109.90
13	86	J. B. Marcou	Services, August 1 to 10, 1888	32.61
14	87	James H. Fiske	Laboratory supplies	2.00
14	88	Chas. H. Kraft	do	10.05
31	89	Pay-roll of employés	Services, August, 1888	2,175.00
31	90	do	do	1,359.78
31	91	do	do	851.71
31	92	do	do	668.51
31	93	do	do	436.59
31	94	do	do	1,108.31
31	95	do	do	2,442.13
31	96	William H. Dall	do	202.20
31	97	W. C. Frye	do	46.00
31	98	G. K. Gilbert	do	337.00
Sept. 4	99	Ira Sayles	do	117.90
4	100	F. W. Geiger	do	60.00
4	101	H. R. Geiger	do	126.40
4	102	C. R. Van Hise	do	183.48
4	103	L. C. Johnson	do	117.90
4	104	Charles D. Walcott	do	202.20
4	105	J. Henry Blake	do	151.60
4	106	H. McDeaderick	do	20.00
4	107	Bailey Willis	do	202.20
4	108	I. C. Russell	do	168.50
4	109	N. S. Shaler	do	270.00
4	110	J. B. Woodworth	do	50.00
4	111	Leo Lesquereux	do	75.00
4	112	Samuel H. Scudder	do	210.60
4	113	George W. Shutt	do	252.70
4	114	A. C. Peale	do	168.50
4	115	A. F. Dunnington	do	134.80
4	116	G. F. Becker	do	337.00
5	117	Pay-roll of employés	do	210.80
5	118	Charles Oley	do	90.00
5	119	W. S. Bayley	do	135.00
5	120	I. C. Russell	Traveling expenses	117.75
5	121	Lawrence C. Johnson	do	69.40
5	122	H. R. Geiger	do	57.84
5	123	C. Willard Hayes	Field expenses	85.76
6	124	Atlantic and Pacific R. R	Transportation of assistants	20.10

Abstract of disbursements made by Jno. D. McChesney, etc.—Continued.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1888.				
Sept. 6	125	Northern Pacific R. R	Transportation of assistants	$261.00
6	126	Baltimore and Ohio R. R	....do	548.90
6	127	Baltimore and Potomac R. R	Freight charges	1.96
7	128	Amos E. Woodward	Traveling expenses	10.75
7	129	William M. Fontaine	Services, July and August, 1888	337.00
7	130	W. J. McGee	Traveling expenses	171.70
7	131	Nelson H. Darton	....do	113.05
7	132	....do	Services, August, 1888	100.00
7	133	William C. Day	....do	135.00
7	134	Ira Sayles	Traveling expenses	24.19
7	135	R. H. Chapman	Services, August, 1888	84.20
11	136	H. R. Geiger	Traveling expenses	51.64
11	137	Authur Keith	Field expenses	131.75
11	138	....do	....do	1.90
13	139	Western Union Telegraph Co	Telegrams, July, 1888	27.32
13	140	W. B. Clark	Services, August, 1888	100.00
13	141	I. C. White	....do	192.39
13	142	R. M. Davis	Photographic material	27.40
13	143	George H. Eldridge	Field expenses	43.75
14	144	....do	....do	23.80
14	145	Carlisle Stevens & Co	Field subsistence	28.71
14	146	George T. Quinby	Services, July, 1888	50.00
14	147	Baltimore and Potomac R. R	Transportation of assistants	6.50
14	148	Bailey Willis	Field expenses	104.71
17	149	Charles H. Kraft	Laboratory supplies	7.47
17	150	Collier Cobb	Services, August 13 to 31, 1888	30.64
17	151	R. S. Tarr	Services, August, 1888	50.00
17	152	Robert Robertson	....do	60.00
17	153	I. C. Russell	Field expenses	55.90
17	154	Dunbaugh & Joy	Field supplies	40.64
17	155	Eimer & Amend	Chemical supplies	51.41
17	156	....do	Laboratory supplies	35.78
18	157	J. and H. Berge	....do	6.99
18	158	Erasmus Haworth	Traveling expenses	78.97
18	159	J. H. D. Baker	Field expenses	9.30
18	160	I. C. Russell	Traveling expenses	232.05
18	161	F. W. Clarke	....do	67.55
19	162	Amos E. Woodward	....do	24.97
19	163	....do	Services, September 1 to 18, 1888	29.03
19	164	W. and L. E. Gurley	Topographical material	246.00
19	165	....do	....do	322.60
19	166	August F. Foerste	Traveling expenses	74.74
21	167	....do	Services, August, 1888	40.00
21	168	Frank Leverett	Services, July 1 to September 15, 1888.	330.00
21	169	Pennsylvania R. R	Transportation of assistants	104.15
21	170	J. Bishop & Co	Laboratory material	18.87
21	171	Frasse & Co	Laboratory supplies	1.84
21	172	E. H. King	Office furniture	160.00
21	173	James E. Humphrey	Services, August, 1888	35.00
21	174	S. J. Haislett	Topographic supplies	64.00
21	175	J. B. Smith	Field supplies	23.06
21	176	....do	....do	11.15
21	177	S. S. Garnett	Field expenses	129.75
21	178	R. S. Tarr	Traveling expenses	78.83
24	179	Quartermaster's Department, U. S. Army.	Topographic material	91.30
24	180	Warren Upham	Salary, August, 1888	101.10
28	181	L. H. Schneider's Son	Chemical and topographic supplies.	97.81
28	182	John F. Stephenson	Freight charges	8.96
28	183	United States Express Co	....do	41.35
28	184	Robert Robertson	Traveling expenses	104.65
29	185	Pay-roll of employés	Services, September, 1888	619.40
29	186	....do	....do	2,307.20
29	187	....do	....do	992.10
29	188	....do	....do	296.60
29	189	....do	....do	1,169.77
29	190	....do	....do	1,323.80
29	191	....do	....do	2,334.43
29	192	....do	....do	298.40
29	193	....do	....do	289.20
29	194	G. K. Gilbert	....do	326.00
29	195	Wm. H. Dall	....do	195.60
29	196	Nelson H. Darton	....do	100.00
29	197	C. W. Richmond	....do	49.00
29	198	W. J. Peters	....do	97.80
29	199	C. T. Reid	....do	50.00
29	200	W. H. Herron	....do	58.80
29	201	Sam. H. Scudder	....do	203.80

Abstract of disbursements made by Jno. D. McChesney, etc.—Continued.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1888.				
Sept. 29	202	J. H. Blake	Services, September, 1888	$146.80
29	203	R. T. Hill	do	97.80
29	204	Wm. M. Fontaine	do	163.00
29	205	F. W. Geiger	do	60.00
29	206	Sumner H. Bodfish	do	163.00
29	207	I. C. White	do	195.60
29	208	Harriet Biddle	do	30.00
29	209	L. G. Eakins	do	97.80
29	210	Leo Lesquereux	do	75.00
29	211	Geo. F. Becker	do	326.00
29	212	W. H. Melville	do	163.00
29	213	A. F. Dunnington	do	130.40
29	214	H. R. Geiger	do	122.20
29	215	Ira Sayles	do	114.20
29	216	A. C. Peale	do	163.00
29	217	Lawrence C. Johnson	do	114.20
29	218	W. C. Day	do	40.00
29	219	Chas. H. Cherry	do	30.00
29	220	A. Lamme & Co	Field subsistence	114.71
29	221	Missouri Pacific R. R.	Transportation of assistants	7.15
29	222	Collier Cobb	Traveling expenses	103 75
29	223	Northern Pacific R. R.	Freight	16.22
29	224	Gayton A. Douglass & Co	Repairs, etc	9.75
29	225	Adams Express Co	Freight charges	227.40
29	226	W. D. Heistand	Services, September, 1888	22.00
29	227	C. R. Van Hise	Services, September 1 to 30, 1888	195.60
29	228	W. S. Bayley	do	125.00
29	229	Charles Oley	Services, September 3 to 23, 1888	63.00
29	230	Phillip Sess	Services, August 18 to September 24, 1888.	74.00
29	231	Joseph Vasseur	Services, August 17 to September 23, 1888.	74.00
29	232	Geo. W. Shutt	Services, September 1 to 30, 1888	244.60
29	233	Mutual District Messenger Co	Rent of night watch	10.00
29	234	do	do	5.00
29	235	C. R. Van Hise	Traveling expenses	311.60
29	236	Geo. W. Knox	Freight charges	20.04
29	237	Chesapeake and Potomac Telephone Co.	Rent of telephone	155.75
29	238	James G. Bowen	Care and forage of public animals	66.00
29	239	do	do	33.50
29	240	do	do	21.50
29	241	Great Falls Ice Co	Ice, July, August, and September, 1888.	51.84
29	242	Western Union Telegraph Co	Telegrams	33.51
29	243	H. R. Geiger	Traveling expenses	54.11
29	244	J. B. Smith	Field supplies	19.92
29	245	Denver and Rio Grande Western R. R.	Transportation of assistants	32.55
29	246	Eimer & Amend	Supplies	140.23
29	247	N. S. Shaler	Services, September, 1888	250.00
29	248	J. B. Woodworth	do	50.00
29	249	Collier Cobb	do	50.00
29	250	Pay-roll of employés	do	193.40
29	251	do	do	158.40
		Total		52,412.31

SALARIES, OFFICE OF THE DIRECTOR.

1888.				
July 31	1	James Stevenson	Services, July 1 to 25, 1888	$203.80
31	2	Pay-roll of employés	Services, July, 1888	2,576.64
Aug. 31	3	do	Services, August, 1888	2,774.76
20	4	A. B. Searle	Services, August 1 to 12, 1888	29.35
31	5	Robert Stein	Services, August, 1888	101.10
Sept. 30	6	Pay-roll of employés	Services, September, 1888	2,898.60
		Total		8,584.25

Abstract of disbursements made by Mark B. Kerr, disbursing agent U. S. Geological Survey, during the first quarter of 1889.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1888.				
July 16	1	W. T. Griswold	Field expenses	$32.20
17	2	Paul Holman	do	6.20
17	3	Goldberg, Bowen & Co	Field subsistence, etc	32.06
17	4	F. J. Bringham	Field supplies	15.50
17	5	D. N. Freisleben	Field subsistence, etc	18.25
13	6	Redick H. McKee	Field expenses	33.90
17	7	Hecla Mercantile and Banking Co	Field subsistence, etc	41.57
16	8	A. F. Dunnington	Field expenses	22.95
17	9	Perkins & Wise	Field subsistence, etc	49.77
17	10	Wm. B. Ross	Field expenses	19.25
17	11	E. T. Perkins, jr	do	33.65
17	12	do	do	93.08
18	13	A. F. Dunnington	do	79.20
31	14	H. S. Wallace	Services, July, 1888	117.90
31	15	C. H. Fitch	do	134.80
31	16	E. M. Hasbrouck	do	50.00
31	17	R. U. Goode	do	151.60
31	18	Chas. F. Urquhart	do	75.80
31	19	Paul Holman	do	70.80
31	20	Pay-roll (Davis)	do	329.51
31	21	Arthur P. Davis	Field expenses	67.60
31	22	Pay-roll (McKee)	Services, July, 1888	289.10
31	23	Pay-roll (Wilson)	do	219.60
31	24	Pay-roll (Dunnington)	do	250.26
31	25	J. E. Taylor	do	21.75
31	26	E. C. Ryan	do	60.00
31	27	Pay-roll (Douglas)	do	364.43
31	28	Pay-roll (Griswold)	do	305.94
31	29	Pay-roll (Perkins)	do	227.26
31	30	Mark B. Kerr	do	151.60
Aug. 4	31	J. S. Diller	Traveling expenses	100.85
6	32	A. H. Thompson	do	98.71
13	33	A. F. Dunnington	Field expenses	36.75
15	34	J. S. Diller	do	118.30
15	35	H. M. Wilson	do	78.11
15	36	Redick H. McKee	do	57.55
15	37	A. F. Dunnington	do	36.00
16	38	E. T. Perkins, jr	do	131.85
16	39	W. T. Griswold	do	134.28
20	40	E. M. Douglas	do	90.03
20	41	Frank Tweedy	do	29.37
20	42	Pay-roll (Diller)	Services, July, 1888	266.07
20	43	Pay-roll (Tweedy)	do	339.80
20	44	A. H. Thompson	Traveling expenses	98.09
20	45	John Roach	Repairs, etc	25.50
20	46	A. E. Laudenslager	Field subsistence	68.84
20	47	do	do	84.77
25	48	do	do	108.36
25	49	Warren St. Mooers	Forage	44.99
25	50	George Chase	Repairs, etc	46.90
25	51	E. C. Ryan	Traveling expenses	12.00
25	52	do	Field expenses	16.40
25	53	A. F. Dunnington	do	25.45
25	54	do	do	39.00
25	55	Redick H. McKee	do	57.93
25	56	do	do	51.75
25	57	H. M. Wilson	do	47.40
25	58	do	do	82.00
25	59	W. T. Griswold	do	47.00
25	60	do	do	82.11
25	61	Otis O. Helman	Services, July, 1888	10.16
25	62	Harry Vick	do	8.06
25	68	Arthur P. Davis	Field expenses	17.10
25	64	J. S. Diller	do	184.86
25	65	Arthur P. Davis	Traveling expenses	49.55
25	66	H. M. Wilson	Field expenses	75.90
25	67	do	do	24.75
25	68	A. F. Dunnington	do	75.50
25	69	Hecla Mercantile and Banking Co.	Field subsistence	50.45
25	70	R. H. Chapman	Traveling expenses	44.75
25	71	Guilford B. Chapman	Services	6.45
25	72	Henry Vilas	do	29.03
25	73	do	Traveling expenses	20.75
25	74	Frank E. Gove	Services, July, 1888	36.77
25	75	Philip Sawyer	do	29.03
25	76	do	Traveling expenses	20.75
25	77	H. D. Bushnell	Services, July, 1888	29.03
25	78	do	Traveling expenses	24.25

Abstract of disbursements made by Mark B. Kerr, etc.—Continued.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1888.				
Aug. 25	79	Dan D. Calkins	Traveling expenses	$106.65
25	80	......do	Services, July, 1888	30.97
25	81	E. M. Douglas	Traveling expenses	26.38
25	82	J. H. Emmet & Co	Field supplies	20.91
25	83	W. A. McKenzie	Field expenses	20.03
25	84	Reaser Bros	Field subsistence, etc	86.12
25	85	Robt. Muldrow	Traveling expenses	79.50
25	86	W. T. Griswold	Field expenses	78.65
25	87	Mark B. Kerr	Traveling expenses	98.00
25	88	Perkins & Wise	Field subsistence	53.21
28	89	Frank E. Gove	Traveling expenses	68.65
28	90	H. S. Wallace	......do	29.00
31	91	R. U. Goode	Services, August, 1888	151.60
31	92	C. H. Fitch	......do	134.80
31	93	H. S. Wallace	......do	117.90
31	94	Chas. F. Urquhart	......do	75.80
31	95	Paul Holman	......do	70.80
31	96	Pay-roll	......do	706.60
Sept. 1	97	Chas. Bages	......do	12.00
3	98	E. C. Ryan	......do	60.00
3	99	.....do	Field expenses	30.00
3	100	C. H. Fitch	Traveling expenses	21.75
3	101	E. M. Hasbrouck	......do	20.55
17	102	Chas. F. Urquhart	......do	50.75
17	103	R. U. Goode	......do	25.45
17	104	Jas. E. Shelley	......do	27.50
17	105	Low & Low	Wagon	66.50
17	106	H. M. Wilson	Field expenses	113.05
17	107	R. H. McKee	......do	88.20
17	108	A. F. Dunnington	......do	24.95
17	109	Pay-roll (Perkins)	Services, August, 1888	289.20
17	110	Pay-roll (McKee)	......do	292.10
17	111	Pay-roll (Griswold)	......do	351.60
17	112	Pay-roll (Wilson)	......do	259.95
17	113	Pay-roll (Douglas)	.....do	488.50
17	114	R. H. Chapman	Field expenses	13.47
17	115	Chas. W. Howell	Services, July, 1888	23.22
17	116	Wm. Bolander	Field supplies	17.95
3	117	Mark B. Kerr	Services, August, 1888	151.60
3	118	A. H. Thompson	......do	227.40
3	119	Mark B. Kerr	Field expenses	12.16
17	120	John H. Hughes	Field material	2.75
17	121	L. B. Putney	Forage	8.15
17	122	Ad. Gusdorf	Field supplies	5.78
17	123	Arthur P. Davis	Field expenses	54.23
17	124	Pay-roll (Dunnington)	Services, August, 1888	261.00
17	125	A. F. Dunnington	Field expenses	61.44
17	126	......do	......do	35.10
17	127	H. M. Wilson	......do	82.36
17	128	......do	......do	52.17
17	129	Pay-roll (Wallace)	Services, August, 1888	163.87
17	180	Pay-roll (Fitch)	......do	87.10
17	131	Pay-roll (Goode)	......do	55.47
17	132	Lincoln Martin	Traveling expenses	32.60
17	133	Louis N. Marquart	Repairs, etc	60.90
17	134	R. U. Goode	Field expenses	219.72
17	135	Stuart Scott	Pasturage	45.00
17	136	W. H. Scott	Herding, etc	46.00
17	137	H. H. Sigman	Field supplies	53.10
17	138	L. Bair	......do	101.10
17	139	Jas. E. Shelley	Services, July, 1888	60.00
17	140	E. H. Keller	Field material	254.00
17	141	Huilburt & Semple	Field supplies	73.52
17	142	W. W. McCullough	Subsistence, etc	240.57
17	143	Van Arsdell & Co	Forage	19.31
17	144	A. E. Laudenslager	Field supplies	20.21
17	145	E. M. Douglas	Field expenses	117.80
17	146	Pay-roll (Tweedy)	Services	339.80
17	147	Frank Tweedy	Field expenses	40.21
17	148	E. T. Perkins	......do	128.25
17	149	E. J. Post & Co	Field supplies	6.50
19	150	Paul Holman	Field expenses	11.75
19	151	......do	Traveling expenses	6.00
21	152	Western Union Telegraph Co	Telegrams	6.41
22	153	Pay-roll (Diller)	Services, August, 1888	383.50
		Total		14,317.92

Abstract of disbursements made by C. D. Davis, special disbursing agent U. S. Geological Survey, during the first quarter of 1889.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1888.				
Aug. 18	1	W. S. Bayley	Services, July 4 to 31, 1888	$120.00
18	2	C. H. Hall	Services, July, 1888	60.75
18	3	Jos. Block & Son	Supplies	22.16
18	4	Dunbaugh & Joy	Geological supplies	22.67
18	5	......do	......do	22.52
18	6	Alpheus Hyatt	Traveling expenses	60.50
18	7	A. C. Peale	......do	107.93
18	8	W. J. McGee	......do	174.89
18	9	I. C. Russell	Field expenses	67.92
18	10	Eimer & Amend	Chemical supplies	9.60
18	11	Swamper Cariboo	Services, July 19 to August 6, 1888	38.00
18	12	Jackson Cariboo	Services, July 13 to August 3, 1888	43.00
18	13	Joe Cariboo	Services, July 23 to August 3, 1888	30.00
18	14	E. J. Owenhouse	Geological field material	5.75
20	15	Warren Upham	Services, July, 1888	101.10
20	16	C. L. Whittle	......do	50.00
20	17	Geo. Ryneal, jr	Topographic supplies	16.25
20	18	S. F. Emmons	Traveling expenses	100.60
20	19	Pennsylvania R. R	Transportation of assistants	392.11
22	20	Lewis S. Hayden	Publications	50.00
22	21	Robert Robertson	Traveling expenses	98.19
22	22	F. Marshall Smith	......do	15.00
22	23	W. C. Day	Services	150.00
22	24	Chas. W. Richmond	Traveling expenses	26.00
23	25	John C. Parker	Geological supplies	1.80
23	26	Miner & Miller	Services and supplies, etc	16.35
25	27	Jas. E. Humphrey	Services, July, 1888	35.00
25	28	Z. D. Gilman	Chemical supplies, etc	157.41
25	29	Denver and Rio Grande R. R	Transportation of assistants	25.50
29	30	W. A. Raborg	Traveling expenses	19.35
31	31	W. J. McGee	Services, August, 1888	202.18
31	32	Pay-roll of employés	......do	569.75
31	33	S. F. Emmons	......do	337.00
31	34	Laurence Thompson	......do	96.77
31	35	Robt. T. Hill	......do	101.10
31	36	L. G. Eakins	......do	101.09
31	37	Chas. W. Richmond	......do	50.50
31	33	Pay-roll of employés	......do	195.80
		Total		3,694.54

Abstract of disbursements made by P. H. Christie, special disbursing agent U. S. Geological Survey, during the first quarter of 1889.

1888.				
July 17	1	F. P. Gulliver	Miscellaneous field expenses	$45.75
17	2	......do	......do	21.80
17	3	......do	Traveling expenses	4.10
17	4	M. Hackett	Miscellaneous field expenses	27.37
17	5	W. H. Ford	Field material	18.00
23	6	Chas. M. Yeates	Miscellaneous field expenses	61.97
26	7	W. H. Ford	Field material	52.75
28	8	M. Hackett	Miscellaneous field expenses	99.81
31	9	R. C. McKinney	......do	12.03
31	10	Pay-roll	Services, July, 1888	1,519.10
31	11	......do	......do	276.90
31	12	......do	......do	110.60
31	13	......do	......do	336.60
31	14	J. W. Hays	......do	101.10
31	15	R. O. Gordon	......do	75.80
31	16	A. E. Murlin	......do	84.20
31	17	J. L. Bridwell	......do	11.61
Aug. 2	18	E. C. Barnard	Traveling expenses	41.35
2	19	......do	Miscellaneous field expenses	75.71
2	20	Chas. M. Yeates	......do	62.55
2	21	A. E. Murlin	......do	30.93
3	22	W. H. Ford	Field material	35.00
3	23	F. J. Chapman	Forage of stock	26.10
3	24	E. M. Harnsberger	......do	47.09
8	25	Z. N. Lockhart	Stock	465.00
8	26	L. C. Fletcher	Miscellaneous field expenses	148.65
10	27	R. O. Gordon	......do	57.55
10	28	E. C. Barnard	......do	77.28
13	29	M. Hackett	Traveling expenses	43.05
13	30	R. C. McKinney	......do	21.05

Abstract of disbursements made by P. H. Christie, etc.—Continued.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1888.				
Aug. 13	31	R. C. McKinney	Miscellaneous field expenses	$7.31
15	32	W. F. Latham	Forage of stock	37.74
15	33	N. B. Dunn	......do	183.29
15	34	W. H. Ford	Field material	65.00
15	35	W. F. Fling	Forage of stock	10.96
15	36	J. S. Minter	Field supplies	28.75
15	37	Judd & Hogg	......do	19.79
15	38	Chas. M. Yeates	Miscellaneous field expenses	43.80
17	39	E. C. Barnard	......do	41.70
17	40	M. Hackett	......do	53.42
17	41	L. C. Fletcher	......do	161.63
17	42	Z. N. Lockhart	Stock	175.00
18	43	M. Hackett	Miscellaneous field expenses	38.60
20	44	C. W. Goodlove	......do	44.70
20	45	......do	Traveling expenses	10.42
20	46	Louis Nell	......do	24.20
20	47	John Boler	......do	3.00
20	48	Louis Nell	Miscellaneous field expenses	64.03
28	49	M. Hackett	Traveling expenses	24.89
29	50	Chas. M. Yeates	Miscellaneous field expenses	58.35
29	51	L. C. Fletcher	......do	84.21
29	52	......do	......do	91.11
29	53	Morris Bien	......do	47.64
31	54	Pay-roll (Yeates, August)	Services, August 1888	336.60
31	55	Pay-roll (Nell, August)	......do	335.14
31	56	Pay-roll (Fletcher, August)	......do	435.39
31	57	Pay-roll (Knight)	......do	173.50
31	58	Chas. E. Cooke	......do	70.80
31	59	R. C. McKinney	......do	101.10
31	60	P. H. Christie	......do	151.60
31	61	R. M. Towson	......do	84.20
31	62	A. E. Murlin	......do	84.20
31	63	R. O. Gordon	......do	75.80
31	64	J. W. Hays	......do	101.10
31	65	D. C. Harrison	......do	101.10
31	66	Pay-roll (Barnard, August)	......do	341.90
31	67	Pay-roll (Hackett, August)	......do	282.97
31	68	Pay-roll (Bien, August)	......do	268.07
Sept. 3	69	R. C. McKinney	Miscellaneous field expenses	39.56
3	70	A. E. Murlin	......do	23.45
3	71	E. C. Barnard	......do	83.07
3	72	S. J. Haislett	Field material	30.90
3	73	W. F. Fling	Forage of stock	6.00
3	74	W. H. Ford	Field material	18.00
4	75	R. Lee Longstreet	Traveling expenses	6.50
5	76	Morris Bien	......do	6.00
5	77	D. C. Harrison	......do	16.75
5	78	S. J. Haislett	Miscellaneous field expenses	5.50
5	79	J. D. Privett	......do	20.20
5	80	Morris Bien	......do	42.50
5	81	R. O. Gordon	......do	47.33
5	82	M. Hackett	......do	143.28
6	83	J. W. Hays	......do	72.24
6	84	Fred J. Knight	......do	46.60
7	85	L. C. Fletcher	......do	90.70
7	86	A. B. Rivers	Services, August 20 to 31, 1888	9.67
8	87	J. H. Kelly	Traveling expenses	9.45
8	88	P. H. Christie	......do	73.77
8	89	......do	Miscellaneous field expenses	95.36
10	90	R. S. Thornton	Services, August, 1888	25.00
10	91	D. C. Harrison	Miscellaneous field expenses	30.80
11	92	R. M. Towson	......do	42.15
12	93	F. P. Fitzwilliam	Services, August 20 to 31, 1888	9.67
12	94	Fred J. Knight	Miscellaneous field expenses	51.55
12	95	......do	......do	57.60
12	96	E. C. Barnard	......do	69.65
12	97	J. W. Hays	Traveling expenses	10.20
12	98	R. M. Towson	......do	8.30
12	99	L. C. Fletcher	......do	30.65
13	100	L Morgan	......do	8.65
13	101	Morris Bien	Miscellaneous field expenses	109.24
13	102	Louis Nell	......do	134.90
14	103	Chas. M. Yeates	......do	38.75
14	104	L. C. Fletcher	......do	88.95
18	105	Geo. E. Kennedy & Son	Field supplies	60.45
20	106	R. C. McKinney	Miscellaneous field expenses	28.99
20	107	E. C. Barnard	......do	66.94
20	108	D. C. Harrison	......do	16.55
25	109	Chas. M. Yeates	......do	113.07
25	110	L. C. Fletcher	......do	66.25

Abstract of disbursements made by P. H. Christie, etc.—Continued.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1888.				
Sept. 25	111	E. C. Barnard	Miscellaneous field expenses	$103.05
26	112	J. W. Hays	do	2.00
26	113	A. E. Murlin	do	27.85
26	114	Chas. E. Cooke	Traveling expenses	2.25
26	115	Morris Bien	Miscellaneous field expenses	137.84
29	116	J. A. Savery	Field material and supplies	14.05
29	117	W. H. Ford	Field material	18.00
29	118	Louis Nell	Micellaneous field expenses	133.95
29	119	L. C. Fletcher	do	107.95
29	120	Pay-roll	Services, September, 1888	358,60
29	121	do	do	332.00
		Total		11,446.49

Abstract of disbursements made by John. H. Renshawe, disbursing agent U. S. Geological Survey, during the first quarter of 1889.

1888.				
July 17	1	William J. Peters	Traveling expenses	$18.01
17	2	C. T. Reid	do	18.01
28	3	H. L. Baldwin, jr	Field expenses	55.65
28	4	do	Traveling expenses	11.30
28	5	Wm. H. Herron	do	40.85
31	6	C. T. Reid	Services, July, 1888	50.00
31	7	William J. Peters	do	101.10
31	8	H. L. Baldwin, jr	do	117.90
31	9	H. B. Blair	do	117.90
31	10	Wm. H. Herron	do	60.60
31	11	William J. Peters	Field expenses	54.50
31	12	Geo. T. Hawkins	Services, July, 1888	84.20
31	13	Basil Duke	do	60.00
31	14	W. E. Lackland	do	50.00
31	15	S. S. Gannett	do	151.60
31	16	J. H. Hagerty	Care of stock, etc	25.00
31	17	Ernest M. Warren	do	64.00
31	18	Van H. Manning, jr	Services, July, 1888	70.80
Aug. 1	19	H. B. Blair	Traveling expenses	10.00
9	20	W. T. Walker	do	7.35
10	21	H. L. Baldwin, jr	Field expenses	61.50
13	22	Wm. J. Peters	do	57.09
13	23	Geo. T. Hawkins	Traveling expenses	27.45
16	24	Wm. H. Herron	Field expenses	3.00
16	25	Geo. T. Hawkins	do	15.81
22	26	William J. Peters	do	71.44
22	27	S. E. Cook	Traveling expenses	15.90
22	28	S. S. Gannett	Field expenses	39.55
22	29	do	Traveling expenses	44.65
22	30	H. L. Baldwin, jr	Field expenses	84.80
22	31	H. B. Blair	do	34.60
31	32	H. L. Baldwin, jr	Services, August, 1888	117.90
31	33	Wm. H. Herron	do	60.60
31	34	Van H. Manning, jr	do	70.80
31	35	Pay-roll (S. S. G.)	do	289.97
31	36	William J. Peters	do	101.10
31	37	Van H. Manning, jr	Traveling expenses	7.00
31	38	M. H. Warren	Field expenses	24.00
31	39	C. T. Reid	Services, August	50.00
Sept. 3	40	S. S. Gannett	Field expenses	91.28
4	41	Pay-roll (H. B. B.)	Services, August	288.07
5	42	William J. Peters	Field expenses	43.95
6	43	H. L. Baldwin, jr	do	141.62
7	44	H. B. Blair	do	38.85
8	45	Basil Duke	Traveling expenses	18.00
10	46	W. E. Lackland	do	16.50
12	47	H. L. Baldwin, jr	Field expenses	44.23
15	48	J. H. Hagerty	Traveling expenses	4.45
15	49	William J. Peters	Field expenses	71.49
19	50	H. L. Baldwin, jr	do	45.00
20	51	C. T. Reid	Traveling expenses	42.15
21	52	S. S. Gannett	Field expenses	150.80
24	53	Van H. Manning, jr	Traveling expenses	27.99
24	54	do	Field expenses	22.95
30	55	do	Services, September, 1888	68.40
30	56	H. L. Baldwin, jr	do	114.20
30	57	W. U. Simons	Services, September 30, 1888	34.84
		Total		3,620.70

Abstract of disbursements made by Fielding Burnes, disbursing agent U. S. Geological Survey, during the first quarter of 1889.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1888.				
July 19	1	Robt. D. Cummin	Miscellaneous field expenses	$97.83
19	2	do	Traveling expenses	2.92
19	3	W. R. Atkinson	do	6.37
19	4	do	Miscellaneous field expenses	12.30
19	5	E. G. Kennedy	Traveling expenses	5.13
19	6	Jeremiah Ahern	do	5.00
19	7	Willard D. Johnson	Field material, etc	21.90
21	8	C. C. Bassett	Miscellaneous field expenses	90.11
21	9	F. P. Gulliver	Traveling expenses	11.38
23	10	Wm. H. Lovell	Miscellaneous field expenses	56.80
25	11	E. W. F. Natter	do	50.75
31	12	Pay-roll of employés	Services, July, 1888	429.60
31	13	C. J. Akin	do	50.00
31	14	W. R. Atkinson	do	75.00
31	15	Jeremiah Ahern	do	84.29
31	16	Charles C. Bassett	do	84.29
31	17	E. B. Clark	do	75.80
31	18	Robt. D. Cummin	do	101.10
31	19	F. P. Gulliver	do	50.00
31	20	Raymond H. Hale	do	75.00
31	21	W. E. Horton	do	40.32
31	22	G. E. Hyde	do	48.39
31	23	J. H. Jennings	do	84.20
31	24	G. L. Johnson	do	50.00
31	25	Willard D. Johnson	do	151.60
31	26	E. G. Kennedy	do	50.00
31	27	Wm. Kramer	do	70.80
31	28	James Longstreet, jr	do	50.50
31	29	Wm. H. Lovell	do	84.20
31	30	E. W. F. Natter	do	134.80
31	31	Lawson Sanford	do	50.00
31	32	R. H. Stuart	do	50.00
31	33	Frank Sutton	do	75.80
31	34	J. W. Thom	do	19.35
31	35	Marcus Baker	Traveling expenses	14.56
Aug. 3	36	Sumner H. Bodfish	do	53.60
3	37	do	Miscellaneous field expenses	66.00
3	38	Jeremiah Ahern	Traveling expenses	6.33
3	39	do	Miscellaneous field expenses	119.23
3	40	W. R. Atkinson	do	86.80
3	41	Robt. D. Cummin	do	94.62
7	42	Wm. H. Lovell	do	76.16
7	43	C. C. Bassett	do	82.75
7	44	Willard D. Johnson	do	139.96
7	45	do	Traveling expenses	9.63
7	46	do	do	14.91
14	47	Lawson Sanford	do	4.87
14	48	E. W. F. Natter	do	35.79
14	49	do	Miscellaneous field expenses	53.81
14	50	Frank Sutton	do	92.46
14	51	do	Traveling expenses	21.52
14	52	do	do	6.02
14	53	John D. Black	Services, July, 1888	50.00
14	54	W. C. Frye	do	34.00
15	55	Wm. H. Lovell	Miscellaneous field expenses	41.79
15	56	G. L. Johnson	Traveling expenses	8.36
16	57	Robt. D. Cummin	Miscellaneous field expenses	80.75
17	58	Henry Ulke, jr	Traveling expenses	10.85
18	59	C. C. Bassett	Miscellaneous field expenses	65.22
18	60	J. L. Smith	Field material	22.00
27	61	W. H. Lovell	Miscellaneous field expenses	98.26
31	62	Pay-roll of employés	Services, August, 1888	429.60
31	63	E. B. Clark	do	75.80
31	64	Jos. H. Wheat	do	50.50
31	65	J. H. Jennings	do	84.20
31	66	R. H. Stuart	do	50.00
31	67	Wm. Kramer	do	70.80
31	68	J. W. Thom	do	50.00
31	69	John D. Black	do	50.00
31	70	E. W. F. Natter	do	134.80
31	71	G. E. Hyde	do	50.00
31	72	Jeremiah Ahern	do	84.20
31	73	C. J. Akin	do	60.00
31	74	Willard D. Johnson	Services, August, 1888	151.60
31	75	F. P. Gulliver	do	50.00
31	76	Robt. D. Cummin	do	101.10
31	77	Lawson Sanford	do	50.00
31	78	Frank Sutton	do	75.80

Abstract of disbursements made by Fielding Burnes, etc.—Continued.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1888.				
Aug. 31	79	R. H. Hale	Services, August, 1888	$75.00
31	80	Henry Ulke, jr	do	41.93
31	81	Charles C. Bassett	do	84.20
31	82	James Longstreet, jr	do	50.50
31	83	W. R. Atkinson	do	75.00
31	84	E. G. Kennedy	do	50.00
31	85	Wm. H. Lovell	do	84.20
31	86	G. L. Johnson	do	50.00
31	87	J. B. Beers & Co	Field material	8.00
Sept. 4	88	C. C. Bassett	Miscellaneous field expenses	86.62
4	89	W. A. Atkinson	do	100.45
4	90	Jeremiah Ahern	do	71.69
4	91	W. H. Lovell	do	82.80
5	92	Willard D. Johnson	do	163.55
7	93	E. W. F. Natter	do	119.07
7	94	do	Traveling expenses	50.72
7	95	Robt. D. Cummin	Miscellaneous field expenses	91.60
11	96	Frank Sutton	do	86.87
11	97	Sumner H. Bodfish	Traveling expenses	31.10
13	98	Robt. D. Cummin	do	6.90
13	99	Lawson Sanford	do	6.90
13	100	Frank Sutton	do	7.62
13	101	Jeremiah Ahern	do	3.63
17	102	Marcus Baker	do	76.79
18	103	Robt. D. Cummin	Miscellaneous field expenses	77.26
18	104	C. C. Bassett	do	62.00
19	105	Henry Ulke, jr	Traveling expenses	8.90
19	106	do	Services, September 1 to 15, 1888	25.00
20	107	S. S. Gannett	Traveling expenses	15.00
22	108	Charles C. Bassett	do	3.48
24	109	J. L. Smith	Field material	12.00
4	110	W. H. Lovell	Miscellaneous field expenses	51.50
4	111	Willard D. Johnson	do	84.66
4	112	do	Traveling expenses	10.73
30	113	Pay-roll of employés	Services, September, 1888	415.80
30	114	do	do	197.80
30	115	do	do	250.00
30	116	do	do	230.66
		Total		8,313.93

Abstract of disbursements made by R. R. Hawkins, special disbursing agent U. S. Geological Survey, during the first quarter of 1889.

1888.				
July 30	1	Goldberg, Bowen & Co	Field supplies	$55.81
30	2	A. Carlisle & Co	do	11.00
30	3	Geo. Spaulding & Co	Labels	7.50
30	4	Main & Winchester	Supplies	25.69
31	5	E. A. Schneider	Services, July, 1888	60.00
31	6	R. R. Hawkins	Cash expenditures	6.80
31	7	Pay-roll	Services, July, 1888	591.30
31	8	W. Lindgren	Field expenditures	47.50
31	9	George Phillips	Services, July, 1888	45.00
31	10	H. W. Turner	Field expenditures	89.85
Aug. 4	11	Frank Rader	Services, July, 1888	35.00
4	12	A. Carlisle & Co	Office and field supplies	10.00
8	13	W. Lindgren	Field expenditures	54.34
8	14	H. W. Turner	do	26.80
14	15	A. Lietz & Co	Level	22.75
22	16	W. Lindgren	Field expenditures	25.80
31	17	Pay-roll	Services, August, 1888	591.30
31	18	E. A. Schneider	do	60.00
Sept. 18	19	W. Lindgren	Field expenditures	26.50
18	20	George Phillips	Services, August, 1888	45.00
18	21	Frank Rader	do	35.00
19	22	H. W. Turner	Field expenditures	70.30
29	23	Pay-roll	Services, September, 1888	388.64
29	24	W. Lindgren	Field expenditures	49.80
29	25	E. A. Schneider	Services, September, 1888	60.00
29	26	G. W. Granniss	Rent of rooms	157.98
		Total		2,599.66

Abstract of disbursements made by A. O. D. Taylor, jr., special disbursing agent U. S. Geological Survey, during the first quarter of 1889.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1888.				
July 19	1	T. Nelson Dale	Traveling expenses	$20.31
19	2	H. L. Smyth	Field expenses	26.33
23	3	T. Nelson Dale	Traveling expenses	20.87
23	4	Adams Express Company	Express charges	4.00
24	5	H. L. Smyth	Field expenses	68.30
31	6	Raphael Pumpelly	Pay for July, 1888	337.00
31	7	T. Nelson Dale	......do	150.00
31	8	H. L. Smyth	......do	84.20
31	9	A. O. D. Taylor, jr	......do	101.10
31	10	W. J. Withrow	......do	38.70
31	11	Pay-roll	July, 1888	150.00
31	12	W. Beals, jr	Pay for July, 1888	40.00
31	13	T. Nelson Dale	Traveling expenses	26.35
Aug. 1	14	J. Eliot Wolff	Pay for July, 1888	75.00
2	15	A. Prescott Baker	Rent for July, 1888	50.00
3	16	Ben K. Emerson	Traveling expenses	73.99
7	17	W. Beals, jr	......do	18.90
7	18	J. Eliot Wolff	Field expenses	10.50
16	19	H. L. Smyth	......do	19.55
16	20	......do	......do	16.47
16	21	......do	......do	6.89
16	22	......do	Field subsistence	68.40
16	23	T. Nelson Dale	Traveling expenses	27.25
16	24	J. D. S. Packer	Team hire	45.00
17	25	J. Nelson Dale	Traveling expenses	20.50
17	26	Ben K. Emerson	Field supplies	7.55
17	27	Chas. S. Werrick	Traveling expenses	27.83
17	28	Joseph H. Perry	......do	27.50
23	29	H. L. Smyth	Field expenses	33.71
23	30	J. Eliot Wolff	Traveling expenses	44.00
27	31	T. Nelson Dale	......do	20.28
27	32	.....do	Field expenses	13.35
27	33	Ben K. Emerson	Pay for July, 1888	100.00
27	34	J. D. S. Packer	Team hire	4.50
31	35	Raphael Pumpelly	Pay for August, 1888	337.00
31	36	H. L. Smyth	......do	84.20
31	37	A. O. D. Taylor, jr	......do	101.10
31	38	T. Nelson Dale	......do	150.00
31	39	J. Eliot Wolff	......do	91.30
Sept. 4	40	Richard Bliss	Bibliographical work	38.40
12	41	J. A. Williams	Traveling expenses	18.15
		Total		2,598.48

Abstract of disbursements made by Arnold Hague, special disbursing agent U. S. Geological Survey, during the first quarter of 1889.

1888. Sept. 30	1	Arnold Hague	Traveling expenses	$53.50

Abstract of disbursements made by Jno. D. McChesney, Chief Disbursing Clerk, U. S. Geological Survey, during the second quarter of 1889.

1888.				
Oct. 12	1	Bailey Willis	Field expenses	$44.47
12	2	Z. D. Gilman	Laboratory supplies	26.86
12	3	.....do	Supplies for illustrations	52.25
12	4	Bailey Willis	Services, September, 1888	195.60
9	5	I. C. Russell	......do	163.00
12	6	......do	Field expenses	82.15
12	7	H. McDeaderick	Services, September, 1888	60.00
12	8	Wm. B. Clark	......do	90.00
5	9	Albert Williams, jr	Services, July 2 to August 7, 1888	160.00
16	10	Walter C. Mitchell	Services, October 1 to 8, 1888	5.65
16	11	Z. D. Gilman	Supplies for illustrations	121.28
16	12	Adams Express Company	Freight charges	156.25
16	13	O. C. Marsh	Services, August, 1888	337.00
16	14	.....do	Services, September, 1888	326.00
16	15	A. Hermann	Services, July 1 to September 30, 1888.	239.19
16	16	F. A. Bostwick	....do	239.19

Abstract of disbursements made by Jno. D. McChesney, etc.—Continued.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1888. Oct. 16	17	R. W. Westbrook	Services, July 1 to September 30, 1888.	$180.00
16	18	G. Baur	Services, August, 1888	150.00
16	19	do	Services, September, 1888	150.00
16	20	Fred Brown	Services, July, 1888	140.00
16	21	do	Services, August, 1888	140.00
16	22	H. Gibb	do	60.00
16	23	do	Services, September, 1888	60.00
16	24	F. Berger	Services, August, 1888	80.00
16	25	do	Services, September, 1888	80.00
16	26	L. P. Bush	Services, August, 1888	50.00
16	27	do	Services, September, 1888	50.00
16	28	M. P. Felch	Services, July, 1888	170.00
16	29	do	Services, August, 1888	170.00
16	30	O. A. Peterson	do	55.00
16	31	do	Services, September, 1888	55.00
16	32	W. H. Burwell	Services, August, 1888	55.00
16	33	do	Services, September, 1888	55.00
16	34	J. B. Hatcher	Services, August, 1888	200.00
16	35	L. Lamothe	do	50.00
17	36	Collier Cobb	Traveling expenses	24.10
17	37	Lawrence Thompson	do	23.00
17	38	do	do	21.45
17	39	I. C. Russell	do	195.03
17	40	Carlisle, Stevens & Co	Subsistence, etc	7.81
17	41	do	do	47.43
17	42	C. Willard Hayes	Cash paid for expenses	101.89
17	43	Charles S. Cudlip	Supplies for illustrations	121.30
17	44	National Press Intelligence Co	Newspaper clippings	11.55
17	45	Chesapeake and Ohio R. R	Transportation of assistants	13.20
17	46	J. H. Ropes	Services, August, 1888	45.00
17	47	Robert Robertson	Services, September, 1888	60.00
17	48	Warren Upham	do	97.80
17	49	Chas. H. Cherry	do	27.00
17	50	J. S. Stone	Services, July 15 to August 31, 1888	75.00
17	51	S. Griswold	do	75.00
18	52	Robert T. Hill	Traveling expenses	143.10
16	53	R. S. Tarr	do	96.62
18	54	do	Services, September, 1888	50.00
18	55	John McCosker	Shoeing and field supplies	36.00
18	56	Arthur Keith	Cash paid for supplies	72.12
18	57	Samuel L. Penfield	Services, July 1 to September 30, 1888.	250.00
18	58	Chas. S. Cudlip	Supplies for illustrations	210.04
18	59	Geo. T. Quinby	Traveling expenses	49.25
18	60	do	do	97.55
18	61	Ira Sayles	do	62.29
18	62	T. Marshall Smith	do	14.47
18	63	D. McClelland	Topographic supplies	8.00
19	64	Nelson H. Darton	Traveling expenses	155.04
19	65	Pay-roll of employés	Services, September, 1888	604.80
19	66	Sam P. Barbee	Rent of store-room	37.50
19	67	F. B. Bull	Services, October 1 to 12, 1888	19.35
19	68	E. H. Hill	Services, ranching animals	24.00
19	69	Chas. H. Cherry	Services, October 8 to 11, 1888	10.00
19	70	C. A. White	Traveling expenses	238.05
20	71	Chas. D. Loughrey	Services, August 4 to October 4, 1888.	120.00
20	72	Noah R. King	do	100.00
20	73	John B. Bean	Hire of transportation	300.00
20	74	James Torristell	Hire of transportation and services.	213.00
20	75	Baltimore and Ohio R. R	Transportation of assistants	83.75
20	76	Pennsylvania R. R	do	87.50
20	77	Julius Bien & Co	Copy of Geological and Topographical Atlas.	289.20
20	78	C. Whitman Cross	Traveling expenses	130.49
20	79	do	Field expenses	35.73
22	80	Chas D. Walcott	Services, September, 1888	195.60
22	81	W. S. Bayley	Traveling expenses	102.31
22	82	do	do	104.05
23	83	C. E. Dutton	do	15.70
23	84	Chas. W. Richmond	do	52.75
23	85	A. H. Brown	Services, October 1 to 17, 1888	52.50
23	86	Geo. W. Knox	Freight	51.94
23	87	H. R. Geiger	Traveling expenses	86.77
24	88	S. J. Haislett	Field supplies	32.00
24	89	L. G. Eakins	Traveling expenses	61.00
25	90	Lewis S. Hayden	Publications	25.00
25	91	Eric M. Noble	Services, August 30 to October 3, 1888.	56.00
27	92	R. T. Hill	Traveling expenses	66.65
27	93	A. C. Peale	do	95.47
27	94	A. H. Thompson	do	155.54

Abstract of disbursements made by Jno. D. McChesney, etc.—Continued.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1888.				
Oct. 30	95	C. D. White	Traveling expenses	$61.55
31	96	C. P. Sinnott	Services, September, 1888	40.00
31	97	F. W. Geiger	Services, October, 1888	60.00
31	98	H. R. Geiger	do	126.40
31	99	I. C. White	do	202.20
31	100	Ira Sayles	do	117.90
31	101	Lawrence C. Johnson	do	117.90
31	102	S. H. Bodfish	do	168.50
31	103	Leo Lesquereux	do	75.00
31	104	J. Henry Blake	do	151.60
31	105	A. F. Dunnington	do	134.80
31	106	Geo. W. Shutt	do	252.70
31	107	G. F. Becker	do	337.00
31	108	W. H. Melville	do	168.50
31	109	O. C. Marsh	do	337.00
31	110	L. P. Bush	do	50.00
31	111	W. H. Burwell	do	55.00
31	112	O. A. Peterson	do	55.00
31	113	G. Baur	do	150.00
31	114	F. Berger	do	80.00
31	115	H. Gibb	do	70.00
31	116	J. B. Hatcher	Services, September, 1888	200.00
31	117	do	Services, October, 1888	200.00
31	118	Robert Robertson	Services, October 1 to 29, 1888	56.13
31	119	Pay-roll of employés	Services, October, 1888	336.60
31	120	do	do	160.80
31	121	do	do	925.60
31	122	do	do	1,128.80
31	123	do	do	183.22
31	124	do	do	2,173.30
31	125	do	do	508.90
31	126	do	do	1,211.00
31	127	do	do	2,373.25
31	128	do	do	1,306.34
31	129	G. K. Gilbert	do	337.00
31	130	D. T. Day	do	202.20
31	131	Jno. H. Renshawe	do	210.60
31	132	Bailey Willis	do	202.20
31	133	H. McDeaderick	do	64.00
31	134	C. R. Van Hise	do	202.20
31	135	Geo. E. Luther	do	100.00
31	136	F. J. Harriman	do	21.80
Nov. 2	137	M. P. Felch	Services, September and October, 1888.	340.00
2	138	Pay-roll of employés	Services, October, 1888	158.86
2	139	do	do	195.80
2	140	G. E. Verrill	Traveling expenses	39.15
2	141	Josiah Pierce, jr	do	39.25
2	142	H. M. Wilson	do	16.25
2	143	do	do	12.75
2	144	Robert Robertson	do	74.75
5	145	C. L. Whittle	do	130.09
5	146	Robert Robertson	do	19.51
5	147	David T. Day	do	46.16
5	148	C. Whitman Cross	do	166.45
6	149	Geo. H. Eldridge	Miscellaneous field expenses	116.19
6	150	Western Union Telegraph Co.	Telegrams	25.36
7	151	Baltimore and Ohio R. R	Freight charges	8 78
6	152	do	Transportation of assistants	654.30
6	153	N. S. Shaler	Services, October, 1888	270.00
6	154	W. M. Fontaine	do	168.50
6	155	E. E. Jackson & Co	Laboratory supplies	5.28
6	156	do	Topographic supplies, etc	201.50
6	157	C. Willard Hayes	Field expenses	67.02
6	158	C. P. Sinnott	Traveling expenses	39.13
6	159	Alpheus Hyatt	do	49.75
6	160	J. B. Woodworth	Services, October, 1888	50.00
6	161	Atchison, Topeka and Santa Fé R. R.	Transportation of assistants	29.09
6	162	Missouri Pacific R. R	do	3.00
6	163	Buffalo Dental Manufacturing Company.	Laboratory supplies	15.00
6	164	Emile Greiner	do	7.50
8	165	S. F. Emmons	Services, September and October, 1888.	663.00
9	166	Geo. H. Williams	Services, October, 1888	65.00
9	167	W. S. Bailey	do	67.50
9	168	Aug. F. Foerste	Services, September and October, 1888.	83.87

Abstract of disbursements made by Jno. D. McChesney, etc.—Continued.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1888.				
Nov. 12	169	J. S. Newberry	Services, July, August, and September, 1888.	$900.00
12	170	R. S. Tarr	Services, October, 1888	50.00
12	171	.....do	Services, November, 1888	11.66
12	172	......do	Traveling expenses	40.81
12	173	Chas. S. Cudlipp	Material for illustrations	154.54
14	174	Sparks Brothers	18 horses	2,358.00
14	175	Asken Bros	26 horse blankets	105.00
14	176	Missouri Pacific R. R	Transportation of assistants	30.30
15	177	Northern Pacific R. R	......do	93.50
15	178	Quartermaster's Department, U. S. Army.	Tents	302.91
15	179	Keuffel & Esser	Instruments	23.36
15	180	Fred Brown	Services, September 1 to October 31, 1888.	280.00
15	181	W. S. Bailey	Traveling expenses	142.19
15	182	August Frederick Foerste	Traveling expenses	64.32
15	183	C. H. Pond	Dating stamp	14.50
16	184	Chas. D. Walcott	Services, October, 1888	202.20
17	185	W. T. Griswold	Traveling expenses	144.87
17	186	Fauth & Co	Instruments	450.00
19	187	C. E. Dutton, jr	Services, October 1 to 18, 1888	40.00
20	188	E. R. Rail	Field material, etc	616.11
20	189	D. G. Kitzmeyer	......do	441.65
20	190	D. Kaiser	Subsistence supplies	67.05
20	191	G. T. Davis	......do	109.05
20	192	W. B. Clark	Services, October, 1888	90.00
20	193	Bailey Willis	Miscellaneous field supplies	35.88
20	194	H. M. Wilson	......do	96.05
20	195	......do	Field material	387.00
20	196	......do	Traveling expenses	20.00
20	197	Pay-roll of employés	Services, October, 1888	20.79
20	198	C. Willard Hayes	Traveling expenses	66.00
Oct. 27	199	A. C. Peale	......do	113.20
Nov. 21	200	W. J. McGee	......do	31.00
21	201	Warren Upham	Services, October, 1888	101.10
22	202	Thos. Parry	Services, November 1 to 19, 1888	22.16
22	203	R. S. Tarr	Traveling expenses	17.90
22	204	Geo. T. Quinby	......do	17.35
22	205	Columbus Freeman	......do	16.55
22	206	Wm. B. Lane	Services, November 1 to 19, 1888	31.66
22	207	Richard E. Edes	Traveling expenses	19.70
22	208	Erasmus Haworth	......do	98.12
22	209	Albert Williams	Services, October 1 to November 21, 1888.	220.00
22	210	Henry J. Green	Instruments and repairs	835.60
22	211	Pennsylvania R. R	Transportation of assistants	59.50
22	212	Arthur Keith	Traveling expenses	4.75
23	213	......do	......do	3.25
23	214	......do	......do	18.40
23	215	Ira Sayles	......do	42.86
23	216	......do	......do	20.00
23	217	J. H. Boring	......do	9.25
23	218	......do	......do	24.33
23	219	G. T. Davis	Field subsistence, etc	52.97
23	220	Josiah Pierce, jr	Field expenses	24.79
23	221	W. D. Torreyson	Field material, etc	134.00
23	222	G. E. Verrill	Field expenses, etc	32.90
24	223	H. M. Wilson	Field expenses	185.08
24	224	Wm. L. Ford	Laboratory supplies	7.50
27	225	John R. Proctor	Services, July 1 to November 27, 1888.	230.00
Dec. 3	226	W. F. Hillebrand	Traveling expenses	547.71
Nov. 30	227	O. C. Marsh	Salary, November, 1888	326.00
30	228	O. A. Peterson	......do	55.00
30	229	H. Gibb	......do	70.00
30	230	W. H. Burwell	......do	55.00
30	231	J. B. Hatcher	......do	200.00
30	232	G. Baur	......do	150.00
30	233	L. P. Bush	......do	50.00
30	234	F. Berger	......do	80.00
30	235	Geo. W. Shutt	......do	244.60
30	236	W. H. Melville	......do	163.00
30	237	G. F. Becker	......do	326.00
30	238	Jno. H. Renshawe	......do	203.80
30	239	A. F. Dunnington	......do	130.40
30	240	H. R. Geiger	......do	122.20
30	241	F. W. Geiger	......do	60.00
30	242	H. R. Geiger	Traveling expenses	60.01

Abstract of disbursements made by Jno. D. McChesney, etc.—Continued.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1888.				
Nov. 30	243	Chas. Darwin	Traveling expenses	$17.10
30	244	R. S. Swift	18 mules	2,421.00
30	245	Wm. M. Fontaine	Salary, November, 1888	163.00
30	246	Lawrence C. Johnson	do	114.20
30	247	Leo Lesquereux	do	75.00
30	248	J. Henry Blake	do	146.80
30	249	I. C. White	do	195.60
30	250	Ira Sayles	do	114.20
30	251	David T. Day	do	195.60
30	252	Lawrence Thompson	do	125.00
30	253	Chas. S. Prosser	do	83.33
30	254	Pay-roll of employés	do	2,730.80
30	255	do	do	1,192.40
30	256	do	do	1,092.40
30	257	do	do	687.80
30	258	do	do	1,173.00
30	259	do	do	110.00
30	260	do	do	2,286.92
30	261	do	do	1,272.32
30	262	W. D. Castle	Supplies	20.10
Dec. 3	263	Robert Robertson	Services, October 30 to 31, 1888	3.87
3	264	S. H. Bodfish	Services, November, 1888	163.00
3	265	Geo. H. Williams	do	110.00
3	266	C. M. Boss	Services, October, 1888	40.00
3	267	Wisconsin Typewriter Company	Geological supplies	90.00
3	268	Lawrence C. Johnson	Traveling expenses	44.37
3	269	C. P. Sinnott	do	18.56
3	270	S. E. Ladd	do	32.25
3	271	do	do	40.89
4	272	C. W. Hall	Services, October 1 to November 30, 1888.	58.50
4	273	Robert Hay	Services, November, 1888	70.00
4	274	B. W. Gillis	do	13.00
4	275	C. R. Van Hise	do	195.60
4	276	Geo. E. Luther	do	100.00
4	277	Baltimore and Ohio R. R	Transportation of assistants	28.00
4	278	do	Freight charges	4.05
4	279	Denver and Rio Grande R. R	Transportation of assistants	18.73
4	280	C. Willard Hayes	Field expenses	54.21
4	281	Smedley Bros. & Co	Freight charges	3.79
4	282	Lawrence C. Johnson	Traveling expenses	96.98
5	283	J. B. Woodworth	Services, November, 1888	50.00
5	284	Northern Pacific R. R	Transportation of assistants	260.45
5	285	Texas, Santa Fé and Northern R. R.	do	7.50
5	286	N. S. Shaler	Services, November, 1888	260.00
5	287	Z. D. Gilman	Chemical supplies	12.08
5	288	do	Topographic supplies	163.19
5	289	Quartermaster's Department, U. S. Army.	do	16.02
5	290	Adams Express Co	Freight charges	80.55
6	291	John Schultzback	Instruments	83.00
6	292	Edward J. Hennon	Laboratory supplies	10.00
6	293	do	Repairs	11.30
8	294	Alexander Davis	Traveling expenses	2.78
8	295	Chas. D. Walcott	do	15.00
8	296	C. Kirchoff, jr	Services, July 1 to October 3, 1888	200.00
8	297	George F. Kuntz	do	50.00
8	298	Wm. P. Rust	Services, July 1 to October 31, 1888	315.00
8	299	do	Services, November, 1888	65.00
8	300	J. S. Topham	Material for illustrations	10.00
8	301	St. Louis and San Francisco Rwy	Transportation of assistants	10.10
10	302	J. S. Diller	Salary, November, 1888	163.00
10	303	Hume, Cleary & Co	Supplies for illustrations	1.75
10	304	Melville Lindsay	do	1.99
10	305	Fred A. Schmidt	Topographic supplies	49.00
10	306	W. H. Morrison	*Paleontologic* supplies	18.00
10	307	Eimer & Amend	Laboratory supplies	131.45
10	308	do	do	14.18
10	309	L. Feuchtwonger & Co	do	13.00
10	310	Emil Greiner	do	11.25
10	311	J. & H. Birge	Chemical supplies	4.39
11	312	S. F. Emmons	Traveling expenses	100.00
11	313	do	do	144.00
11	314	do	do	162.50
11	315	C. Whitman Cross	do	166.65
11	316	Geo. H. Eldridge	do	182.10
11	317	Frank Leverett	Services, September 17 to November 30, 1888.	315.00 115.22

Abstract of disbursements made by Jno. D. McChesney, etc.—Continued.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1888.				
Dec. 11	318	Arthur Keith	Miscellaneous expenses	
11	319	Warren Upham	Services, November, 1888	$97.80
11	320	Utah Central Rwy	Transportation of assistants	19.00
12	321	Chicago, Milwaukee and St. Paul R. R.	......do	58.00
12	322	Baltimore and Ohio R. R	Freight charges	75
12	323	......do	......do	4.73
12	324	Pay-roll of employés	Services, November, 1888	32.67
12	325	G. K. Gilbert	Traveling expenses	46.41
12	326	......do	......do	6.95
14	327	Wm. L. Ford	Laboratory supplies	2.50
14	328	L. H. Schneider's Son	Laboratory and topographic supplies.	66.35
14	329	Geo. Ryneal, jr	Supplies	303.67
14	330	W. B. Smith	Services, November, 1888	7[illegible].00
14	331	James Storr	Services, October 1 to 25, 1888	40.32
17	332	J. S. Diller	Field expenses	46.45
17	333	A. H. Thompson	Services, November, 1888	220.20
17	334	Chain, Hardy & Co	Geological supplies	20.43
17	335	W. J. Westmann	Services, October and November, 1888	8.00
17	336	Peter McCourt	Rent of room	40.00
17	337	W. L. Wilson	Services, November 26 to 28, 1888	9.00
17	338	Lawrence Thompson	Traveling expenses	19.00
17	339	Wm. B. Clark	Services, November, 1888	130.00
18	340	United States Express Company	Freight charges	236.90
18	341	M. P. Felch	Services, November 1888	170.00
18	342	H. S. Williams	Services, August 1 and November 30, 1888.	497.20
18	343	August F. Foerste	Services, November, 1888	35.00
18	344	Jos. D. Weeks	Services, July 1 to October 3, 1888	500.00
18	345	R. T. Hill	Services, November, 1888	60.00
18	346	Eimer & Amend	Laboratory supplies	37.93
18	347	American Tool and Machine Company.	......do	5.75
19	348	Giles, Lith & Liberty Printing Company.	Drawings	12.50
19	349	Eric M. Noble	Services, November 1 to 10, 1888	6.75
19	350	Bailey Willis	Field expenses	13.05
19	351	Buffalo Dental Manufacturing Company.	Laboratory supplies	2.50
19	352	Ernest Kübel	Repairs to office furniture	6.00
19	353	Geo. H. Eldridge	Topographic supplies	9.00
19	354	International and Great Northern R. R.	Transportation of assistants	16.65
20	355	W. S. Bailey	Services, November, 1888	80.00
20	356	Unexcelled Fire-works Company	Pasteboard tubes	49.50
20	357	C. H. Pond	Irrigation supplies	14.00
21	358	James C. Hooe	Services, July 1 to November 15, 1888	30.00
21	359	G. E. Ladd	Services, August 6 to November 30, 1888.	153.55
21	360	......do	Traveling expenses	52.60
21	361	Edward Kübel	Cash paid for supplies, etc	13.57
21	362	Robert Leitch & Son	Topographic supplies	40.01
21	363	H. L. Smyth	Salary, November, 1888	81.60
22	364	J. D. Fogg, jr	Supplies for library	.70
22	365	Geo. N. Rider	Publications	7.00
22	366	Samuel L. Penfield	Services, October. 1888	50.00
22	367	J. B. Smith & Co	Field subsistence	24.26
24	368	Bailey Willis	Traveling expenses	46.30
24	369	Albert Williams	Services, December 10 to 22, 1888	35.00
27	370	Western Union Telegraph Co	Telegrams	81.28
27	371	Library Bureau	Letter-file case	77.00
27	372	Alfred C. Lane	Traveling expenses	30.88
27	373	Missouri Pacific R. R	Transportation of assistants	25.75
27	374	......do	......do	6.75
27	375	Houghton, Mifflin & Co	Publications	6.50
27	376	Melville Lindsay	Laboratory supplies	20.64
27	377	Chicago, Burlington and Quincy R. R.	Transportation of assistants	26.55
27	378	S. J. Haislett	Tents	40.00
27	379	Wyckoff, Seamans & Benedict	Type-writer	85.00
27	380	J. Eliot Wolff	Geologic field expenses	17.43
27	381	E. Morrison	Supplies for mineral resources	9.73
31	382	W. H. Melville	Services, December, 1888	168.50
31	383	Geo. F. Becker	......do	337.00
31	384	Geo. W. Shutt	......do	252.70
31	385	W. M. Fontaine	......do	168.50
31	386	Ira Sayles	......do	117.90
31	387	J. Henry Blake	......do	151.60

Abstract of disbursements made by Jno. D. McChesney, etc.—Continued.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1888.				
Dec. 31	388	Leo Lesquereux	Services, December, 1888	$75.00
31	389	I. C. White	do	202.20
31	390	H. L. Smyth	do	84.20
31	391	Buffalo Dental Manufacturing Company.	Laboratory supplies	2.00
31	392	Chas. H. Kraft	do	50.90
31	393	D. Appleton & Co	Publications	1.00
31	394	Geo. Cartner	do	7.00
31	395	Publisher of Sabin's Dictionary	do	4.00
31	396	V. Schoonmaker	Topographic material	225.00
31	397	E. H. Hill	Care and forage of animals	92.69
31	398	Sam. P. Barbee	Storage of property	42.00
31	399	L. P. Bush	Services, December, 1888	50.00
31	400	G. Baur	do	150.00
31	401	W. H. Burwell	do	55.00
31	402	O. A. Peterson	do	55.00
31	403	J. B. Hatcher	do	200.00
31	404	H. Gibb	do	70.00
31	405	A. Hermann	Services, October 1 to December 31, 1888.	250.00
31	406	F. Berger	Services, December, 1888	80.00
31	407	T. A. Bostwick	Servicees, October 1 to December 31, 1888.	250.00
31	408	O. C. Marsh	Services, December, 1888	337.00
31	409	J. B. Woodward	do	50.00
31	410	N. S. Shaler	do	260.00
31	411	W. B. Smith	do	75.00
31	412	Geo. E. Luther	do	100.00
31	413	C. R. Van Hise	do	202.20
31	414	Lucas Harvey	Services, September 21 to November 30, 1888.	138.97
31	415	Pay-roll of employés	December, 1888	2,468.30
31	416	do	do	1,126.30
31	417	do	do	1,557.40
31	418	do	do	1,211.00
31	419	do	do	794.43
31	420	do	do	1,488.90
31	421	do	do	156.13
31	422	Harriet Biddle	Services October, November, and December, 1888.	30.00
31	423	R. W. Tripp	Geological specimens	8.00
31	424	State of California	Publications	27.50
31	425	W. B. Smith	Traveling expenses	60.35
31	426	J. W. Queen & Co	Laboratory material	9.95
31	427	do	do	276.70
31	428	do	do	12.22
31	429	do	Geological material, etc	199.23
31	430	Atchison, Topeka and Santa Fé R. R.	Transportation of assistants	35.45
31	431	Chicago and Northwestern Rwy.	do	12.50
31	432	Richmond and Danville R. R	do	396.15
31	433	Pay-roll of employés	Services, December, 1888	3,369.70
31	434	Wm. B. Clark	do	130.00
		Total		81,466.10

SALARIES, OFFICE OF THE DIRECTOR.

1888.				
Oct. 31	1	Pay-roll of employés	Services, October, 1888	$2,993.20
Nov. 30	2	do	Services, November, 1888	2,898.60
Dec. 31	3	do	Services, December, 1888	2,993.20
		Total		8,885.00

Abstract of disbursements made by Mark B. Kerr, disbursing agent U. S. Geological Survey, during the second quarter of 1889.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1888.				
Oct. 1	1	E. M. Hasbrouck	Field expenses	$6.00
1	2	Arthur P. Davis	do	63.33
1	3	C. H. Fitch	do	36.55
1	4	H. S. Wallace	do	42.80
1	5	H. M. Wilson	do	30.45
1	6	do	do	43.45
1	7	A. F. Dunnington	do	34.45
8	8	do	do	33.70
8	9	Redick H. McKee	do	11.65
8	10	do	do	82.78
13	11	Pay-roll (Wilson)	Services, September, 1888	221.80
13	12	Pay-roll (Dunnington)	do	270.00
13	13	Pay-roll (McKee)	do	307.80
13	14	Pay-roll (Douglas)	do	488.00
13	15	Pay-roll (Tweedy)	do	335.40
13	16	Pay-roll (Davis)	do	814.30
13	17	Pay-roll (Goode)	do	345.20
13	18	Pay-roll (Fitch)	do	340.40
13	19	Pay-roll (Wallace)	do	334.20
13	20	Pay-roll (Griswold)	do	325.80
13	21	Pay-roll (Perkins)	do	286.60
13	22	Pay-roll (Diller)	do	378.00
13	33	Geo. Wolsey	Subsistence	26.92
13	24	A. F. Dunnington	Field expenses	40.10
13	25	Redick H. McKee	do	46.35
13	26	H. M. Wilson	do	46.10
13	27	C. H. Fitch	do	43.06
13	28	E. M. Hasbrouck	do	33.88
13	29	H. W. Noel	Services; September, 1888	5.00
13	30	do	do	24.00
13	31	R. U. Goode	Field expenses	114.50
13	32	do	Traveling expenses	18.75
13	33	E. M. Douglas	Field expenses	176.10
13	34	Frank Tweedy	do	70.75
13	35	W. T. Griswold	do	79.57
13	36	do	do	60.76
13	37	E. C. Ryan	Services, September, 1888	60.00
13	38	do	Board and lodging	30.00
13	39	Albert Dukes	Services, September, 1888	19.50
13	40	J. W. Miller	Field supplies	19.35
13	41	do	do	22.06
13	42	Reaser Bros	do	185.12
13	43	do	do	92.50
13	44	J. S. Diller	Field expenses	392.17
13	45	Mark B. Kerr	Services	146.80
13	46	do	Field expenses	3.00
13	47	Paul Holman	Services, September, 1888	68.40
13	48	E. T. Perkins, jr	Field expenses	185.55
13	49	W. R. Mayfield	Services, October, 1888	9.67
13	50	A. F. Dunnington	Field expenses	55.75
13	51	Redick H. McKee	do	60.31
13	52	Dan D. Calkins	do	54.00
13	53	W. T. Griswold	do	64.25
15	54	Paul Holman	do	3.45
15	55	A. Leitz & Co.	Repairs, etc	52.00
15	56	J. W. Miller	Field supplies	30.88
16	57	A. F. Dunnington	Field expenses	59.65
17	58	R. H. McKee	do	63.94
17	59	do	do	45.27
18	60	Arthur P. Davis	do	74.87
19	61	R. H. Chapman	Services, September, 1888	81.60
21	62	R. Henry Phillips	Traveling expenses	22.25
22	63	Dan D. Calkins	Field expenses	43.25
25	64	H. M. Wilson	do	2.75
25	65	W. L. Tremble & Co	Forage	27.00
25	66	R. U. Goode	Field expenses	110.77
25	67	H. S. Wallace	do	100.75
25	68	H. M. Wilson	do	116.86
27	69	F. G. Pratt & Co	Field subsistence	22.21
27	70	A. E. Laudenslager	do	27.49
27	71	G. W. Bond & Co	Field supplies	10.45
27	72	Arthur P. Davis	Field expenses	49.35
27	73	A. F. Dunnington	do	73.55
27	74	C. H. Fitch	do	64.17
31	75	Paul Holman	Services, October, 1888	70.80
31	76	Pay-roll (Perkins)	do	257.71
31	77	E. C. Ryan	do	60.00
31	78	Pay-roll (McKee)	do	288.93
31	79	E. T. Perkins, jr	Field expenses	101.23

Abstract of disbursements made by Mark B. Kerr, etc.—Continued.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1888.				
Oct. 31	80	H. M. Wilson	Field expenses	$74.50
31	81	do	Services, October, 1888	92.39
31	82	Pay-roll (Davis)	do	801.43
Nov. 5	83	W. Lindgren (Cal. Geology)	Traveling expenses	10.00
7	84	Pay-roll (Fitch)	Services, October, 1888	368.96
7	85	Pay-roll (Goode)	do	361.13
7	86	Pay-roll (Wallace)	do	346.64
7	87	Pay-roll (Diller, Cascade)	do	274.95
7	88	W. H. Noell	do	30.00
7	89	Pay-roll (Chapman)	do	357.73
8	90	Frank Tweedy	Field expenses	69.62
8	91	Pay-roll (Tweedy)	Services, October, 1888	348.48
8	92	Pay-roll (Dunnington)	do	258.48
8	93	E. C Ryan	Field expenses	25.26
8	94	Redick H. McKee	do	31.25
8	95	A. F. Dunnington	do	44.55
8	96	Jas. E. Shelley	do	20.05
8	97	H. W. Turner (California)	do	24.24
8	98	J. Karher & Co.	Field repairs, etc	19.50
8	99	A. E. Laudenslager	Field subsistence	86.43
8	100	Harry H. Hackett	Services, October 30, 1888	3.23
8	101	Geo. R. Hargadine	Pasturage	70.00
8	102	Dan D. Calkins	Field expenses	20.50
8	103	Arthur Bishoff	Field material	37.88
8	104	Geo. Chase	Field repairs	66.10
8	105	Reaser Bros	Field subsistence	146.28
8	106	W. H. McKenzie	Field supplies	61.95
8	107	Redick H. McKee	Field expenses	40.95
8	108	A. F. Dunnington	do	34.00
8	109	Pay-roll (Griswold)	Services, October, 1888	339.99
8	110	W. T. Griswold	Field expenses	62.05
5	111	Mark B. Kerr	Services, October, 1888	151.60
13	112	A. F. Dunnington	Field expenses	29.90
14	113	E. M. Sleator	One map	1.00
15	114	H. S. Wallace	Field expenses	47.28
15	115	Frank E. Gove	Services, July, 1888	23.16
15	116	Philip S. Levills	Traveling expenses	25.25
15	117	E. M. Hasbrouck	Field expenses	46.05
15	118	R. H. Chapman	do	47.66
15	119	Arthur P. Davis	do	85.15
15	120	Van Arsdell & Co	Forage	24.90
16	121	A. F. Dunnington	Field expenses	63.60
17	122	R. U. Goode	do	132.74
17	123	A. T. Kyle, jr. (Cascade)	Pasturage	48.75
17	124	E. C. Landers	Forage	250.00
21	125	Sparks Bros	do	14.50
21	126	A. Holmes	Services, November 1 to 10, 1888	15.00
21	127	C. H. Fitch	Field expenses	9.25
21	128	do	Traveling expenses	60.65
22	129	Redick H. McKee	Field expenses	42.00
22	130	Arthur P. Davis	do	57.20
28	131	A. H. Thompson	Traveling expenses	191.50
28	132	C. H. Fitch	Services, November, 1888	146.80
28	133	E. T. Perkins, jr	do	114.20
28	134	Josiah Pierce, jr	Field expenses	73.06
28	135	G. E. Verrill	do	67.17
28	136	H. M. Wilson	do	51.89
30	*137			
28	138	Redick H. McKee	Field expenses	78.25
30	139	E. C. Ryan	Services, November, 1888	60.00
30	140	Arthur P. Davis	do	163.00
30	141	Charles W. Howell	do	60.00
30	142	Redick H. McKee	Field expenses	21.00
30	143	Pay-roll (McKee)	Services, November, 1888	177.40
30	144	Frank Senn	do	6.67
30	145	Harry H. Hackett	do	50.00
30	146	J. H. Boring	Services, October, 1888	45.16
30	147	H. W. Noell	Services, November, 1888	30.00
30	148	Pay-roll (Goode)	do	611.40
30	149	Pay-roll (Wallace)	do	390.40
30	150	Pay-roll (Wilson)	do	809.20
30	151	Wm. L. Maxwell	Traveling expenses	6.00
30	152	Dan D. Calkins	do	33.75
30	153	Wm. L. Maxwell	Services, October, 1888	20.32
30	154	Pay-roll (Becker)	Services, November, 1888	327.47
30	155	Pay-roll (McKee)	do	140.00
30	156	S. P. Johnson	Services, December, 1888	27.09
30	157	R. H. Chapman	Services, November, 1888	97.80

*(Withdrawn.) Paid by Jno. D. McChesney, Chief Disbursing Clerk, for November, 1888.

Abstract of disbursements made by Mark B. Kerr, etc.—Continued.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1888.				
Nov. 30	158	Alice M. Prouty	Services, December, 1888	$5.16
30	159	W. T. Griswold	Services, November, 1888	146.80
Dec. 15	160	David T. Day	Traveling expenses	61.65
15	161	Pay-roll (Davis)	Services, November, 1888	220.00
15	162	Pay-roll (Douglas)	do	547.96
15	163	Frank Tweedy	Traveling expenses	115.20
15	164	H. M. Wilson	Field expenses	72.12
15	165	do	Field supplies	5.00
15	166	H. S. Wallace	Field expenses	47.85
15	167	Chas. F. Urquhart	do	73.73
15	168	C. S. Swift	Services, November, 1888	39.00
15	169	Chas. W. Friend	do	19.00
15	170	H. A. Messenger	Pasturage	18.50
15	171	R. H. Chapman	Services, October, 1888	9.27
15	172	E. M. Douglas	Field expenses	81.35
15	173	G. W. Granniss	Rent, laboratory rooms	52.66
15	174	Pay-roll (Goode)	Services, December, 1888	60.47
15	175	R. U. Goode	Field expenses	125.85
15	176	Pay-roll (Davis)	Services, November, 1888	763.10
15	177	Mark B. Kerr	Field expenses	4.25
15	178	do	do	19.94
Nov. 30	179	do	Services, November, 1888	146.80
Dec. 15	180	Redick H. McKee	Field expenses	110.72
15	181	Harry A. Hackett	Services, December 3; 1888	4.84
15	182	Lincoln Martin	Field expenses	46.55
15	183	Jose D. Martinez	Forage	12.00
15	184	Lincoln Martin	Services, December, 1888	29.03
15	185	Houston Stephens	Services, December, 1888	14.51
15	186	H. S. Wallace	do	65.22
15	187	H. M. Wilson	Field expenses	39.67
15	188	G. T. Davis	Field subsistence, etc	99.14
15	189	A. F. Dunnington	Field expenses	2.50
15	190	do	Traveling expenses	129.75
15	191	H. M. Wilson	Field expenses	80.86
15	192	G. E. Verrill	do	36.00
15	193	Josiah Price, jr	do	51.53
15	194	Wm. Bolander	do	100.15
15	195	A. F. Dunnington	do	40.31
17	196	Wells, Fargo & Co	Expressage	5.75
17	197	Western Union Telegraph Co	Telegrams	2.65
17	198	do	do	11.77
17	199	do	do	16.48
17	200	do	do	4.50
17	201	do	do	9.22
17	202	Frank Reade	Services, November 15 to December 15, 1888.	62.00
17	203	Eimer & Amend	Laboratory supplies	44.05
17	204	J. S. Diller	Field expenses	10.00
17	205	Arthur P. Davis	Services, October, 1888	9.27
17	206	Paul Holman	Services, November, 1888	68.40
17	207	E. T. Perkins	Traveling expenses	135.25
17	208	G. E. Verrill	Field expenses	32.35
19	209	A. H. Thompson	Traveling expenses	180.00
20	210	Henry Gannett	do	132.90
23	211	Josiah Pierce, jr	Field expenses	37.93
23	212	Arthur P. Davis	do	76.02
23	213	R. H. Chapman	do	32.20
23	214	Thos. Clement	Storage	12.50
23	215	W. S. Montgomery	Pasturage	67.00
23	216	C. S. Swift	Services. December 1 to 10, 1888	15.00
23	217	Mark B. Kerr	Services, December, 1888	151.60
31	218	Pay-roll (Becker)	do	379.60
31	219	G. W. Granniss	Rent of laboratory rooms	55.00
31	220	R. U. Goode	Services, December, 1888	168.50
31	221	do	Traveling expenses	74.30
31	222	do	Field expenses	94.32
31	223	A. H. Thompson	Services, December, 1888	227.40
31	224	R. A. Chapman	do	101.10
31	225	Paul Holman	Traveling expenses	122.00
31	226	H. S. Wallace	Field expenses	28.49
31	227	do	do	12.95
31	228	do	Traveling expenses	63.75
31	229	James E. Shelley	do	62.50
31	230	Chas. F. Urquhart	do	59.00
31	231	do	Field expenses	32.49
19	232	R. R. Hawkins	Services, November, 1888	20.38
31	233	Pay-roll (Kerr)	Services, December, 1888	1,375.28
		Total		25,944.14

Abstract of disbursements made by C. D. Davis, special disbursing agent U. S. Geological Survey, during the second quarter of 1889.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1888.				
Oct. 8	1	W. H. Lovell	Field expenses	$121.80
8	2	C. C. Bassett	do	108.46
10	3	E. W. F. Natter	do	102.35
10	4	do	Traveling expenses	47.51
10	5	Marcus Baker	do	77.24
11	6	J. B. Beers & Co	Atlas	10.00
12	7	S. H. Bodfish	Field expenses	26.66
12	8	W. R. Atkinson	do	74.44
12	9	do	do	9.59
15	10	Rob't D. Cummin	Traveling expenses	13.78
15	11	Lawson Sanford	do	13.78
20	12	W. R. Atkinson	Field expenses	23.00
20	13	S. S. Gannett	do	55.75
22	14	Marcus Baker	do	18.97
25	15	C. C. Bassett	do	69.99
25	16	W. H. Lovell	do	106.36
25	17	R. S. Woodward	Traveling expenses	50.40
31	18	Pay-roll of employés	Services, October, 1888	319.06
31	19	do	do	468.75
31	20	do	do	339.23
31	21	do	do	273.51
31	22	do	do	278.00
31	23	do	do	317.10
Nov. 1	24	W. H. Lovell	Field expenses	41.50
5	25	Frank Sutton	do	86.80
7	26	do	Traveling expenses	6.32
7	27	F. P. Gulliver	Field expenses	63.13
7	28	W. H. Lovell	do	122.85
9	29	C. C. Bassett	do	159.56
9	30	E. W. F. Natter	do	90.04
9	31	do	Traveling expenses	54.47
9	32	Jeremiah Ahern	do	11.13
9	33	do	Field expenses	84.95
12	34	W. R. Atkinson	do	143.95
12	35	do	Traveling expenses	14.19
12	36	S. H. Bodfish	do	44.36
12	37	do	do	41.40
12	38	S. H. Bodfish	Miscellaneous field expenses	93.40
13	39	Charles C. Bassett	do	31.32
13	40	do	Traveling expenses	18.77
14	41	S. S. Gannett	Field expenses	111.40
15	42	P. H. Christie	Traveling expenses	39.95
16	43	S. S. Gannett	Field expenses	48.75
16	44	do	Traveling expenses	54.91
16	45	D. C. Harrison	do	16.50
17	46	R. M. Towson	Field expenses	39.20
17	47	Charles M. Yeates	Miscellaneous field expenses	173.29
17	48	D. C. Harrison	do	17.75
22	49	Morris Bien	do	156.84
22	50	Louis Nell	do	136.08
22	51	L. C. Fletcher	do	138.00
22	52	F. P. Metzger	Traveling expenses	10.25
23	53	E. C. Barnard	Miscellaneous field expenses	79.20
23	54	do	do	100.30
23	55	do	do	48.10
23	56	M. Hackett	do	173.67
26	57	R. O. Gordon	do	56.66
30	58	R. S. Thornton	Services, November, 1888	25.00
30	59	D. C. Harrison	do	97.80
30	60	A. B. Rivers	do	25.00
30	61	R. C. McKinney	do	97.80
30	62	V. T. Carmichael	do	25.00
30	63	R. M. Towson	do	97.80
30	64	Mrs. J. J. Whittle	do	25.00
30	65	R. Lee Longstreet	do	97.80
30	66	Pay-roll of employés	do	502.00
30	67	do	do	493.00
30	68	do	do	509.20
30	69	do	do	541.00
30	70	do	do	531.80
30	71	Fred. J. Knight	do	146.80
30	72	A. E. Murlin	do	97.80
30	73	J. M. Duncan	do	25.00
30	74	Louis Nell	Miscellaneous field expenses	176.87
30	75	Morris Bien	do	88.07
30	76	P. H. Christie	do	7.25
Dec. 3	77	E. S. Parker	Traveling expenses	23.40
3	78	R. C. McKinney	Field expenses	49.75

Abstract of disbursements made by C. D. Davis, etc.—Continued.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1888.				
Dec. 4	79	R. O. Gordon	Services, November, 1888	$97.80
4	80	M. E. Gordon	do	25.00
6	81	Clifford Arrick	Traveling expenses	2.00
6	82	Pay-roll of employés	Services, November, 1888	421.80
6	83	D. C. Harrison	Traveling expenses	57.30
7	84	L. C. Fletcher	do	100.45
7	85	do	Field expenses	226.32
7	86	A. E. Murlin	Traveling expenses	45.10
10	87	F. P. Metzger	do	124.05
10	88	R. McC. Micbler	do	38.26
10	89	R. O. Gordon	do	19.65
10	90	L. D. Brent	do	33.10
12	91	Louis Nell	do	72.45
12	92	John Boler	do	26.70
12	93	do	Services, December 1 to 7, 1888	6.78
12	94	R. O. Gordon	Field expenses	94.94
14	95	R. C. McKinney	do	30.00
14	96	J. D. Lincoln	Services, December, 1888	19.35
14	97	do	Traveling expenses	25.25
14	98	M. Hackett	do	105.15
14	99	George H. Lamar	do	25.55
14	100	George V. Davis	do	19.60
14	101	do	Services, December 1 to 10, 1888	9.68
14	102	R. C. McKinney	Traveling expenses	19.55
14	103	C. W. Goodlove	do	43.45
17	104	H. T. Irwin	do	17.40
17	105	Morris Bien	do	54.25
17	106	Nat. Tyler, jr	do	6.85
17	107	Shack Smith	Services, December 1 to 12, 1888	15.48
17	108	A. B. Rivers	Services, December 1 to 3, 1888	2.42
17	109	A. M. Neely	do	3.87
17	110	M. Hackett	Field expenses	166.73
18	111	Louis Nell	do	327.10
18	112	Mrs. J. J. Whittle	Services, December 1 to 6, 1888	4.84
18	113	J. M. Duncan	Services, December 1 to 12, 1888	9.68
18	114	V. T. Carmichael	Services, December 1 to 14, 1888	11.29
18	115	M. Spurlock	Services, December 1 to 17, 1888	16.45
18	116	L. Morgan	Services, December 1 to 15, 1888	19.35
18	117	Charles M. Yates	Traveling expenses	28.50
21	118	R. M. Towson	do	18.55
21	119	do	Field expenses	82.44
21	120	Charles M. Yates	do	185.70
21	121	Z. Dunn	Services, December 1 to 7, 1888	9.03
21	122	A. E. Wilson	Traveling expenses	28.50
22	123	W. Fletcher	do	27.30
22	124	do	Services, December 1 to 8, 1888	10.32
22	125	J. L. Bridwell	Services, December 1 to 22, 1888	28.39
22	126	E. C. Barnard	Traveling expenses	26.25
22	127	do	do	55.95
28	128	Louis Nell	Field expenses	27.65
31	129	Pay-roll of employés	Services, December, 1888	3,044.70
31	130	F. J. Chapman	Pasturage	16.59
31	131	Morris Bien	Field expenses	112.76
31	132	do	do	154.78
31	133	James G. Reaves	Pasturage and storage	49.85
31	134	P. P. Glover	Pasturage	50.00
31	135	W. R. Murphy	do	44.90
31	136	N. A. Morse	Storage	3.00
31	137	E. C. Barnard	Field expenses	314.30
31	138	John W. Price	Pasturage	42.90
		Total		15,825.21

Abstract of disbursements made by Anton Karl, special disbursing agent U. S. Geological Survey, during the second quarter of 1889.

1888.				
Oct. 17	1	J. C. McGuire	Traveling expenses	$19.50
16	2	Anton Karl	do	19.00
17	3	Louis William Mohun	do	19.25
16	4	W. H. Hyatt	Horseshoeing	6.00
16	5	do	Field materials	125.75
16	6	do	do	405.00
16	7	do	do	254.50
19	8	F. Morgan	Services, October 17 and 18, 1888	5.00

Abstracts and disbursements made by Anton Karl, etc.—Continued.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1888.				
Oct. 22	9	Willard D. Johnson	Traveling expenses	$24.25
22	10	William S. Post	do	19.25
22	11	W. B. Corse	do	18.50
22	12	Alexander C. Barclay	do	45.35
22	13	Samuel A. Foot	do	18.00
22	14	Perry Fuller	do	18.00
22	15	W. C. Hertman	Services, October 22, 1888	1.75
22	16	Willard D. Johnson	Camp equipment	680.10
23	17	W. C. Furst	Subsistence	63.00
23	18	W. H. Hyatt	Transportation	25.00
24	19	A. E. Finn	Subsistence	6.60
24	20	Willard D. Johnson	Camp equipment	189.14
24	21	do	Subsistence and camp equipment	188.87
27	22	John B. Karcher	do	10.50
27	23	E. Weaver	Transportation	9.00
30	24	Robert A. Farmer	Traveling expenses	18.85
30	25	Pay-roll	Services, October, 1888	487.68
30	26	do	do	270.09
30	27	J. W. Hays	Traveling expenses	21.10
30	28	W. H. Hyatt	Field material	242.75
Nov. 3	29	A. E. Finn	Subsistence	34.00
6	30	Willard D. Johnson	Camp equipment	390.93
7	31	D. C. Crawford	Subsistence	28.50
7	32	John T. Williams	Transportation	24.25
14	33	Willard D. Johnson	do	382.00
15	34	A. E. Finn	Field material	5.00
15	35	Anton Karl	Field expenses	10.60
16	36	Willard D. Johnson	Camp equipment	162.98
12	37	Annie Campbell	Subsistence	30.50
12	38	John Taylor	Transportation	22.00
15	39	Anton Karl	Traveling expenses	8.50
19	40	Mrs. James Kennedy	Subsistence	28.12
19	41	J. B. McNeal	Transportation	23.25
19	42	John Burt	Subsistence and transportation	6.00
21	43	Clay Bell	Subsistence	22.00
23	44	S. A. Snyder	Transportation and field material	1.75
23	45	Anton Karl	Traveling expenses	6.25
26	46	do	Telegrams	6.17
29	47	S. A Snyder	Field expenses	8.25
29	48	F. Bradley	Expressage	1.70
28	49	H. S. Stansbury	Services, November 26, 1888	2.25
29	50	John Fisher	do	2.50
29	51	Edward Elgenfritz	Subsistence	41.16
30	52	Pay-roll	Services, November, 1888	313.00
30	53	Willard D. Johnson	Field material	99.26
30	54	do	Subsistence	117.15
Dec. 1	55	Pay-roll	Services, November, 1888	723.09
4	56	Charles P. Abdell	Traveling expenses	40.80
3	57	Noah Cann	Subsistence	14.70
3	58	S. Montrose	do	9.00
7	59	John Boyd	do	25.00
18	60	J. W. Dobbins	Traveling expenses	5.40
8	61	Willard D. Johnson	Subsistence and field material	221.01
7	62	E. Forster	do	1.50
9	63	Noah Cann	Transportation	1.90
10	64	John Boyd	Subsistence	1.25
13	65	W. H. Lithgran	do	21.00
14	66	H. F. Comstock	Expressage	1.00
13	67	J. S. Parker	Lodging and transportation	44.25
16	68	A. E. Finn	Subsistence and transportation	19.85
17	69	Edward Rollandet	Field material	5.00
17	70	Anton Karl	Traveling expenses	5.45
17	71	do	do	14.10
20	72	Clay Bell	Subsistence	12.00
24	73	Anton Karl	Telegrams and expressage	5.96
31	74	do	Services, December, 1888	168.50
31	75	Pay-roll	Services, December, 1888	833.20
31	76	Anton Karl	Traveling expenses	20.75
19	77	W. H. Hyatt	Transportation	68.50
29	78	J. C. McGuire	do	52.31
		Total		7,305.37

Abstract of disbursements made by P. H. Christie, special disbursing agent, U. S. Geological Survey, during the second quarter of 1889.

Date.	No. of vouchor.	To wnom paid.	For what paid.	Amount.
1888.				
Oct. 1	1	Pay-roll	Services, September, 1888	$366.46
1	2	do	do	386.20
1	3	do	do	366.73
1	4	do	do	462.60
1	5	do	do	165.06
1	6	J. W. Hayes	do	97.80
1	7	R. C. McKinney	do	97.80
1	8	D. C. Harrison	do	97.80
1	9	A. E. Murlin	do	81.60
1	10	R. M. Towson	do	81.60
1	11	R. O. Gordon	do	73.40
1	12	P. H. Christie	do	146.80
1	13	A. B. Rivers	do	25.00
1	14	F. P. Fitzwilliam	do	25.00
1	15	R. S. Thornton	do	25.00
1	16	W. G. Cleland	Services, September 14 to 30, 1888	14.16
8	17	W. F. Fling	Forage of stock	6.00
8	18	James A. Maher	Traveling expenses	13.20
8	19	William H. Griffin	do	4.50
8	20	R. O. Gordon	Miscellaneous field expenses	48.16
8	21	Morris Bien	do	56.37
8	22	R. M. Towson	do	66.00
8	23	D. C. Harrison	do	23.75
	24	R. C. McKinney	do	29.80
10	25	Morris Bien	do	47.28
11	26	L. C. Fletcher	do	95.09
13	27	E. C. Barnard	do	63.54
13	28	Charles M. Yeates	do	80.28
24	29	M. Hackett	do	202.34
24	30	Morris Bien	do	86.36
24	31	E. C. Barnard	do	45.13
24	32	Louis Nell	do	156.12
24	33	L. C. Fletcher	do	112.00
24	34	Fred. J. Knight	do	94.83
27	35	A. E. Murlin	do	32.80
27	36	R. C. McKinney	do	14.75
27	37	Fred. J. Knight	do	58.30
27	38	R. M. Towson	do	43.00
27	39	E. C. Barnard	Traveling expenses	16.95
27	40	Charles M. Yeates	do	10.40
27	41	M. Hackett	do	8.12
27	42	George H. Lamar	do	6.32
27	43	E. S. Parker	do	5.82
31	44	Robt. J. Breckinridge	Services, October 1 to 16, 1888	30.96
31	45	P. H. Christie	Services, October, 1888	151.60
31	46	Pay-roll	do	519.72
31	47	D. C. Harrison	do	101.10
31	43	R. C. McKinney	do	101.10
31	49	Pay-roll	do	389.18
31	50	A. E. Wilson	Services, October 15 to 31, 1888	32.90
31	51	Pay-roll	Services, October, 1888	535.92
31	52	do	do	404.81
31	53	Lewis J. Battle	do	32.90
31	54	R. B. Cameron	do	32.90
31	55	Pay-roll	do	470.65
31	56	do	do	487.99
31	57	Fred. J. Knight	Services, October 1 to 14, 1888	60.87
31	58	do	Services, October 15 to 31, 1888	83.15
31	59	A. E. Murlin	Services, October 1 to 18, 1888	48.91
31	60	do	Services, October 19 to 31, 1888	42.39
31	61	R. M. Towson	Services, October 1 to 14, 1888	38.04
31	62	do	Services, October 15 to 31, 1888	55.43
31	63	R. O. Gordon	Services, October 1 to 17, 1888	41.58
31	64	do	Services, October 18 to 31, 1888	45.65
31	65	F. P. Metzger	Services, October 17 to 31, 1888	24.19
31	66	B. Peyton Legari	do	24.19
31	67	M. F. Christie	Services, September 1 to 30, 1888	50.00
31	68	A. B. Rivers	Services, October 1 to 31, 1888	25.00
31	69	R. S. Thornton	do	25.00
31	70	Mrs. J. J. Whittle	do	25.00
31	71	V. T. Carmichael	do	25.00
31	72	J. M. Duncan	do	25.00
31	73	W. F. Fling	Forage of stock	6.00
Nov. 5	74	M. Hackett	Miscellaneous field expenses	178.64
7	75	E. C. Barnard	do	81.42
7	76	do	do	84.15
7	77	L. C. Fletcher	do	108.00
7	78	D. C. Harrison	do	19.25

Abstract of disbursements made by R. H. Christie, etc.—Continued.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1888.				
Nov. 7	79	L. C. Fletcher	Miscellaneous field expenses	$134.93
7	80	A. E. Murlin	do	30.30
7	81	Morris Bien	do	171.25
8	82	Louis Nell	do	166.69
8	83	Fred. J. Knight	do	43.35
8	84	R. C. McKinney	do	34.80
8	85	W. H. Ford	Field material	18.00
8	86	V. Schoonmaker	do	75.00
8	87	Joseph F. Page	do	8.54
9	88	W. H. Ford	do	18.00
9	89	V. Schoonmaker	do	75.00
9	90	Buchanan & Lake	Field supplies	17.85
9	91	Robt. J. Breckinridge	Traveling expenses	6.90
9	92	Duncan Hannegan	do	8.85
10	93	A. E. Murlin	do	18.20
10	94	J. D. Lincoln	do	7.98
10	95	B. P. Legari	do	22.00
10	96	D. C. Harrison	Miscellaneous field expenses	24.50
10	97	V. Schoonmaker	Field material	75.00
10	98	P. H. Christie	Services, November 1 to 15, 1888	73.37
		Total		9,379.32

Abstract of disbursements made by P. H. Christie, special disbursing agent U. S. Geological Survey, during the second quarter of 1889.

1888.				
Nov. 30	1	Pay-roll	Services, November, 1888	$467.50
30	2	P. H. Christie	Services, November 16 to 30, 1888	73.37
Dec. 10	3	George T. Quinby	Traveling expenses	28.05
10	4	Frederick H. Newell	do	92.10
10	5	J. B. Williams	do	111.65
11	6	Palace Hotel	Subsistence	90.00
11	7	Gerard D. Koch	Field supplies	112.94
12	8	H. P. Cartwright & Co	do	95.08
12	9	W. A. McKenzie	do	144.43
13	10	R. S. Tarr	Traveling expenses	42.82
13	11	P. H. Christie	do	157.15
14	12	Geo. T. Quinby	Field expenses	101.33
19	13	R. S. Tarr	do	13.95
19	14	Albino Lopez	Subsistence	24.37
19	15	F. H. Newell	Field expenses	35.60
20	16	C. E. Dutton	Traveling expenses	72.85
20	17	Philo Rumsey	Subsistence	53.38
20	18	W. A. McKenzie	Field supplies	49.06
22	19	Grunsfield, Lindheim & Co	do	21.47
22	20	Gerard D. Koch	do	30.32
22	21	W. A. McKenzie	do	52.75
22	22	H. B. Cartwright	do	168.72
26	23	Palace Hotel	Subsistence	37.00
31	24	Pay-roll	Services, December, 1888	825.62
31	25	George E. Curtis	Traveling expenses	18.78
31	26	Alfred C. Lane	do	90.60
31	27	P. H. Christie	Field expenses	94.52
31	28	Pay-roll	Services, December, 1888	97.57
31	29	F. H. Newell	Field expenses	46.93
31	30	George E. Curtis	Services, December 20 to 31, 1888	45.15
		Total		3,295.06

Abstract of disbursements made by John H. Renshawe, disbursing agent, U. S. Geological Survey, during the second quarter of 1889.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1888.				
Oct. 6	1	H. L. Baldwin, jr	Field expenses	$77.43
6	2	William J. Peters	do	58.00
6	3	do	do	23.25
15	4	Geo. T. Hawkins	do	35.40
15	5	do	do	16.15
15	6	H. B. Blair	do	204.78
15	7	Van H. Manning, jr	do	84.92
15	8	H. L. Baldwin, jr	do	85.52
15	9	do	Traveling expenses	28.99
15	10	Wm. H. Herron	do	4.50
22	11	William J. Peters	Field expenses	75.12
22	12	do	do	128.85
30	13	H. L. Baldwin, jr	do	77.75
30	14	Geo. T. Hawkins	do	154.71
31	15	Jno. H. Renshawe	Traveling expenses	123.10
Nov. 1	16	Morrison R. Avery	do	8.75
6	17	H. B. Blair	Field expenses	196.94
14	18	Van H. Manning, jr	do	77.60
14	19	C. T. Reid	Services, October, 1888	50.00
16	20	Geo. T. Hawkins	Field expenses	106.74
20	21	Pay-roll (F. J. K.)	Services, October, 1888	27.09
20	22	W. U. Simons	do	30.00
23	23	William J. Peters	Field expenses	113.75
23	24	Van H. Manning, jr	do	80.03
23	25	do	Services, October, 1888	78.16
26	26	H. L. Baldwin, jr	Field expenses	118.52
29	27	do	Services, November, 1888	130.40
29	28	Wm. H. Herron	do	81.60
29	29	H. L. Baldwin, jr	Traveling expenses	27.38
Dec. 1	30	Pay-roll (F. J. K.)	Services, November, 1888	120.00
1	31	William J. Peters	do	114.20
1	32	C. T. Reid	do	50.00
1	33	Van H. Manning, jr	do	81.60
1	34	W. U. Simons	do	30.00
1	35	Pay-roll (H. B. B.)	do	360.40
1	36	Pay-roll (G. T. H.)	do	217.80
1	37	E. A. Hagerty	Care of stock	12.57
1	38	H. L. Baldwin, jr	Field expenses	40.35
6	39	C. T. Reid	Traveling expenses	26.24
7	40	S. Chester Reid	do	22.55
15	41	S. S. Gannett	Field expenses	86.10
15	42	Jno. H. Renshawe	do	89.15
15	43	do	Traveling expenses	126.68
18	44	H. B. Blair	Field expenses	198.82
18	45	Van H. Manning, jr	Traveling expenses	9.51
18	46	do	do	21.62
18	47	do	Field expenses	37.68
18	48	William J. Peters	do	81.27
18	49	Geo. T. Hawkins	do	79.25
20	50	H. L. Baldwin, jr	do	91.09
22	51	do	Services, October, 1888	127.17
24	52	William J. Peters	Field expenses	88.40
24	53	Geo. T. Hawkins	do	72.65
29	54	Pay-roll (G. T. H.)	Services, October, 1888	200.55
29	55	Pay-roll	Services, December, 1388	221.10
31	56	Pay-roll (H. B. B.)	Services, October, 1888	344.23
31	57	Wm. H. Herron	do	73.59
31	58	do	Services, December, 1888	84.20
31	59	H. L. Baldwin, jr	do	134.80
31	60	C. T. Reid	do	50.00
31	61	H. L. Baldwin, jr	Traveling expenses	38.90
31	62	Wm. H. Herron	do	45.85
31	63	W. U. Simons	Services, December, 1888	21.27
31	64	H. B. Blair	Field expenses	252.35
31	65	William J. Peters	Services, December, 1888	117.90
31	66	do	Services, October, 1888	110.32
31	67	E. B. Sanders	Services, December, 1888	40.00
31	68	Frank Shanka	do	40.00
31	69	Joseph Platt	do	40.00
31	70	Van H. Manning, jr	do	84.20
31	71	Pay-roll (H. B. B.)	do	364.80
		Total		6,754.59

Abstract of disbursements made by R. R. Hawkins, special disbursing agent U. S. Geological Survey, during the second quarter of 1889.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1888.				
Oct. 4	1	Wells, Fargo & Co	Expressage	$15.45
4	2	Western Union Company	Telegrams	4.03
4	3	Goldberg, Bowen & Co	Supplies	18.30
4	4	A. Carlisle & Co	do	5.97
4	5	W. Lindgren	Field expenditures	47.15
6	6	H. W. Turner	do	67.62
10	7	John Taylor & Co	Laboratory supplies	35.87
10	8	A. Leitz & Co	Repairs, etc	9.90
15	9	W. Lindgren	Field expenditures	21.80
22	10	C. E. Watkins	Developing, etc	9.90
22	11	J. Kemp & Co	Repairs	5.50
23	12	Charles Bryant	Storage	6.60
24	13	Frank Rader	Services, September 1 to 30, 1888	35.00
24	14	H. W. Turner	Traveling expenses	27.90
24	15	do	Field expenditures	30.02
31	16	Pay-roll (topography)	Services, October, 1888	493.50
31	17	Frank Rader	do	45.00
31	18	Pay-roll	do	396.00
31	19	G. W. Granniss	Room rent	52.66
31	20	George Phillips	Services, Sept. 1 to Oct. 25, 1888	90.32
31	21	Redick H. McKee (topography)	Field expenditures	115.60
31	22	W. Lindgren	do	33.95
31	23	E. A. Schneider	Services, October 1 to 31, 1888	60.00
31	24	R. R. Hawkins	Cash expenditures	19.07
		Total		1,647.11

Abstract of disbursements made by Fielding Burnes, disbursing agent U. S. Geological Survey, during the second quarter of 1889.

1888.				
Oct. 1	1	Willard D. Johnson	Services, September, 1888	$146.80
1	2	Pay-roll of employés	do	447.00
1	3	do	do	254.00
3	4	F. P. Gulliver	Miscellaneous field expenses	36.71
4	5	Jeremiah Ahern	do	75.00
4	6	do	Traveling expenses	6.47
4	7	Frank Sutton	do	6.47
4	8	do	Miscellaneous field expenses	78.86
4	9	Robt. D. Cummin	do	62.83
5	10	Sumner H. Bodfish	do	10.29
5	11	do	Traveling expenses	47.57
5	12	W. E. Horton	do	7.85
19	13	E. G. Kennedy	do	5.50
29	14	E. C. Robinson	Storage, etc	24.83
29	15	Beers, Ellis & Co	Field material	0.00
29	16	J. H. Jennings	Miscellaneous field expenses	78.08
29	17	W. H. Lovell	do	175.90
29	18	Robt. D. Cummin	do	25.96
29	19	W. R. Atkinson	do	85.65
29	20	do	Traveling expenses	11.94
29	21	S. S. Gannett	do	40.55
29	22	G. L. Johnson	do	17.98
29	23	James Longstreet, jr	do	29.01
29	24	C. J. Akin	do	6.63
Nov. 30	25	Fielding Burnes	Services, October and November, 1888.	298.40
30	26	Pay-roll of employés	Services, November, 1888	269.00
30	27	do	do	340.40
30	28	do	do	282.60
30	29	do	do	337.20
30	30	do	do	364.40
30	31	do	do	473.20
30	32	Jeremiah Ahern	Miscellaneous field expenses	64.97
30	33	do	Traveling expenses	12.73
30	34	Wm. Kramer	Miscellaneous field expenses	50.60
30	35	do	do	40.75
30	36	do	Traveling expenses	26.07
30	37	J. W. Thom	do	14.92
Dec. 1	38	Lawson Sanford	Traveling expenses	12.50
4	39	G. E. Hyde	do	4.80
4	40	F. P. Gulliver	Miscellaneous field expenses	85.75
5	41	Sumner H. Bodfish	do	131.22
5	42	do	Traveling expenses	78.15

Abstract of disbursements made by Fielding Burnes, etc.—Continued.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1888.				
Dec. 5	43	Frank Dutton	Traveling expenses	$37.25
5	44	...do	...do	31.63
5	45	W. E. Horton	...do	36.54
7	46	R. H. Stuart	...do	14.23
7	47	...do	Miscellaneous field expenses	27.69
8	48	E. W. F. Natter	...do	128.48
8	49	...do	Traveling expenses	57.33
11	50	J. H. Jennings	...do	16.49
11	51	...do	Miscellaneous field expenses	46.80
11	52	...do	...do	25.62
14	53	E. B. Clark	...do	138.38
14	54	...do	Traveling expenses	12.19
14	55	Joseph H. Wheat	...do	12.19
22	56	J. L. Smith	Field material	15.00
24	57	W. H. Lovell	Traveling expenses	26.93
28	58	F. P. Gulliver	...do	18.59
28	59	...do	Miscellaneous field expenses	37.40
28	60	E. Robinson	Field material	20.00
31	61	Pay-roll of employés	Services, December, 1888	1,747.60
31	62	The Alteneder	Scales	3.00
31	63	G. Wolven	Veterinary services, etc.	20.00
		Total		7,052.88

Abstract of disbursements made by A. O. D. Taylor, jr., special disbursing agent, U. S. Geological Survey, during the second quarter of 1889.

1888.				
Oct. 1	1	Pay-roll	August, 1888	$190.00
1	2	W. Beals, jr	Pay for August, 1888	40.00
1	3	Chas. S. Merrick	Pay to August 31, 1888	60.00
1	4	Ben. K. Emerson	Pay for August, 1888	100.00
1	5	Joseph H. Perry	Pay to August 31, 1888	60.00
1	6	J. Eliot Wolff	Traveling expenses	67.98
1	7	Chas. S. Merrick	...do	14.12
1	8	Joseph H. Perry	...do	35.50
1	9	W. Beals, jr	...do	16.95
1	10	T. Nelson Dale	...do	21.32
1	11	Ben. K. Emerson	...do	28.77
1	12	Raphael Pumpelly	Field expenses	5.00
1	13	...do	Traveling expenses	92.94
1	14	H. L. Smyth	Field expenses	30.88
1	15	...do	...do	61.00
1	16	...do	...do	16.99
1	17	...do	...do	12.75
1	18	T. Nelson Dale	Traveling expenses	29.44
1	19	J. Eliot Wolff	Field expenses	73.72
1	20	Raphael Pumpelly	Pay for September, 1888	326.00
1	21	T. Nelson Dale	...do	150.00
1	22	H. L. Smyth	...do	81 60
1	23	A. O. D. Taylor, jr	...do	97.80
1	24	A. Prescott Baker	Rent to September 30, 1888	100.00
1	25	J. A. Williams	Services to July 26, 1888	63.60
8	26	T. Nelson Dale	Traveling expenses	21.10
21	27	Ben. K. Emerson	Pay for September, 1888	100.00
24	28	C. L. Whittle	Traveling expenses	50.21
24	29	H. L. Smyth	Field expenses	57.66
24	30	...do	...do	29.98
24	31	Henry Adams Craigin	Traveling expenses	7.25
24	32	H. L. Smyth	Field expenses	73.35
24	33	J. Eliott Wolff	Pay for September, 1888	97.80
24	34	Raoul P. Loder	...do	30.00
24	35	Edward Stabe	...do	50.00
24	36	Alfred H. Brooks	...do	30.00
24	37	Lewis Brown, postmaster	Post-office box rent	5.00
24	38	Henry Bull, jr	Telephone rent	11.50
25	39	Raphael Pumpelly	Incidental expenses	29.55
25	40	J. H. Flagg	Team hire	44.00
25	41	E. & H. T. Anthony & Co	Photographic supplies	4.59
25	42	Keuffel & Esser	Drawing material	14.41
25	43	F. E. Swift	Board at Wilson House	72.00
27	44	Algernon B. Corbin	Stationery supplies	8.10
29	45	Scovill Manufacturing Company	Photographic supplies	43.41
29	46	E. D. Keyes & Co	Field subsistence	47.77
29	47	A. C. Landers	One lamp	3.50

Abstract of disbursements made by A. O. D. Taylor, jr., etc.—Continued.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1888.				
Oct. 31	48	Western Union Telegraph Co	Telegrams	$11.15
31	49	A. Prescott Baker	Rent for October, 1888	50.00
31	50	Raphael Pumpelly	Pay for October, 1888	337.00
31	51	T. Nelson Dale	do	150.00
31	52	H. L. Smyth	do	84.20
31	53	A. O. D. Taylor, jr	do	101.10
31	54	W. Beals, jr	Pay to October 31, 1888	80.00
31	55	C. L. Whittle	Pay, October, 1888	150.00
31	56	Richard Bliss	Bibliographical work	30.30
31	57	W. J. Withrow	Pay for September, 1888	37.24
31	58	H. A. Craigin	do	23.94
Nov. 1	59	H. L. Smyth	Field expenses	40.72
1	60	J. Eliot Wolff	Pay for October, 1888	52.17
1	61	W. Beals, jr	Traveling expenses	63.67
2	62	H. L. Smyth	Field expenses	135.59
8	63	Raphael Pumpelly	Office expenses	42.24
8	64	Sidney Warren	Pay to October 31, 1888	66.60
8	65	H. L. Smyth	Traveling expenses	8.50
8	66	do	Field expenses	32.02
9	67	do	do	21.90
10	68	Edward Stabe	Pay to November 9, 1888	64.94
10	69	do	Traveling expenses	8.65
12	70	J. A. Williams	Services to November 8, 1888	67.90
22	71	H. L. Smyth	Traveling expenses	9.50
23	72	Raoul P. Loder	do	11.10
23	73	A. S. Warren	do	9.75
23	74	do	Field expenses	38.80
23	75	do	Traveling expenses	10.60
23	76	do	Pay to November 22, 1888	29.33
24	77	H. L. Smyth	Field expenses	31.85
26	78	Raoul P. Loder	Pay to November 20, 1888	50.00
28	79	J. A. Williams	Services, August 21 to 31, 1888	40.00
28	80	C. H. Codman & Co	Two scrap albums	4.70
28	81	Alfred H. Brooks	Traveling expenses	9.00
30	82	Eimer & Amend	Photographic supplies	11.59
30	83	G. P. Putnam's Sons	Wrapping paper	5.75
30	84	Henry J. Green	Aneroid barometer	24.25
30	85	J. E. Creed	Team hire	56.00
30	86	A. Prescott Baker	Rent for November, 1888	50.00
30	87	Raphael Pumpelly	Pay for November, 1888	326.00
30	88	T. Nelson Dale	do	150.00
30	89	A. O. D. Taylor, jr	do	97.80
Dec. 4	90	C. A. Claghorn	Team hire	325.50
5	91	Alfred H. Brooks	Pay to November 12, 1888	42.00
5	92	W. & L. E. Gurley	Instruments	148.42
11	93	Raphael Pumpelly	Traveling expenses	99.70
15	94	C. L. Whittle	do	133.59
15	95	W. Beals, jr	do	74.64
19	96	do	Field expenses	4.10
20	97	C. L. Whittle	Pay to November 30, 1888	75.00
22	98	W. Beals, jr	Pay for November, 1888	40.00
31	89	Raphael Pumpelly	Pay for December, 1888	337.00
31	100	T. Nelson Dale	do	150.00
31	101	A. O. D. Taylor, jr	do	101.10
31	102	W. Beals, jr	Traveling expenses	6.90
		Total		6,771.84

Abstract of disbursements made by Arnold Hague, special disbursing agent, U. S. Geological Survey, during the second quarter of 1889.

Oct. 16	1	John F. Yancey	Subsistence	$34.50
18	2	W. T. Scott	Services, August 20 to 31, 1888	19.35
19	3	Geo. H. Keyes	Field material	13.30
19	4	J. A. Clark	Services, October 10 to 15, 1888	15.00
22	5	Yellowstone Park Association	Subsistence stores	56.17
22	6	do	do	31.50
22	7	do	Forage	57.62
22	8	W. J. Henderson	Subsistence	30.50
22	9	J. C. McCartney	Field supplies	21.23
22	10	R. T. Smith	do	33.99
31	11	E. J. Owenhouse	Field material	147.53
31	12	M. J. Shea & Co	Forage	21.53
31	13	A. Lamme & Co	Subsistence stores	162.25
Nov. 13	14	David B. May	Fresh meat	60.70

Abstract of disbursements made by Arnold Hague, etc.—Continued.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
Nov. 30	15	Pay-roll of employés	Salaries, September, 1888	$898.40
30	16	do	Salaries, October, 1888	842.78
30	17	do	Salaries, July and August, 1888	2,440.06
Dec. 5	18	Arnold Hague	Services, September and October, 1888.	663.00
5	19	Pay-roll of employés	Salaries, November, 1888	694.40
8	20	Paul J. Dashiell	Traveling expenses	30.37
10	21	Arnold Hague	do	36.65
10	22	Jos. P. Iddings	do	90.20
10	23	W. H. Weed	do	131.45
10	24	E. H. Shuster	do	69.50
14	25	Jos. P. Iddings	Miscellaneous expenses	13.72
14	26	Arnold Hague	Traveling expenses	104.25
14	27	do	Miscellaneous expenses	44.84
14	28	Peter Koch	Notarial services	5.00
19	29	F. H. Knowlton	Traveling expenses	20.30
19	30	do	do	45.20
29	31	A. Lamme & Co	Subsistence stores	145.83
		Total		6,981.12

Abstract of disbursements made by Jno. D. McChesney, chief disbursing clerk U. S. Geological Survey, during the third quarter of 1889.

1889.				
Jan. 7	1	Z. D. Gilman	Laboratory supplies	$102.89
7	2	C. Solon Stevenson	Publications	15.00
8	3	Henry Gannett	Traveling expenses	103.35
8	4	Chas. H. Sternberg	Paleontologic specimens	200.00
10	5	J. W. Powell	Traveling expenses	58.55
10	6	do	do	46.55
10	7	N. S. Shaler	do	87.35
12	8	P. J. Labor	Publications	31.50
12	9	David T. Day	Traveling expenses	131.26
14	10	John F. Paret	Supplies and publications	4.88
15	11	Albert Williams, jr	Services, December 24, 1888, to January 15, 1889.	35.00
17	12	Chas. S. Cudlip	Supplies	64.75
18	13	J. S. Diller	Field expenses	255.15
18	14	do	do	24.00
18	15	do	Traveling expenses	279.90
18	16	J. Karr	Irrigation instruments	30.00
18	17	Geo. H. Williams	Services, December, 1888	105.00
18	18	Julius Bien & Co	Geological and Topographical Atlas	379.95
18	19	R. R. Morrison	Publications	12.00
18	20	Lawrence C. Johnson	Traveling expenses	94.40
18	21	William D. Clark & Co	Topographic supplies, etc	29.38
18	22	Robert Hay	Services, December 1 to 31, 1888	60.00
18	23	Herman H. Pechin	Phonotyping report	65.00
18	24	Dietrick W. Kolbe	Services, December 22 to 31, 1888	20.00
18	25	G. E. Ladd	Services, December, 1888	40.00
18	26	W. P. Rust	do	65.00
18	27	Lawrence C. Johnson	do	117.90
18	28	Chas. A. Ashburner	do	25.00
18	29	H. S. Williams	do	126.40
19	30	Frank Leverett	do	120.00
19	31	Aug. F. Foerste	do	30.00
19	32	Warren Upham	do	101.10
19	83	C. W. Coman	Services, October, 1888	50.00
19	34	Shepherd & Hurley	Petrographic machinery	48.68
19	35	M. Lukamitsch, jr	Repairs to instruments	34.04
21	36	Robt. Boyd	Office supplies	59.48
21	37	Geo. Ryneal	Material for illustrations, etc	21.71
21	38	Adams Express Company	Freight charges	220.35
21	39	Geo. W. Knox	do	65.22
21	40	W. & L. E. Gurley	Instruments	1,098.00
22	41	Pennsylvania R. R	Transportation of assistants	93.30
22	42	Missouri Pacific R. R	do	15.75
22	43	Denver and Rio Grande Western	do	58.00
22	44	Pennsylvania Company	do	12.00
22	45	Baltimore and Ohio R. R	do	806.65
22	46	Hubbell, Merwin & Co	Supplies	83.40
22	47	W. S. Bayley	Services, December, 1888	72.50
22	48	National Press Intelligence Co	Newspaper clippings	11.00
22	49	Chicago, Burlington and Quincy	Freight charges	4.78

Abstract of disbursements made by Jno. D. McChesney, etc.—Continued.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
Jan. 23	50	L. J. Wing	Laboratory supplies	$40.00
23	51	Denver Fire Clay Company	do	16.00
23	52	Brown & Sharp Manufacturing Company.	do	53.87
23	53	J. Bishop & Co	do	16.19
23	54	Emil Greiner	do	1.00
23	55	Buffalo Dental Manufacturing Company.	do	6.00
23	56	do	do	15.00
23	57	W. J. Park & Co	Geological material	21.65
24	58	Emil Greiner	Laboratory material	6.00
24	59	J. and H. Berge	Laboratory supplies	4.24
24	60	C. W. Hall	Traveling expenses	55.88
24	61	J. B. Woodworth	do	18.40
24	62	C. W. Coman	do	84.28
24	63	Collier Cobb	do	16.57
24	64	Aug, F. Foerste	do	54.45
24	65	C. J. Merriam	Services, December, 1888	38.71
24	66	Pennsylvania Company	Transportation of assistants	16.50
24	67	Missouri Pacific Rwy	do	26.70
24	68	G. E. Ladd	Traveling expenses	79.85
24	69	C. H. Hitchcock	Services, August 11 to September 28, 1888.	75.00
24	70	C. B. Boyd	Publications	5.00
25	71	Gustav E. Stechert	do	167.26
25	72	M. W. Beveridge	Material	1.80
25	73	Adams Express Company	Freight charges	107.00
25	74	George W. Davis	Traveling expenses	32.60
25	75	Charles H. Cherry	Services, January 5 to 14, 1889	45.00
31	76	Pay-roll of employés	Services, January, 1889	2,542.90
31	77	do	do	1,734.30
31	78	do	do	900.81
31	79	do	do	1,152.50
31	80	do	do	918.74
31	81	do	do	410.00
31	82	do	do	165.00
31	83	do	do	3,676.80
31	84	do	do	1,255.90
31	85	Charles D. Poston	Services, December 29, 1888 to January 3, 1889.	50.00
31	86	Z. D. Gilman	Laboratory supplies	6.55
31	87	do	Supplies	137.90
31	88	J. Henry Blake	Services, January, 1889	155.00
31	89	Leo Lesquereux	do	75.00
31	90	Ira Sayles	do	120.60
31	91	O. C. Marsh	do	344.40
31	92	I. C. White	do	206.70
31	93	J. B. Hatcher	do	200.00
31	94	G. Baur	do	150.00
31	95	L. P. Bush	do	50.00
31	96	F. Berger	do	80.00
31	97	H. Gibb	do	70.00
31	98	George W. Shutt	do	258.30
31	99	W. B. Smith	do	75.00
Feb. 1	100	W. B. Clark	do	125.00
2	101	C. E. Dutton	Traveling expenses	82.15
2	102	J. E. Whitfield	do	7.50
2	103	Arthur Keith	do	29.43
2	104	Albert Williams, jr	Services, January 26 to 31, 1889	40.00
2	105	Eric M. Noble	Services, January 2 to 15, 1889	40.25
2	106	J. A. Holmes	Services, November 6 to December 31, 1888.	220.00
2	107	E. H. King	Geological supplies	254.00
2	108	N. S. Shaler	Salary, January, 1889	270.00
4	109	Frank Leverett	do	135.00
4	110	C. R. Van Hise	do	206.70
4	111	C. J. Merriam	do	50.00
4	112	H. S. Williams	do	129.20
4	113	Chicago, Santa Fé and California Rwy.	Transportation of assistants	10.25
4	114	The Missouri Pacific Rwy	do	4.90
4	115	The Eastman Dry Plate and Film Company.	Geological supplies	2.13
4	116	McFadden Company	Laboratory material	14.88
4	117	G. W. Swezez	Publications	2.00
4	118	Western Union Telegraph Co	Telegrams	11.93
4	119	W. Andrew Boyd	Publications	20.00
5	120	Robert Boyd	do	7.00
5	121	George H. Williams	Services, January, 1889	100.00

Abstract of disbursements made by Jno. D. McChesney, etc.—Continued.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889. Feb. 5	122	Robert Hay	Services, January, 1889,	$85.00
5	123	C. R. Van Hise	Cash paid for expenses	52.58
5	124	A. C. Peale	......do	75.62
5	125	N. S. Shaler	Traveling expenses	169.55
5	126	Charles A. Burnett	......do	16.15
7	127	H. L. Smyth	Services, January, 1889	98.89
7	128	J. B. Woodworth	....do	50.00
7	129	George E. Luther	......do	100.00
7	130	John C. Parker	Mineral resources and supplies	9.95
7	131	Eimer & Amend	Laboratory supplies	7.34
7	132	Memphis and Little Rock Rwy	Transportation of assistants	27.80
8	133	Warren Upham	Services, January, 1889	103.30
8	134	Lawrence C. Johnson	......do	120.60
8	135	William P. Rust	......do	67.50
8	136	J. Bishop & Co	Laboratory supplies	12.72
8	137	William Wesley & Son	Publications	110.47
8	138	Lest & Francke	......do	26.47
8	139	Citizens' National Bank	Bills of exchange	1.71
9	140	L. Moxley	Laboratory supplies	10.80
11	141	Smithsonian Institution	Transportation of public documents	73.10
11	142	Wm. C. Day	Services, January 2 to February 9, 1889.	75.00
11	143	Alfred M. Rogers	Services, November 1, 1888, to January 3, 1889.	75.00
11	144	Quartermaster's Department, U. S. Army	Field material	834.72
11	145	G. E. Ladd	Traveling expenses	19.44
14	146	Baltimore and Ohio R. R	Freight charges	38.90
12	147	J. S. Diller	Field expenses	6.67
12	148	John C. Parker	Geologic supplies	2.75
12	149	Wm. Ballantyne & Son	Supplies	63.90
12	150	Wm. H. Morrison	Publications	57.10
14	151	William H. Butler	Supplies	25.50
14	152	Melville Lindsay	Rubber cushion	3.00
14	153	Charles J. Cohen	Paper trays	46.25
14	154	W. S. Bayley	Field expenses	17.99
14	155	E. J. Lewis	Paleontologic supplies	6.50
14	156	Samuel Brown	Salary, February 1 to 14, 1889	23.33
15	157	A. D. Duganne	Salary, February 1 to 15, 1889	26.00
16	158	J. Blake Kendall	Paleontologic material	3.00
16	159	Easton & Rupp	Supplies	3.85
16	160	J. R. McLarrity	......do	4.00
16	161	Chas. H. Cherry	Services, January 15 to February 15, 1889.	70.00
16	162	W. H. Morrison	Topographic supplies	72.90
16	163	Hume & Co	......do	.75
16	164	L. H. Schneider's Son	......do	39.32
18	165	E. S. Ritchie & Sons	Instruments	150.00
18	166	Ira Sayles	Traveling expenses	14.72
18	167	Dietrick W. Kolb	Services, January 7 to 23, 1889	32.50
18	168	Herman Baumgarten	Supplies	3.00
18	169	Washington Gas-Light Co	Gas, July, 1888	77.14
18	170	......do	Gas, August, 1888	78.25
18	171	......do	Gas, September, 1888	77.51
18	172	......do	Gas, October, 1888	43.51
18	173	......do	Gas, November, 1888	60.88
18	174	......do	Gas, December, 1888	63.76
18	175	......do	Gas, January, 1889	65.26
18	176	Albert Williams	Services, February 1 to 16, 1889	65.00
20	177	John F. Stephenson	Freight charges	11.95
20	178	Fred. A. Schmidt	Topographic supplies	32.45
20	179	C. L. Whittle	Services, July 1, 1888, to February 12, 1889.	48.00
20	180	Geo. E. Littlefield	Publications	2.25
20	181	Emil Greiner	Laboratory material	8.25
20	182	Thomas Somerville & Sons	......do	5.00
20	183	E. E. Jackson & Co	Supplies	304.44
21	184	Joseph F. James	Services, January 4 to February 8, 1889.	27.50
23	185	Chain Hardy & Co	Supplies	9.38
23	186	W. S. Bayley	......do	10.80
28	187	California Southern R. R	Transportation of assistants	60.00
28	188	Lawrence C. Johnson	Services, February, 1889	108.80
28	189	C. W. Coman	Services, January, 1889	50.00
28	190	John R. Proctor	Services, December 1, 1888, to February 26, 1889	130.00
28	191	J. Henry Blake	Services, February, 1889	140.00
28	192	Leo Lesquereux	......do	75.00

Abstract of disbursements made by Jno. D. McChesney, etc.—Continued.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
Feb. 28	193	William Ham Hall	Services, January 7 to February 16, 1889.	$425.00
28	194	Geo. W. Shutt	Services, February, 1889	233.40
28	195	Atchison, Topeka & Santa Fé R. R	Transportation of assistants	159.15
28	196	O. C. Marsh	Services, February, 1889	311.20
28	197	N. S. Shaler	do	240.00
28	198	I. C. White	do	186.60
Mar. 1	199	J. B. Hatcher	do	200.00
1	200	L. P. Bush	do	50.00
1	201	F. Berger	do	80.00
1	202	H. Gibb	do	70.00
1	203	G. Baur	do	150.00
1	204	Chas. D. Poston	do	25.00
1	205	Hensel Bruckmann & Lorbacher	Charges on packages	1.50
1	206	Emil Greiner	Laboratory supplies	3.15
1	207	David T. Day	Traveling expenses	10.40
1	208	Washington Gas-Light Co	Laboratory supplies	65.26
Feb. 28	209	Pay-roll of employés	Services, February, 1889	3,321.40
28	210	do	do	1,105.27
28	211	do	do	2,234.93
28	212	do	do	1,596.40
28	213	do	do	999.13
28	214	do	do	1,040.00
28	215	do	do	802.20
28	216	do	do	380.00
28	217	do	do	165.00
Mar. 2	218	E. H. King	Paleontologic supplies	56.00
2	219	Albert Williams, jr	Pay, February 18 to March 2, 1889	25.00
2	220	Henry Gannett	Traveling expenses	38.05
5	221	J. B. Woodworth	Pay for February, 1889	50.00
5	222	C. R. Van Hise	do	186.60
5	223	E. R. Maurer	Pay, November 23, 1888, to February 18, 1889.	13.40
5	224	T. W. Stanton	Pay, February, 1889	31.50
5	225	Geo. E. Luther	do	100.00
5	226	Henry B. Hitz	Pay, February 11 to 28, 1889	38.57
5	227	Fred A. Schmidt	Publications	33.50
6	228	Alfred M. Rogers	Miscellaneous expenses	21.50
6	229	Geo. E. Gray	do	4.25
6	230	Scott & Murch	Material	17.25
6	231	James D. & E. S. Dana	Publications	6.00
6	232	Dan Phillips	Services, December 19 to 22, 1888	19.75
6	233	Geo. Linhart	Services, November 27 and 28, 1888	8.00
6	234	Library Bureau	Publications	5.00
6	235	W. S. Bayley	Services, January 1 to February 28, 1889.	100.00
5	236	Denver and Rio Grande R. R	Transportation of assistants	18.00
6	237	Robert Stein	Services, February, 1889	100.00
6	238	Geo. H. Williams	do	60.00
6	239	C. W. Coman	Traveling expenses	31.20
7	240	United Lines Telegraph Company	Telegrams	1.23
7	241	The E. S. Greeley & Company	Laboratory material	10.55
7	242	Chas. S. Cudlip	Supplies for illustrations	78.34
7	243	C. J. Merriam	Services, February, 1889	50.00
7	244	H. S. Williams	do	116.66
7	245	William B. Clark	do	110.00
7	246	C. W. Coman	Services, November and December, 1888.	50.00
7	247	Wm. P. Rust	Services, February, 1889	60.00
7	248	Western Union Telegraph Company.	Telegrams	11.81
8	249	L. Moxley	Laboratory supplies	10.80
9	250	Chas. S. Cudlip	Supplies for illustrations	75.00
9	251	Warren Upham	Services, February, 1889	93.40
12	252	Baltimore and Potomac R. R	Transportation of assistants	10.00
12	253	The American Tool and Machine Company.	Laboratory materials	17.25
12	254	Emil Greiner	do	5.10
12	255	H. Rosendale	Material	10.70
12	256	G. K. Gilbert	Geological supplies	20.00
13	257	Baltimore and Ohio R. R	Transportation of assistants	68.00
13	258	The Missouri Pacific Rwy	do	29.90
13	259	James G. Bowen	Pasturage	17.75
13	260	Lawrence C. Johnson	Traveling expenses	52.93
13	261	J. Bishop & Co	Laboratory supplies	5.14
13	262	H. L. Smyth	Services, February, 1889	93.40
13	263	Henry J. Green	Instruments	1,034.75
13	264	J. N. Burkett & Co	Laboratory supplies	12.00
13	265	William Ballantyne & Son	Supplies	11.40

Abstract of disbursements made by Jno. D. McChesney, etc.—Continued.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889. Mar. 13	266	C. R. Van Hise	Traveling expenses	$80.04
13	267	Missouri Pacific Rwy	Transportation of assistants	83.30
13	268	Goodnow & Wightman Manufacturing Company.	Laboratory material	10.92
13	269	Adams Express Company	Freight	163.50
22	270	Wash B. Williams	Miscellaneous supplies	71.90
23	271	Brentanos	Publications	1.20
23	272	do	do	2.50
23	273	Stevenson's Express	Freight charges	5.59
23	274	Chas. H. Cherry	Services, February 16 to March 15, 1889.	76.00
23	275	Chas. H. Kraft	Laboratory supplies	10.00
23	276	Frank Leverett	Services, February 1 to March 19, 1889.	200.00
23	277	Union Stone Company	Geological supplies	21.25
23	278	A. J. Phinney	Services, January 1 to March 1, 1889.	50.00
23	279	Texas and Pacific Rwy	Transportation of assistants	2.00
23	280	Burlington and Missouri River R. R.	do	140.60
23	281	Geo. W. Knox	Freight charges, etc	62.04
23	282	John C. Parker	Geological supplies	5.30
27	283	Brentanos	Supplies	70.50
27	284	Citizens' National Bank	Bill of exchange	1.08
27	285	Zoological Society	Publications	43.19
27	286	William Wesley & Son	do	5.11
27	287	L. G. Thompson	Field transportation	260.00
27	288	Bailey Willis	Traveling expenses	36.59
30	289	L. P. Bush	Services, March 1889	50.00
30	290	G. Baur	do	150.00
30	291	H. Gibb	do	70.00
30	292	J. B. Hatcher	do	200.00
30	293	F. Berger	do	80.00
30	294	A. Hermann	Services, January 1 to March 31, 1889	250.00
30	295	T. A. Bostwick	do	250.00
30	296	O. C. Marsh	Services, March, 1889	344.40
30	297	I. C. White	do	146.67
30	298	Lawrence C. Johnson	do	120.60
30	299	J. Henry Blake	do	155.00
30	300	Leo Lesquereux	do	75.00
30	301	E. H. Shuster	do	75.00
30	302	N. S. Shaler	do	260.00
30	303	Richard J. Hinton	Services, March 25 to 31, 1889	33.87
30	304	Henry B. Hitz	Services, March, 1889	60.00
80	305	Pay-roll of employés	do	3,676.80
30	306	do	do	1,245.50
30	307	do	do	2,444.10
30	308	do	do	1,711.80
30	309	do	do	1,095.93
30	310	do	do	1,102.50
30	311	do	do	896.90
30	312	do	do	410.00
30	313	do	do	220.32
30	314	J. B. Woodworth	do	50.00
30	315	Harriet Biddle	Services, January 1 to March 31, 1889	30.00
30	316	Geo. W. Shutt	Services, March, 1889	258.30
30	317	C. R. Van Hise	Salary, March, 1889	206.70
30	318	Geo. E. Luther	do	100.00
30	319	Geo. H. Williams	do	105.00
30	320	Geo. A. Rider	Publications	14.00
30	321	Albert Williams, jr	Services, March 5 to 31, 1889	35.00
30	322	William B. Clark	Services, March, 1889	105.00
30	323	Joseph J. James	Services, February 16 to March 31, 1889.	92.50
30	324	R. P. Whitfield	Drawings of fossils	948.00
30	325	C. J. Merriman	Services, March, 1889	50.00
30	326	E. H. King	Material	150.00
		Total		63,156.62

SALARIES, OFFICE OF DIRECTOR.

1889. Jan. 31	1	Pay-roll of employés	Services, January, 1889	$3,040.30
Feb. 28	2	do	Services, February, 1889	2,764.40
Mar. 31	3	do	Services, March, 1889	3,060.30
		Total		8,865.00

Abstract of disbursements made by Mark B. Kerr, disbursing agent, U. S. Geological Survey, during the third quarter of 1889.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
Jan. 3	1	R. H. Chapman	Traveling expenses	$43.94
4	2	L. G. Stephenson	do	81.00
4	3	Robt. Muldrow	do	152.25
4	4	E. M. Douglas	do	87.40
4	5	Frank E. Gove	do	59.75
5	6	Redick H. McKee	do	131.25
5	7	Frank E. Gove	Field expenses	58.05
5	8	James E. Shelley	do	45.45
5	9	do	do	18.90
11	10	Pay-roll (Urquhart)	Services, December, 1888	79.35
7	11	E. M. Hasbrouck	Traveling expenses	63.00
7	12	Josiah Pierce, jr	do	107.75
15	13	do	Field expenses	19.87
15	14	H. M. Wilson	Traveling expenses	107.75
15	15	G. E. Verrill	Field expenses	37.61
15	16	H. D. Bushnell	Traveling expenses	21.75
15	17	Lincoln Martin	Field expenses	15.53
15	18	Mark B. Kerr	Traveling expenses	69.20
28	19	Pay-roll	Services, December, 1888	823.20
19	20	Mark B. Kerr	Field expenses	34.38
22	21	Western Union Telegraph Co	Telegrams	6.28
28	22	E. M. Hasbrouck	Field expenses	67.63
28	23	H. M. Wilson	do	298.00
28	24	Philip Sawyer	Traveling expenses	18.50
28	25	do	Field expenses	9.35
28	26	R. U. Goode	do	57.18
28	27	G. E. Verrill	Traveling expenses	98.50
28	28	Lincoln Martin	do	78.25
28	29	Arthur P. Davis	Field expenses	82.76
28	30	do	do	19.85
28	31	do	Traveling expenses	18.50
28	32	R. Henry Phillips	Pay, December, 1888	84.20
28	33	Pay-roll (Davis)	Services, December, 1888	839.95
30	34	Pay-roll (Becker)	Services, January, 1889	385.60
31	35	G. F. Becker	do	344.40
31	36	W. H. Melville	do	172.20
31	37	Pay-roll (Wallace)	Services, December, 1888	90.31
29	38	W. A. McKenzie	Field material	53.70
29	39	Isador Ferron	Forage	20.00
29	40	D. L. Sammiss	do	23.66
29	41	W. A. Wright	Services, December, 1888	30.00
29	42	Eimer & Amend	Laboratory supplies	44.25
29	43	Amos Scott	Services, December, 1888	60.00
29	44	Reaser Bros	Forage	18.50
29	45	Geo. Chase	Repairs, etc	20.75
29	46	Kanzenbach & Habuland	Subsistence, etc	23.58
29	47	Arthur Bishoff	Field subsistence, etc	9.70
31	48	Abner Doble	Field material	9.00
31	49	Chas. W. Howell	Services, December, 1888	60.00
31	50	H. A. Messenger	Pasturage	20.00
31	51	O. Goniard	Storage	27.50
31	52	A. T. Kyle, jr	Pasturage, November and December, 1888.	76.05
31	53	Pay-roll (office)	Services, January, 1889	1,058.10
31	54	do	do	1,311.40
31	55	do	do	430.50
31	56	Pay-roll (Davis)	do	394.16
31	57	Pay-roll (Johnson)	do	950.00
31	58	E. C. Ryan	Traveling expenses	135.00
31	59	Jas. E. Shelley	Field expenses	4.10
Feb. 15	60	Thos. Smith	Pasturage	28.00
15	61	Joseph Peters	do	24.00
28	62	Houston Stephens	Services, December, 1888	16.00
15	63	A. H. Thompson	Traveling expenses	195.95
21	64	H. W. Lenner	Field expenses	35.40
21	65	do	Traveling expenses	18.15
28	66	Pay-roll (Becker)	Services, February, 1889	358.80
28	67	G. F. Becker	do	311.20
28	68	W. H. Melville	do	155.60
28	69	Lincoln Martin	Services, December, 1888	30.97
26	70	R. H. Chapman	Field expenses	3.00
26	71	Henry Vilas	Traveling expenses	11.70
26	72	do	do	66.70
27	73	Willard D. Johnson	Field expenses	275.15
27	74	G. W. Granniss	Rent, laboratory rooms	55.00
27	75	do	do	55.00
27	76	Reaser Bros	Subsistence, etc	107.08
27	77	F. G. Pratt & Co	do	18.26

Abstract of disbursements made by Mark B. Kerr, etc.—Continued.

Date.	No. of voucher.	To whom paid.	For whom paid.	Amount.
1889.				
Feb. 27	78	Stuart & McNair	Subsistence, etc	$33.22
27	79	McClutchem, Payne & Co	Forage	38.03
27	80	Adolph Lea	do	9.00
27	81	Isaac N. Hoger	Pasturage, January, 1889	26.88
27	82	do	Pasturage, February, 1889	52.50
27	83	E. C. Ryan	Services, December, 1888	60.00
28	84	Chas. W. Howell	Services, January, 1889	60.00
28	85	H. W. Noell	Services, December, 1888	30.00
28	86	Pay-roll (Phillips)	Services, February, 1889	277.80
28	87	Pay-roll (office)	do	1,542.20
28	88	do	do	978.80
28	89	do	do	389.00
Mar. 5	90	Chas. W. Howell	do	60.00
5	91	Amos Scott	Services, January, 1889	60.00
5	92	Amos Scott	Services, February, 1889	60.00
5	93	A. J. Newman	Pasturage	14.20
5	94	Willard D. Johnson	Traveling expenses	16.70
5	95	Pay-roll (Johnson)	Services, February, 1889	875.40
5	96	R. Henry Phillips	Field expenses	19.80
9	97	G. W. Granniss	Gas for laboratory	30.00
9	98	John Taylor & Co	Laboratory material	5.90
9	99	do	do	11.25
9	100	Main & Winchester	Field supplies	11.50
9	101	A. Carlisle & Co	Office supplies	3.50
9	102	W. & L. E. Gurley	Instruments	26.95
9	103	R. Henry Phillips	Field expenses	26.17
9	104	John W. Hayes	do	468.62
9	105	do	Traveling expenses	5.85
19	106	Willard D. Johnson	Field expenses	30.08
19	107	Isiah Prendell	Forage	67.50
19	108	J. & J. Raycroft	do	50.00
19	109	A. T. Kyle, jr	Pasture	75.40
19	110	John W. Hayes	Field expenses	24.25
21	111	W. Lindgren	do	73.73
23	112	Marchey Kelly	Services, January 23 to 30, 1889	20.00
23	113	McClutchen, Payne & Co	Forage	32.14
23	114	do	do	7.49
23	115	Stuart & McNair	Subsistence	24.62
23	116	C. V. Mead	do	18.45
23	117	Eugene Moreno	Forage	13.50
23	118	R. Henry Phillips	Field expenses	37.53
31	119	Pay-roll (Becker)	Services, March, 1889	385.60
31	120	G. F. Becker	do	344.40
31	121	W. H. Melville	do	172.20
31	122	Pay-roll (office)	do	1,767.50
31	123	do	do	1,058.10
31	124	do	do	402.47
31	125	R. Henry Phillips	do	286.10
31	126	Amos Scott	do	60.00
31	127	Chas. W. Howell	do	60.00
31	128	H. C. Daugberg	Pasturage	198.00
31	129	Jacob Klein	Storage	15.00
31	130	Thos. Clements	do	15.00
31	131	C. R. Montgomery	Pasturage	102.00
		Total		21,809.44

Abstract of disbursements made by C. D. Davis, special disbursing agent U. S. Geological Survey, during the third quarter of 1889.

1889.				
Jan. 10	1	Fred. J. Knight	Services, December, 1888	$151.60
17	2	N. B. Dunn	Pasturage	179.36
17	3	J. C. Hobson	do	33.07
17	4	Z. N. Lockhart	do	8.56
17	5	W. F. Fling	do	24.22
17	6	R. S. Thornton	Services, December 1 to 16, 1888	12.90
18	7	M. Hackett	Field expenses	2.35
26	8	Fred. J. Knight	Traveling expenses	14.05
31	9	Pay-roll of employés	Services, January, 1889	3,187.70
Feb. 11	10	Henkel & Corpening	Storage	6.00
18	11	L. Morgan	Traveling expenses	8.15
28	12	Pay-roll of employés	Services, February, 1889	2,959.60
28	13	W. F. Fling	Pasturage	48.00
28	14	Z. N. Lockhart	do	20.00
28	15	N. B. Dunn	do	288.00

Abstract of disbursements made by C. D. Davis, etc.—Continued.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1888.				
Feb. 28	16	James T. Reaves	Pasturage	$70.00
28	17	W. R. Murphy	......do	96.00
28	18	J. C. Hobson	......do	100.00
28	19	John W. Priee	......do	140.00
28	20	P. P. Glover	......do	100.00
Mar. 22	21	N. A. Morse	Storage	6.00
22	22	N. B. Dunn	Two mules	330.00
22	23	D. P. Gunnels and R. N. Warnock	Storage	7.67
27	24	L. D. Brent	Traveling expenses	16.60
27	25	D. C. Harrison	......do	33.65
31	26	Pay-roll of employés	Services, March, 1889	3,084.40
		Total		10,927.88

Abstract of disbursements made by P. H. Christie, special disbursing agent U. S. Geological Survey, during the third quarter of 1889.

1889.				
Jan. 7	1	Frank Harrison	Traveling expenses	$51.75
7	2	Nettleton & Campbell	Instruments	148.00
14	3	C. E. Dutton	Traveling expenses	100.30
14	4	W. A. Farish	......do	15.90
14	5	Robert Robinson	......do	63.47
18	6	Frank P. Fisher	......do	16.45
18	7	P. H. Christie	......do	12.45
18	8	......do	Miscellaneous field expenses	35.10
18	9	W. A. McKenzie	Miscellaneous field supplies	34.30
21	10	G. W. Bond & Bro	Forage	28.70
26	11	William Malboenf	Field material	50.30
26	12	A. C. Schmidt	......do	79.00
26	13	R. C. Stewart	Field supplies	40.71
26	14	James W. Queen & Co	Instruments, etc	66.13
26	15	W. & L. E. Gurley	......do	372.00
26	16	Hugh London	Mules	275.00
28	17	Plaza Hotel	Subsistence	56.50
31	18	Pay-roll	Service, January, 1889	1,380.84
31	19	C. W. Taylor	Office supplies	15.00
Feb. 1	20	L. C. Rice	Field supplies	26.75
4	21	The Denver Fire Clay Company	......do	27.48
5	22	Mequillet & Maerum	......do	6.37
6	23	Hermann H. Heiser	Field material	55.00
7	24	W. E. Scott & Co	......do	46.00
7	25	R. W. Stewart & Co	......do	33.00
7	26	Hermann H. Heiser	......do	9.00
8	27	The Schiff Carleston Grocery Company.	Subsistence supplies	51.30
8	28	Mequillet & Macrum	Field supplies	8.37
9	29	Chas. H. Smith	Subsistence	53.63
12	30	George T. Quinby	Field expenses	99.10
13	31	J. B. Williams	Traveling expenses	14.40
13	32	P. H. Christie	......do	22.45
13	33	......do	Field expenses	86.84
18	34	F. H. Newell	......do	150.81
18	35	W. & L. E. Gurley	Instruments	50.00
21	36	Wall & Pursel	Field material	90.00
21	37	Hermann H. Heiser	......do	60.00
22	38	George T. Quinby	Traveling expenses	20.20
25	39	......do	Field expenses	52.82
28	40	P. H. Christie	Services, February, 1889	140.00
28	41	Pay-roll	......do	125.00
28	42	......do	......do	956.66
28	43	......do	......do	125.00
28	44	H. B. Cartwright & Co.	Subsistence supplies	109.55
28	45	Palace Hotel	Subsistence	18.50
28	46	R. S. Tarr	Traveling expenses	11.30
28	47	W. A. McKenzie	Field material	83.07
28	48	R. S. Tarr	Field expenses	130.16
Mar. 13	49	P. H. Christie	......do	3.00
13	50	......do	Traveling expenses	75.56
13	51	Gore, Janney & Co	Field supplies	2.25
21	52	F. H. Newell	Field expenses	177.59
31	53	Pay-roll	Services, March, 1889	1,308.11
31	54	Draper Manufacturing Company	Instruments	30.00
31	55	Harold M. Dyar	Services, March, 1889	12.90
		Total		7,114.07

Abstract of disbursements made by John H. Renshawe, disbursing agent U. S. Geological Survey, during the third quarter of 1889.

Date.	No. of voucher	To whom paid.	For what paid.	Amount.
1889.				
Jan. 2	1	Van H. Manning, jr	Traveling expenses	$14.00
8	2	C. T. Reid	do	38.88
11	3	S. S. Gannett	do	16.25
12	4	do	Field expenses	62.45
21	5	William J. Peters	do	114.05
21	6	do	Traveling expenses	36.50
21	7	do	do	21.75
21	8	H. B. Blair	do	38.50
31	9	S. S. Gannett	Field expenses	223.15
21	10	Basil Duke	Traveling expenses	41.25
21	11	W. E. Lackland	do	42.25
21	12	F. D. Beatle	Atlas, St. Louis County, Mo	5.00
22	13	Geo. T. Hawkins	Traveling expenses	57.75
22	14	do	Field expenses	31.55
22	15	do	do	102.12
24	16	do	do	25.50
24	17	S. Chester Reid	Traveling expenses	49.75
25	18	J. H. Hagerty	Services, January, 1889	4.52
25	19	W. T. Walker	do	28.38
26	20	S. E. Cook	do	25.16
28	21	Fred J. Knight	Traveling expenses	67.89
28	22	do	Field expenses	8.95
28	23	do	do	382.75
31	24	Pay-roll	Services, January, 1889	931.70
Feb. 7	25	L. C. Lahnman	Storage	3.00
7	26	Stockwether & Funk	Care of stock, etc	20.10
7	27	J. H. Hagerty	do	43.55
23	28	Pay-roll	Services, February, 1889	866.60
Mar. 14	29	Stockwether & Funk	Care of stock, etc	13.00
14	30	J. H. Hagerty	do	50.00
14	31	H. E. Williams	Services, February, 1889	7.00
14	32	Chas. M. Simons	Storage to February 28	14.97
31	33	Pay-roll	Services, March, 1889	931.70
Jan. 9	34	Morrison B. Avery	Traveling expenses	38.50
		Total		4,358.47

Abstract of disbursements made by Anton Karl, special disbursing agent U. S. Geological Survey, during the third quarter of 1889.

1889.				
Jan. 18	1	Arthur P. Davis	Transportation and subsistence	$85.89
3	2	John Parker	do	4.00
23	3	Willard D. Johnson	do	291.06
25	4	J. W. Hays	Field supplies	297.05
25	5	do	Subsistence	113.57
31	6	Anton Karl	Services, January, 1889	172.20
Mar. 30	7	Geo. Maier	Field material	5.76
Feb. 2	8	Wm. Noedel	Subsistence	132.53
2	9	A. E. Laudenslager	do	59.67
2	10	Van Arsdell & Co	Field material	47.19
2	11	Geo. W. Bond & Bro	Subsistence	19.16
2	12	J. W. Miller	Field material	51.02
2	13	Manley L. Hart	Services, December 1 to 24, 1888	38.71
2	14	F. Geo. Pratt & Co	Subsistence	28.18
2	15	L. B. Putney	Field material	21.49
2	16	J. J. Shumway	Services, January 21 to 31, 1889	17.74
2	17	G. W. Bond & Bro	Field material	14.53
Mar. 30	18	Willard D. Johnson	Field expenses	270.00
30	19	Sam'l A. Foot	Services	4.73
30	20	W. N. Emmert	Subsistence	20.65
		Total		1,695.13

Abstract of disbursements made by A. O. D. Taylor, jr., special disbursing agent U. S. Geological Survey, during the third quarter of 1889.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
Jan. 21	1	J. Eliot Wolff	Pay to December 31, 1888	$48.91
21	2	A. Prescott Baker	Rent for December, 1888	50.00
21	3	J. Eliot Wolff	Field expenses	7.67
21	4	Richard Bliss	Bibliographical work	51.00
23	5	J. Eliot Wolff	Traveling expenses	37.98
23	6	J. A. Williams	Services, January 22, 1889	69.40
23	7	Adams Express Company	Express charges	24.05
24	8	H. L. Smyth	Traveling expenses	48.93
25	9	Raphael Pumpelly	Miscellaneous office expenses	41.10
29	10	Western Union Telegraph Co	Telegrams	3.42
29	11	W. Beals, jr	Services, December 11, 1888, to January 7, 1889.	34.20
29	12	C. L. Whittle	Pay for December, 1888	75.00
29	13	The Scovill & Adams Company	Photographic supplies	39.74
31	14	Chas. E. Hammett, jr	Stationery supplies	3.58
31	15	C. H. Codman & Co	Photographic supplies	3.66
31	16	Raphael Pumpelly	Pay for January, 1889	344.40
31	17	T. Nelson Dale	do	150.00
31	18	A. O. D. Taylor, jr	do	103.30
31	19	Richard Bliss	Bibliographical work	27.30
31	20	A. Prescott Baker	Rent for January, 1889	50.00
Feb. 1	21	Caswell, Massey & Co	Photographic supplies	2.50
1	22	Providence Telegraph Company	Telephone rent	11.50
15	23	W. J. Withrow	Traveling expenses	11.75
16	24	C. L. Whittle	Pay for January, 1889	53.02
20	25	J. A. Williams	Services	46.00
23	26	W. Beals, jr	do	24.15
26	27	Newport Water-Works	Water	9.00
26	28	G. P. Putnam's Sons	Stationery supplies	17.20
28	29	Raphael Pumpelly	Pay for February, 1889	311.20
28	30	A. O. D. Taylor, jr	do	93.40
28	31	T. Nelson Dale	do	150.00
28	32	A. Prescott Baker	Rent for February, 1889	50.00
28	33	James I. Bowler	Team hire	10.50
Mar. 1	34	Richard Bliss	Bibliographical work	20.70
27	35	Newport Gas-Light Company	Gas	11.05
28	36	William Andrews	Freight and cartage	16.00
28	37	New York and Boston Despatch Express Co.	Express charges	12.05
28	38	Keuffel & Esser	Drawing material	4.97
28	39	Eimer & Amend	Photographic supplies	4.75
28	40	E. & H. T. Anthony & Co	do	18.79
		Total		2,092.17

Abstract of disbursements made by Arnold Hague, special disbursing agent U. S. Geological Survey, during the third quarter of 1889.

1889.				
Jan. 12	1	Pay-roll of employés	Salaries, December, 1888	$715.30
12	2	Charles J. Cohen	Pasteboard trays	32.95
16	3	Jos. Hart	Services, November and December, 1888.	90.00
22	4	Henry J. Green	Instruments	24.00
31	5	Pay-roll of employés	Salaries, January, 1889	729.40
Feb. 8	6	E. J. Owenhouse	Storage	30.00
28	7	Pay-roll of employés	Salaries, February, 1889	666.20
Mar. 23	8	Jos. Hart	Services, January and February, 1889	90.00
31	9	Pay-roll of employés	Salaries, March, 1889	654.40
		Total		3,032.25

Abstract of disbursements made by Fielding Burnes, disbursing agent U. S. Geological Survey, during the third quarter of 1889.

1889.				
Jan. 22	1	W. R. Atkinson	Traveling expenses	$25.20
31	2	Pay-roll of employés	Services, January, 1889	1,590.29
Feb. 28	3	do	Services, February, 1889	1,526.60
Mar. 14	4	Marcus Baker	Traveling expenses	24.10
31	5	Pay-roll of employés	Services, March, 1889.	1,658.23
		Total		4,824.42

Abstract of disbursements made by Jno. D. McChesney, Chief Disbursing Clerk U. S. Geological Survey, during the fourth quarter of 1889.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
Apr. 6	1	Albert Williams	Services, April 1 to 6, 1889	$25.00
8	2	Gore, Janney & Co	Supplies	80.00
9	3	Z. D. Gilman	do	187.29
9	4	H. L. Muldrow	Horse	275.00
11	5	Chas. H. Cherry	Services, March 16 to April 14, 1889	50.00
11	6	W. P. Rust	Services, March, 1889	65.00
11	7	Robert Hay	do	110.00
11	8	T. W. Stanton	Services, March 2 to April 6, 1889	24.75
11	9	J. Schultzbach	Supplies	474.00
11	10	Washington Gas-Light Co	Laboratory supplies	55.25
11	11	Western Union Telegraph Co	Telegrams, February, 1889	5.91
20	12	John R. Proctor	Services, March 1 to April 20, 1889	70.00
20	13	Edward Kübel	Repairs to instruments	20.85
22	14	Hume & Co	Topographic supplies	12.93
22	15	R. R. Bowker	Publications	1.00
22	16	Sam. P. Barbee	Storage	37.50
22	17	Chas. F. Urquhart	Traveling expenses	65.85
22	18	R. U. Goode	do	66.75
22	19	Lawrence C. Johnson	do	28.95
22	20	Dunbaugh & Joy	Geologic supplies	45.78
22	21	Alfred M. Rogers	Storage	180.00
22	22	C. W. Coman	Services, February 1 to March 31, 1889	100.00
22	23	National Press Intelligence Co	Furnishing newspaper clippings	14.35
22	24	Atchison, Topeka & Santa Fé R. R.	Transportation of assistants	163.90
22	25	Richmond and Danville R. R	do	31.60
22	26	Denver and Rio Grande R. R	do	35.60
22	27	Utah Central Rwy	do	18.10
22	28	Chicago and Alton R. R	do	27.75
23	29	Wyckoff, Seamans & Benedict	Geologic supplies and repairs	48.25
23	30	Utah Central Rwy	Freight	1.26
23	31	Wm. Ballantyne & Son	Publications	13.10
23	32	J. S. Newberry	Services, October 1 to November 20, 1889.	498.95
23	33	Eva B. Middleton	Services, March 25 to April 15, 1889	25.00
23	34	Warren Upham	Services, March, 1889	103.30
23	35	Charles Catlett	Services, April, 1889	12.36
23	36	Emil Greiner	Laboratory supplies	5.00
23	37	Eimer & Amend	do	4.05
23	38	L. H. Schneider's Son	Supplies	128.74
24	39	Gottlieb Spitzer	Topographic material	25.50
26	40	James G. Bowen	Livery and field transportation	27.75
26	41	Wash. B. Williams	Supplies for illustration	10.00
26	42	J. S. Topham	Topographic supplies	5.00
27	43	Chas. H. Cherry	Services, April 5 to 27, 1889	55.00
27	44	Henry Baumgarten	Topographic supplies	3.00
27	45	Wm. A. Raborg	Traveling expenses	12.24
29	46	Geo. Ryneal, jr	Supplies	355.40
29	47	Royce & Marean	Laboratory supplies	7.10
29	48	W. B. Moses & Son	Topographical and paleontological supplies.	10.50
29	49	J. F. Gibbs	Services, March 6 to 26, 1889	90.00
29	50	Wabash Rwy	Transportation of assistants	13.45
29	51	Moore & Cullom	Forage and transportation	24.00
29	52	Crane & Co	Irrigation supplies	30.00
29	53	Keuffel & Esser	Topographic supplies	68.20
29	54	do	do	17.40
29	55	Gustav E. Steckert	do	10.00
29	56	E. Morrison	Supplies	3.60
29	57	Edward J. Hannan	do	2.50
29	58	W. B. Moses & Son	Topographic supplies	6.00
29	59	Julius Bien & Co	Copies of Geological and Topographical Atlas.	448.75
29	60	Denver and Rio Grande R. R	Freight charges	4.58
29	61	Adams Express Co	do	109.65
30	62	Sam. H. Scudder	Services, April, 1889	206.00
30	63	Leo. Lesquereux	do	75.00
30	64	E. H. Shuster	do	75.00
30	65	Ira Sayles	do	115.40
80	66	Henry B. Hitz	do	60.00
30	67	Lawrence C. Johnson	do	115.40
30	68	O. C. Marsh	do	329.70
30	69	Pay-roll of employés	do	3,518.95
30	70	do	do	1,190.90
30	71	do	do	581.10
30	72	do	do	2,358.89
30	73	do	do	1,651.80
30	74	do	do	1,026.26
30	75	do	do	964.20
30	76	do	do	908.60

Abstract of disbursements made by Jno. D. McChesney, etc.—Continued.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
Apr. 30	77	Pay-roll of employés	Services, April, 1889	$396.70
30	78	do	do	320.00
May 1	79	J. Henry Blake	do	148.30
1	30	N. S. Shaler	Services, January 16 to April 30, 1889	260.00
1	81	Eric M. Noble	Supplies	130.00
1	82	Browne and Sharpe Manufacturing Co.	do	3.93
1	83	W. H. Warner	Services, April, 1889	19.80
1	84	William B. Clark	do	130.00
3	35	J. B. Woodworth	do	50.00
3	86	C. W. Coman	do	50.00
3	87	Joseph F. James	do	65.00
3	88	Geo. E. Luther	do	100.00
3	89	C. R. Van Hise	do	197.80
3	90	H. L. Smyth	Services, March and April, 1889	202.20
3	91	E. H. Keller	Topographical supplies	25.50
3	92	N. P. Jones	Photographic prints	7.55
3	93	E. R. Maurer	Services, April 13 to 27, 1889	6.00
4	94	Z. D. Gilman	Supplies	21.25
4	95	J. S. Topham	Field material	63.00
4	96	Washington Gas-Light Co	Supplies	54.01
4	97	Jas. Melton	Board, etc	32.50
4	98	C. J. Merriam	Services, April, 1889	50.00
4	99	W. P. Rust	do	65.00
4	100	H. S. Williams	do	123.60
4	101	E. & H. T. Anthony & Co	Supplies for illustrations	48.00
4	102	Chas. H. Sternberg	Paleontologic specimens	32.00
4	103	Wm. C. Day	Services, February 11 to April 10, 1889.	100.00
4	104	United Lines Telegraph Co	One telegram	1.15
4	105	Western Union Telegraph Co	Telegrams	10.36
6	106	Frank Leverett	Services, March 20 to April 30, 1889	180.00
6	107	Warren Upham	Services, April, 1889	98.90
6	108	James G. Bowen	Livery and transportation	49.50
6	109	Geo. H. Williams	Services, April, 1889	120.00
6	110	D. A. Crider	Traveling expenses	20.70
6	111	Wesley Pratt	do	11.25
6	112	W. T. Smillie	do	11.25
6	113	Pay-roll of employés	Services, April, 1889	165.67
6	114	Geo. W. Shutt	do	247.25
8	115	Ira Sayles	Traveling expenses	22.67
8	116	E. M. Hasbrouck	do	22.00
8	117	R. O. Gordon	do	57.25
8	118	Chas. S. Cudlip	Supplies for illustrations	456.86
8	119	Chas. H. Cherry	Services, April 29 to May 7, 1889	18.00
8	120	W. R. Atkinson	Traveling expenses	68.15
10	121	Smithsonian Institution	Transportation of publications	162.95
10	122	E. W. F. Natter	Traveling expenses	10.24
10	123	do	Field expenses	14.90
10	124	R. C. Jones	Publications	6.00
10	125	Lawrence C. Johnson	Traveling expenses	43.09
10	126	C. W. Coman	do	9.98
10	127	do	do	63.79
10	128	Morrison R. Avery	do	15.25
10	129	Smedley Bros. & Co	Freight charges	108.27
10	130	Jos. T. Bushman	Treatment of sick animal	24.00
12	131	Robert Leitch & Sons	Topographic supplies	35.35
13	132	Geo. S. King	Services, May 1 to 13, 1889	20.97
13	133	C. A. White	Traveling expenses	24.75
14	134	Robt. D. Cummin	do	12.00
16	135	William D. Clark & Co	Supplies	46.87
16	136	Z. D. Gilman	do	227.99
16	137	Melville Lindsay	Topographic and illustration supplies.	3.70
16	138	Smithsonian Institution	Transportation of exchanges	398.90
16	139	Lutz & Bros	Geological material	8.00
16	140	E. E. Jackson & Co	Supplies	366.04
16	141	John F. Paret	do	2.75
18	142	John H. Jennings	Traveling expenses	19.60
18	143	Geo. Ryneal, jr	Topographical supplies	338.47
18	144	E. W. Woodruff	Irrigation supplies	3.00
18	145	Joseph Willett	Services, April 1 to May 6, 1889	25.00
18	146	Frasse & Co	Laboratory supplies	17.50
18	147	Pennsylvania R. R	Transportation of assistants	192.07
18	148	Chas. H. Kraft	Laboratory supplies	31.59
18	149	Alvah Bushnell	Irrigation supplies	24.96
18	150	Thos. Sinclair & Sons	Topographic maps	140.00
18	151	James W. Queen & Co	Laboratory supplies	5.00
18	152	do	Supplies	490.23

Abstract of disbursements made by Jno. D. McChesney, etc.—Continued.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
May. 18	153	R. U. Goode	Topographic expenses	$31.52
18	154	E. J. Lewis	Paleontologic material	35.86
18	155	Fred. A. Schmidt	Supplies	127.70
18	156	Robert Boyd	do	67.71
20	157	William B. Clark	Services, May 1 to 15, 1889	65.00
21	158	Daniel Shanahan	Topographic supplies	4.00
21	159	T. W. Stanton	Services, May 3 to 18, 1889	18.00
21	160	F. E. Conrad & Co	Supplies and forage	391.83
21	161	Denver and Rio Grande R. R	Transportation of assistants	17.80
21	162	United States Express Co	Freight charges	215.25
21	163	R. D. Cummin	Topographic material	6.50
21	164	Emil Greiner	Laboratory supplies	5.20
21	165	Geo. Ritter	Services, May 18 to 21, 1889	9.00
22	166	Baldwin Bros. & Co	Freight charges	10.22
23	167	J. Edward Whitfield	Services, May 1 to 16, 1889	70.33
23	168	J. R. McGarrity	Freight charges	14.00
22	169	E. B. Clark	Traveling expenses	11.30
22	170	J. W. Thom	do	11.30
22	171	Wm. Kramer	do	10.47
22	172	C. J. Akin	do	10.07
22	173	Robt. D. Cummin	do	8.62
22	174	Glen. S. Smith	do	8.62
22	175	G. E. Hyde	do	20.68
22	176	Lewis J. Battle	do	16.05
23	177	David T. Day	do	59.08
22	178	Fremont, Elkhorn and Missouri Valley R. R.	Freight	103.97
22	179	Dietrick W. Kolb	Services, May 1 to 14, 1889	22.00
22	180	Geo. W. P. Coates	Pasturage	98.79
23	181	Lyman Bridges	Services, April 2 to May 14, 1889	380.00
24	182	Wm. Ballantyne	Supplies	10.40
24	183	Darling, Browne & Sharpe	do	72.00
24	184	Edward Kahler	do	28.80
24	185	H. Rosendale	Repairs	1.25
24	186	J. L. Smith	Topographic map	90.50
25	187	Franklin R. Carpenter	Services, May 17 to 24, 1889	25.00
25	188	H. S. Wallace	Traveling expenses	64.90
29	189	Charles C. Bassett	Services, April, 1889	98.90
29	190	Lyman Bridges	Services, May 15 to 31, 1889	140.11
29	191	E. M. Hasbrouck	Field expenses	3.00
31	192	Pay-roll of employés	Services, May, 1889	155.00
31	193	T. D. Haile	do	50.00
31	194	O. C. Marsh	do	340.60
31	195	J. B. Fletcher	do	200.00
31	196	N. S. Shaler	do	270.00
31	197	Leo Lesquereux	do	75.00
31	198	Geo. F. King	Services, January 2 to April 19, 1889	50.00
31	199	Lawrence C. Johnson	Services, May, 1889	119.20
31	200	Sam H. Scudder	do	213.00
31	201	J. Henry Blake	do	153.40
31	202	George M. Turner	Services, May 10 to 24, 1889	12.00
31	203	R. M. Moore	Services, April, 1889	5.83
31	204	R. J. Moore	Services, May, 1889	35.00
31	205	J. B. Woodworth	do	50.00
31	206	Geo. E. Ladd	Services, May 1 to 10, 1889	18.00
31	207	C. M. Gordon	Services April 26 to 30, 1889	6.65
31	208	do	Services, May, 1889	40.00
31	209	Lincoln Martin	Traveling expenses	19.25
31	210	James E. Shelley	do	25.70
31	211	G. E. Ladd	do	27.63
31	212	Geo. T. Hawkins	do	23.90
31	213	G. L. Johnson	do	6.38
31	214	L. Manasse	Repairs to topographical instruments.	7.00
31	215	Apollo Hall	Services, January 1 to May 31, 1889	75.00
31	216	Pay-roll of employés	Services, May, 1889	179.84
31	217	Montana Central Rwy	Transportation of assistants	5.85
31	218	Pay-roll of employés	Services, May, 1889	3,807.50
31	219	do	do	1,268.12
31	220	do	do	2,288.10
31	221	do	do	1,696.40
31	222	do	do	1,116.13
31	223	do	do	907.14
31	224	do	do	906.07
31	225	do	do	406.60
31	226	do	do	372.50
31	227	do	Services, May, 1889	2,036.04
31	228	H. B. Hitz	do	60.00
31	229	Ira Sayles	do	119.20

Abstract of disbursements made by Jno. D. McChesney, etc.—Continued.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
June 3	230	Henry Bufford	Services, May 23 to 29, 1889	$12.00
3	231	Joseph F. James	Services, May, 1889	67.50
3	232	C. W. Coman	do	50.00
3	233	Wm. P. Rust	do	67.50
4	234	Geo. W. Shutt	do	255.50
3	235	Daniel O'Hare	Services, May 18 to 31, 1889	36.00
3	236	William A. Balch	do	36.00
3	237	Wm. B. Clark	Services, May 16 to 31, 1889	70.00
4	238	Baltimore and Ohio R. R	Freight	8.08
4	239	Western Union Telegraph Co	Telegrams, April, 1889	30.52
4	240	W. H. Lovell	Field expenses	24.70
4	241	Geo. H. Williams	Services, May, 1889	120.00
4	242	Columbia Phonograph Company	Irrigation supplies	9.96
4	243	Washington Gas-Light Company	Laboratory supplies	48.51
4	244	W. H. Lovell	Traveling expenses	5.90
4	245	Sumner H. Bodfish	do	42.18
5	246	Josiah Pierce, jr	Sarlary, May, 1889	100.00
5	247	Quartermaster's Department, U. S. Army.	Topographic field material	43.62
5	248	do	Topographic and irrigation material.	335.56
5	249	do	Topographic material	133.20
7	250	Howard A. Graham	Services, May, 1889	36.92
7	251	C. J. Merriam	do	50.00
7	252	Geo. E. Luther	do	100.00
7	253	Wm. Kohr	Services and material	40.00
7	254	Chas. H. Sternberg	Paleontologic specimens	86.00
7	255	Jesse Lemsford	Field material	65.00
8	256	Lizzie M. Reed	Photographic prints	3.00
8	257	Wm. Kramer	Field expenses	52.06
8	258	do	Traveling expenses	7.88
8	259	J. H. Wheat	do	8.17
7	260	E, W. F. Natter	do	13.70
7	261	R. U. Goode	do	36.50
7	262	Ben. K. Emerson	do	41.00
7	263	James Longstreet, jr	do	13.70
7	264	Ambrose F. Dudley	do	12.85
7	265	C. R. Van Hise	Services, May, 1889	204.40
7	266	Geo. T. Hawkins	Field expenses	137.82
7	267	do	do	187.94
7	268	do	do	63.10
7	269	E. W. F. Natter	do	65.20
7	270	Cullen & Boyd	Forage of public animals	35.70
10	271	Sumner H. Bodfish	Salary, June 1 to 21, 1889	10.99
10	272	Frank Dutton	Field expenses	58.19
10	273	Glenn S. Smith	do	23.95
10	274	F. P. Gulliver	Traveling expenses	8.17
10	275	Lewis J. Battle	Field expenses	9.13
10	276	S. S. Gannett	Traveling expenses	23.98
10	277	do	Field expenses	85.20
10	278	J. H. Jennings	Traveling expenses	6.15
10	279	do	Field expenses	78.68
10	280	R. D. Cunningham	Field supplies	115.00
10	281	R. D. Cummins	do	43.17
10	282	J. M. Rockwell	do	44.65
10	283	Nance & Meyer	do	29.50
10	284	Howsley Bros	do	81.00
10	285	N. H. Burns & Co	do	199.67
11	286	H. S. Wallace	do	78.50
11	287	Warren Upham	Services, May, 1889	102.20
11	288	Chas. H. Cherry	Services, May 15 to June 8, 1889	36.00
11	289	Ohio and Mississippi Rwy	Freight charges	2.71
11	290	Frank Sutton	Traveling expenses	36.45
11	291	W. E. Horton	do	22.63
12	292	Burlington and Missouri River R. R.	Freight charges	18.15
12	293	Utah Central Rwy	do	9.92
12	294	Chicago, Milwaukee and St. Paul R. R.	do	12.97
12	295	E. B. Clark	Field supplies	54.40
12	296	Geo. Cartner	Publications	6.00
12	297	R. O. Gordon	Field expenses	108.90
12	298	W. H. Lovell	do	74.37
12	299	F. P. Gulliver	do	118.21
12	300	Robert Hay	Services, April 1 to May 11, 1889	105.00
12	301	W. R. Atkinson	Traveling expenses	77.77
13	302	Chas. F. Urquhart	Field expenses	76.75
14	303	C. Whitman Cross	Geologic expenses	29.96
14	304	James G. Bowen	Forage and transportation	53.00
15	305	Baltimore and Ohio R. R	Transportation of assistants	91.70

Abstract of disbursements made by Jno. D McChesney, etc.—Continued.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
June 15	306	J. L. Smith	Field material	$22.50
15	307	Mrs. S. A. Boyett	Board and lodging	25.00
15	308	Vernon F. Marsters	Services, April 25 to May 31, 1889	60.00
15	309	Ira Sayles	Traveling expenses	69.19
15	310	Levy, Dreyfus & Co	Topographic material	288.78
15	311	H. B. Blair	Topographic field expenses	125.75
17	312	I. C. Russell	Traveling expenses	58.50
17	313	do	Geologic field expenses	40.13
17	314	W. H. Lowdermilk	Publications	585.90
17	315	W. B. Clark	Services, June 1 to 13, 1889	55.00
17	316	Castle & Henshaw	Irrigation and geologic material	20.50
17	317	Chas. S. Cudlip	Illustration material	503.40
17	318	E. A. Birge	Services, August, 1888	15.00
17	319	H. L. Smyth	Services, May, 1889	102.20
18	320	S. S. Gannett	Topographic field expenses	68.12
21	321	Ulrico Hoepli	Publications	4.92
21	322	Ashton Nield	do	291.99
21	323	Citizens' National Bank	Exchange	3.09
21	324	William D. Clark & Co	Topographic supplies	74.92
21	325	C. Becker	Geologic material	2.00
21	326	Emil Greiner	Laboratory material	25.65
21	327	Pennsylvania R. R	Transportation of assistants	70.20
22	328	S. J. Haislett	Field material	95.50
22	329	James B. Lambie	Geologic supplies	.79
22	330	J. S. De Lancey	One sorrel mare	175.00
25	331	W. B. Clark	Traveling expenses	322.69
25	332	E. A. Schneider	do	19.50
25	333	W. E. Lackland	do	21.70
25	334	H. B. Blair	do	10.00
25	335	Basil Duke	do	14.05
25	336	J. H. Gray	do	7.75
25	337	S. E. Cook	do	18.90
25	338	Gordon & Garland	Supplies and forage	35.35
25	339	Atchison, Topeka and Santa Fé R. R.	Transportation of assistants	21.25
27	340	I. C. Russell	Field supplies	21.90
27	341	Z. D. Gilman	Supplies	361.40
27	342	Wyckoff, Seamans & Benedict	Type-writer supplies	138.50
27	343	J. D. Free, jr	Publications	45.00
29	344	Leo Lesquereux	Services, June, 1889	75.00
29	345	O. C. Marsh	do	329.70
29	346	Sam. H. Scudder	do	206.00
29	347	Harriet Biddle	do	30.00
29	348	J. Henry Blake	do	148.30
29	349	Lawrence C. Johnson	do	115.40
29	350	I. C. Russell	do	164.80
29	351	C. R. Van Hise	do	197.80
29	352	N. S. Shaler	do	250.00
29	353	Geo. E. Luther	do	100.00
29	354	H. S. Manly	do	25.00
29	355	J. H. Hagerty	do	40.00
29	356	G. Unsell	do	35.00
29	357	W. U. Simmons	do	20.00
29	358	J. H. Gray	do	41.77
29	359	S. E. Cook	do	39.51
29	360	J. H. Renshawe	do	206.00
29	361	R. U. Goode	do	164.80
29	362	Jefferson Middleton	Traveling expenses	30.77
29	363	R. U. Goode	do	53.15
29	364	Josiah Pierce, jr	Services, June, 1889	100.00
29	365	T. W. Stanton	Services, May 31 to June 29, 1889	57.38
29	366	F. Marshall Smith	Services, June, 1889	50.00
29	367	Vernon F. Marsters	do	50.00
29	368	Wm. P. Rust	do	75.00
29	369	A. M. Gibson	Services, May 13 to June 29, 1889	136.50
29	370	Joseph F. James	Services, June, 1889	62.50
29	371	John R. Proctor	Services, April 20 to June 30, 1889	90.00
29	372	C. J. Merriman	Services, June, 1889	50.00
29	373	W. H. Lovell	Field expenses	98.27
29	374	Paul Holman	Services, June, 1889	69.29
29	375	Pay-roll of employés	do	3,444.82
29	376	do	do	1,695.08
29	377	do	do	2,394.46
29	378	do	do	2,021.46
29	379	do	do	1,217.49
29	380	do	do	1,111.12
29	381	do	do	947.33
29	382	do	do	844.80
29	383	do	do	396.70

Abstract of disbursements made by Jno. D. McChesney, etc.—Continued.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
June 29	384	Pay-roll of employes	Services, Jnne, 1889	$572.50
29	385	......do	......do	60.00
29	386	Lawrence C. Johnson	Traveling expenses	86.90
29	387	Brentanos	Publications	1.40
29	388	Gustav E. Stechert	......do	226.05
29	389	Ohio and Mississippi Rwy	Freight	7.35
29	390	Chicago, Milwaukee and St. Paul R. R.	......do	1.26
29	391	......do	......do	.42
29	392	Baltimore and Ohio R. R	......do	38.52
29	393	Chicago, St. Louis and Pittsburgh R. R.	......do	5.79
29	394	Robt. D. Cummin	Topographical field expenses	9.00
29	395	F. Marshall Smith	Traveling expenses	10.35
29	396	A. Herman	Services, April to June 30, 1889	250.00
29	397	F. Berger	......do	240.00
29	398	T. A. Bostwick	......do	250.00
29	399	H. Gibb	......do	210.00
29	400	Pay-roll of employés	Services, June, 1889	155.00
29	401	......do	......do	170.00
29	402	Nelson H. Darton	Traveling expenses	30.18
		Total		72,445.75

SALARIES, OFFICE OF THE DIRECTOR.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
Apr. 11	1	Crandal Mackey	Services, April, 1889	$17.80
30	2	Pay-roll of employés	......do	2,870.05
May 31	3	......do	Services, May, 1889	2,964.82
June 30	4	......do	Services, June, 1889	2,820.58
		Total		8,673.25

Abstract of disbursements made by C. D. Davis, special agent U. S. Geological Survey, during the fourth quarter of 1889.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
Apr. 2	1	D. C. Harrison	Services, March, 1889	$103.30
13	2	N. A. Morse	Storage	3.00
13	3	James G. Reaves	......do	6.00
13	4	......do	Pasturage	35.00
13	5	John W. Price	......do	70.00
13	6	H. B. Dunn	......do	144.00
13	7	P. P. Glover	......do	50.00
13	8	J. P. Hobson	......do	50.00
13	9	Z. U. Lockhart	......do	10.00
13	10	W. F. Fling	......do	24.00
15	11	A. E. Wilson	Traveling expenses	14.50
19	12	P. H. Christie	Field expenses	11.60
22	13	C. Schneider	Field supplies	10.71
22	14	W. R. Murphy	Forage	48.00
30	15	Pay-roll of employés	Services, April, 1889	2,922.50
May 1	16	F. P. May & Co	Supplies	25.63
1	17	Henkel & Corpening	Storage	3.00
1	18	D. C Harrison	Services, April, 1889	98.90
1	19	L. D. Brent	......do	65.00
7	20	L. C. Fletcher	Field expenses	105.22
7	21	N. A. Poole	Field supplies	15.00
7	22	......do	......do	48.40
9	23	L. C. Fletcher	Field expenses	57.16
9	24	L. O. Wrenn	Supplies	55.37
9	25	R. S. Terry	Board, etc	71.75
10	26	W. R. Murphy	Forage	48.00
10	27	P. P. Glover	......do	50.00
11	28	Richmond and Alleghany R. R.	Freight charges	92.60
13	29	E. C. Barnard	Field expenses	95.75
13	30	......do	Traveling expenses	10.82
13	31	W. O. Beall	......do	8.40
13	32	A. E. Wilson	......do	9.30
13	33	J. L. Bridwell	......do	10.22

Abstract of disbursements made by C. D. Davis, etc.—Continued.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
May 13	34	C. G. Van Hook	Traveling expenses	$19.15
14	35	Clifford Arrick	do	12.75
14	36	L. C. Fletcher	Field expenses	134.70
14	37	F. P. Gulliver	Traveling expenses	8.18
16	88	do	Field expenses	67.32
16	39	Z. U. Lockhart	Freight, animals, etc	722.00
16	40	Chas. E. Cooke	Traveling expenses	3.00
16	41	L. C. Fletcher	do	68.55
16	42	do	Field expenses	74.20
21	43	E. C. Barnard	do	155.17
23	44	L. C. Fletcher	do	62.53
23	45	M. Hackett	do	31.30
23	46	do	Traveling expenses	12.26
31	47	D. C. Harrison	Services, May, 1889	102.20
31	48	L. D. Brent	do	65.00
31	49	R. B. Cameron	do	60.00
31	50	W. C. O'Connell	do	76.60
31	51	Louis J. Battle	do	60.00
31	52	R. O. Gordon	do	102.20
31	53	Fred. J. Knight	do	153.40
31	54	Pay-roll of employés	do	516.40
31	55	do	do	584.26
31	56	do	do	1,426.20
29	57	J. C. Hobson	Forage, etc	50.00
June 3	58	L. C. Fletcher	Field expenses	142.64
4	59	James G. Reaves	Forage, etc., April, 1889	35.00
4	60	do	Forage, etc., May, 1889	35.00
4	61	W. F. Fling	Forage, etc., April, 1889	24.00
4	62	do	Forage, etc., May, 1889	24.00
4	63	N. B. Dunn	Forage, etc., April, 1889	144.00
4	64	John W. Price	do	70.00
4	65	do	Forage, etc., May, 1889	70.00
4	66	J. C. Hobson	do	50.00
5	67	Nannie M. Peyton	Services, May 18 to 31, 1889	19.17
7	68	E. C. Barnard	Field expenses	84.20
7	69	J. M. Duncan	Services, May, 1889	25.00
11	70	L. C. Fletcher	Field expenses	160.69
14	71	R. C. McKinney	Services, May, 1889	102.20
17	72	Geo. E. Kennedy & Son	Subsistence supplies	32.80
18	73	E. C. Barnard	Field expenses	155.13
20	74	L. C. Fletcher	do	198.07
25	75	S. J. Haislett	Tents, etc	201.50
25	76	Louis Nell	Traveling expenses	44.00
25	77	do	Field expenses	55.59
30	78	R. M. Towson	Services, June, 1889	98.90
30	79	Morris Bien	do	148.30
30	80	T. Howard Seeley	do	50.00
30	81	R. O. Gordon	do	98.90
30	82	R. B. Cameron	do	60.00
30	83	Fred J. Knight	do	148.30
30	84	L. D. Brent	do	65.00
30	85	D. C. Harrison	do	98.90
30	86	Lewis J. Battle	do	60.00
30	87	Geo. H. Lamar	do	60.00
30	88	B. Peyton Legare	do	50.00
30	89	W. H. Griffin	do	50.00
30	90	Pay-roll of employés	do	576.50
30	91	do	do	802.87
30	92	N. A. Morse	Storage, April 1 to June 30, 1889	7.80
30	93	L. C. Fletcher	Field expenses	107.21
30	94	R. C. McKinney	Services, June, 1889	98.90
30	95	Pay-roll of employés	do	509.30
30	96	Shack Smith	Services, June 9 to 30, 1889	29.33
30	97	H. T. Irwin	Services, June 16 to 30, 1889	30.00
30	98	Edwd. Patterson	Services, June 17 to 30, 1889	14.00
30	99	Jos. N. Austin	Services, June 18 to 30, 1889	13.00
30	100	Judson D. Lincoln	Services, June 16 to 30, 1889	30.00
30	101	Z. Dunn	Services, June 15 to 30, 1889	20.00
30	102	Nannie M. Peyton	Services, June, 1889	25.00
30	103	W. C. Frye	Traveling expenses	28.65
30	104	M. Hackett	do	19.15
30	105	do	Field expenses	82.69
30	106	F. P. Metzger	do	49.82
30	107	do	Traveling expenses	30.06
30	108	Chattanooga Saddlery Co	Harness	138.00
30	109	Gottlieb Spitzer	Stamps (rubber)	.75
30	110	W. J. O'Connell	Services, June, 1889	74.20
30	111	J. M. Duncan	Services, June 1 to 13, 1889	10.83
		Total		14,299.85

Abstract of disbursements made by Mark B. Kerr, disbursing agent U. S. Geological Survey, during the fourth quarter of 1889.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
Apr. 5	1	J. F. Smith & Co	Pasturage	$9.00
5	2	T. D. Haile	Services, February 20 to March 31, 1889.	59.45
5	3	......do	Field expenses	28.70
5	4	Geo. W. P. Coates	Pasturage	39.00
5	5	J. E. Corrigan	Storage	10.50
18	6	Mark B. Kerr	Field expenses	34.10
18	7	Main & Winchester	.....do	5.50
18	8	A. Leitz & Co	......do	6.00
10	9	John W. Hayes	......do	468.44
15	10	J. W. Dobbins	Traveling expenses	3.85
15	11	S. S. Mitchell	......do	4.15
15	12	Willard D. Johnson	Field expenses	93.95
18	13	Pay-roll (Johnson)	Services, March, 1889	917.60
18	14	M. Studjuski	Field material	755.00
18	15	W. H. Hyde	......do	180.00
18	16	William H. Anderson	......do	250.00
18	17	F. E. M. Jayne	......do	125.00
18	18	Kennedy & Co	Field subsistence	7.58
18	19	......do	......do	22.22
18	20	Martin Tobman	Field forage	30.58
18	21	Isaac N. Hoger	Field pasturage	52.50
18	22	H. W. Turner	Field expenses	15.40
23	23	E. M. Douglas	Traveling expenses	23.20
24	24	R. S. Swift	One mule	130.00
24	25	Goldberg, Bowen & Co	Field expenses	22.92
24	26	G. W. Granniss	Rent laboratory rooms	55.00
30	27	......do	......do	55.00
30	28	Pay-roll (Becker)	Services, April, 1889	373.80
30	29	W. H. Melville	......do	164.80
30	30	G. F. Becker	......do	329.70
24	31	Willard D. Johnson	Field expenses	413.99
24	32	......do	......do	200.33
25	33	R. Henry Philips	......do	20.35
25	34	J. B. Hamilton	Two horses	300.00
25	35	W. H. Hyde	One wagon	90.00
30	36	R. U. Goode	Services, April, 1889	164.80
30	37	Chas. F. Urquhart	......do	98.90
30	38	Pay-roll (office)	......do	800.40
30	39	Pay-roll	......do	329.60
30	40	......do	......do	1,868.35
30	41	Amos Scott	......do	60.00
30	42	Chas. W. Howell	......do	60.00
30	43	Arthur P. Davis	Field expenses	19.15
30	44	Pay-roll (Phillips)	Services, April, 1889	282.40
May 1	45	C. H. Fitch	Traveling expenses	19.00
11	46	Pay-roll (Johnson)	Services, April, 1889	537.60
10	47	H. W. Turner	Field expenses	31.22
10	43	......do	Traveling expenses	19.90
10	49	F. C. Boyce	Pay, April, 1889	60.00
11	50	Wempe Bros	Paper boxes	22.50
11	51	Goldberg, Bowen & Co	Field subsistence, etc	62.92
11	52	H. A. Messenger	Forage, etc	30.20
11	53	Isaiah Rendell	......do	31.80
11	54	R. S. Swift	One mule	130.00
11	55	Main & Winchester	Field supplies	15.59
13	56	Baker & Hamilton	One road wagon	76.50
11	57	McCutcheon, Payne & Co	Field forage	33.55
11	58	Stuart & McNair	Subsistence	14.00
13	59	R. H. Chapman	Traveling expenses	69.10
15	60	James Hennessy	Forage	37.52
16	61	Pay-roll (Hays)	Services, April, 1889	455.40
15	62	Mark B. Kerr	Field expenses	34.90
18	63	Wm. T. Griswold	Traveling expenses	125.75
22	64	E. M. Douglas	......do	135.85
23	*65	Willard D. Johnson	......do	....
23	66	Daniel M. Adams	......do	24.05
23	67	C. H. Fitch	......do	33.90
23	68	Robt. J. Breckenridge	......do	18.25
23	69	P. V. S. Bartlett	Field expenses	39.70
23	70	R. H. Phillips	......do	41.98
23	71	H. M. Wilson	......do	54.75
23	72	R. C. McKinney	Traveling expenses	94.60
23	73	G. E. Verrill	......do	102.25
23	74	Mark B. Kerr	......do	164.08
29	75	......do	Field expenses	15.35
31	76	W. H. Melville	Services, May, 1889	170.40
31	77	G. F. Becker	......do	340.60
31	78	Pay-roll (Becker)	......do	407.40

*Rejected.

Abstract of disbursements made by Mark B. Kerr, etc.—Continued.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
May 31	79	Pay-roll (office)	Services, May, 1889	$1,024.60
31	80	Pay-roll (office and field)	do	256.20
31	81	W. T. Griswold	do	170.40
31	82	C. H. Fitch	do	153.40
31	83	E. T. Perkins, jr	do	119.20
31	84	R. U. Goode	do	170.40
31	85	Chas. F. Urquhart	do	102.20
31	86	Frank E. Gove	do	60.00
31	87	H. M. Wilson	do	170.40
31	88	E. M. Douglas	do	170.40
31	89	R. H. Chapman	do	102.20
31	90	A. H. Thompson	do	255.50
31	91	Mark B. Kerr	do	153.40
31	92	E. M. Hasbrouck	do	60.00
31	93	E. M. Douglas	Services, June, 1889	164.80
June 29	94	Wm. H. Hyde	Field material	233.85
		Total		15,793.77

Abstract of disbursements made by P. H. Christie, special disbursing agent U. S. Geological Survey, during the fourth quarter of 1889.

1889.				
Apr. 18	1	L. D. Hopson	Traveling expenses	$59.90
18	2	J. B. Williams	do	36.80
19	3	Wm. P. Trowbridge, jr	do	47.22
19	4	do	Field expenses	11.35
19	5	W. & L. E. Gurley	Instruments	197.20
19	6	F. H. Newell	Field expenses	106.16
20	7	W. & L. E. Gurley	Instruments	195.00
29	8	R. W. Stewart & Co	Field supplies	88.67
29	9	Lallie & Bailey	Instruments	100.00
29	10	E. S. Ritchie & Sons	do	250.00
30	11	Pay-roll	Services, April, 1889	125.00
May 3	12	Robert Robertson	Traveling expenses	63.40
3	13	do	Field expenses	127.92
6	14	J. B. Williams	Traveling expenses	93.00
Apr. 30	15	Pay-roll	Services, April, 1889	731.32
May 6	16	Harold M. Dyar	Traveling expenses	67.70
Apr. 30	17	R. S. Tarr	Services, April, 1889	75.00
30	18	P. H. Christie	do	148.30
May 7	19	The Schiff Carleton Grocery Co	Subsistence supplies	35.20
8	20	G. W. Bond & Bro	Field supplies	42.32
8	21	George E. Curtis	Field expenses	286.62
10	22	Cartwright & Griswold	Field supplies	8.50
8	23	Denver and Rio Grande R. R	Transportation	121.54
10	24	W. A. McKenzie	Field supplies	40.91
10	25	F. C. Duetscher	do	8.50
10	26	George T. Quinby	Traveling expenses	14.22
10	27	do	Field expenses	73.66
Apr. 30	28	Frank Harrison	Services, April, 1889	75.00
30	29	Fred'k H. Newell	do	125.00
30	30	T. M. Bannon	do	50.00
May 13	31	Palace Hotel	Subsistence	15.63
14	32	J. W. Mitchell	Traveling expenses	13.75
15	33	Lallie & Bailey	Instruments	300.00
20	34	R. S. Tarr	Subsistence	35.00
24	35	F. H. Newell	Traveling expenses	34.50
24	36	do	Field expenses	164.60
24	37	T. M. Bannon	Traveling expenses	55.75
29	38	W. R. Stewart & Co	Field supplies	2.83
30	39	L. D. Hopson	Traveling expenses	19.75
31	40	The Denver Transit and Warehouse Company.	Storage and carting	14.00
31	41	Pay-roll	Services, May, 1889	505.04
31	42	do	do	150.00
31	43	do	do	125.00
31	44	do	do	328.40
31	45	R. S. Tarr	do	75.00
31	46	Frank Harrison	do	75.00
31	47	P. H. Christie	Traveling expenses	51.65
31	48	W. A. Farish	do	53.90
31	49	R. S. Tarr	do	22.05
31	50	do	do	35.60

Abstract of disbursements made by P. H. Christie, etc.—Continued.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
May 31	51	Wm. P. Trowbridge, jr	Traveling expenses	$25.10
31	52	E. B. Rail	Field supplies	156.97
31	53	P. H. Christie	Field expenses	43.79
31	54	Wm. P. Trowbridge, jr	......do	32.00
June 3	55	Robert Robertson	......do	226.94
4	56	Mason Chapman	Stock	60.00
4	57	Robert Robertson	Traveling expenses	41.55
6	58	J. B. Williams	......do	22.80
6	59	......do	Field expenses	164.40
6	60	P. S. Schick	Stock	200.00
7	61	John J. Rogers	Field material	69.75
7	62	R.S. Tarr	Traveling expenses	45.70
8	63	L. D. Hopson	Field expenses	52.50
8	64	Frank R. Coffin & Bro	Field material	156.35
8	65	E. L. Cahalan	Stock	225.00
10	66	J. W. Mitchell	Field expenses	28.25
10	67	W. & L. E. Gurley	Instruments	579.00
10	68	Nathan Falk & Bro	Field supplies	47.67
11	69	Frank R. Coffin & Bro	......do	27.00
12	70	D. H. Moseley	Stock	100.00
13	71	F. H. Newell	Field expenses	75.85
14	72	A. D. Foote	Services, May, 1889	140.11
18	73	J. B. Williams	Traveling expenses	53.05
19	74	R. S. Tarr	Field expenses	22.55
19	75	Eben Pinkham	Stock (horse)	65.00
19	76	Elwood Mead	Instruments	85.00
19	77	......do	Services, December 14, 1888, to April 18, 1889.	70.00
19	78	P. Mace	Stock (horse)	100.00
19	79	B. H. Scott	Stock (horses)	250.00
20	80	Frank R. Coffin & Bro	Field material	355.05
20	81	Overland Hotel	Meals and lodgings	70.00
20	82	John J. Rogers	Field material	223.00
20	83	Fred. Dangel	Subsistence supplies	74.35
20	84	A. D. Foote	Field expenses	110.00
24	85	T. M. Bannon	Traveling expenses	42.15
25	86	W. O. H. Martin	Field supplies	17.65
26	87	George T. Quinby	Traveling expenses	32.55
26	88	......do	Field expenses	122.65
26	89	Frank Harrison	Traveling expenses	37.75
28	90	W. M. Heidenrich	Services, May, 1889	18.06
28	91	J. B. Williams	Traveling expenses	13.60
30	92	M. Cohn	Stock (mules)	250.00
30	93	Pay-roll	Services, June, 1889	323.30
30	94	R. S. Tarr	......do	75.00
30	95	Denver Transit and Warehouse Company.	Storage and cartage	24.00
30	96	Sumner H. Bodfish	Services, June, 1889	184.62
30	97	C. E. Dutton	Traveling expenses	163.15
30	98	Pay-roll	Services, June, 1889	391.41
30	99	E. E. Ames	Field material	262.30
30	100	Sutler Street R. R	Stock (horses)	200.00
30	101	John Roach	Instruments	12.00
30	102	J. J. Evans	Field supplies	10.85
30	103	Hart & Brandenstein	......do	288.71
30	104	S. McKay	Subsistence	22.90
30	105	Burr Jennings	Services, June, 1889	17.33
30	106	Charles Edward Cany	......do	12.00
30	107	C. R. Gutheil	Instruments	331.50
30	108	Douglas Gray	Field material and stock (mules)	266.00
30	109	J. F. Raycraft	Stock (horses)	300.00
30	110	Lyman Bridges	Traveling expenses	125.75
30	111	Frank Harrison	Field expenses	219.37
30	112	B. J. Briggs	Field material	125.00
30	113	J. B. Williams	Services, June, 1889	100.00
30	114	R. S. Tarr	Field expenses	8.62
30	115	Pay-roll	Services, June, 1889	466.66
30	116	Douglas Taylor	......do	34.50
30	117	Wm. M. Welch	......do	34.50
30	118	H. M. Wilson	......do	197.80
30	119	P. H. Christie	Traveling expenses	19.55
30	120	Wm. P. Trowbridge, jr	Field expenses	37.00
30	121	Pay-roll (Foote)	Services, June, 1889	281.75
30	122	Pay-roll	......do	161.99
30	123	Wm. Gilbert	......do	50.00
30	124	Harold M. Dyar	......do	50.00
30	125	Lallie & Bailey	Instruments	212.00
30	126	P. H. Christie	Field expenses	93.69
30	127	Wm. Ham Hall	Services, May, 1889	186.81

Abstract of disbursements made by P. H. Christie, etc.,—Continued.

Date.	No. of voucher.	To whom paid	For what paid.	Amount.
1889.				
June 30	128	Wm. Ham Hall	Services, June, 1889	$329.70
30	129	Geo. T. Quinby	Traveling expenses	30.95
30	130	Curt. W. Miller	Services, June, 1889	20.00
30	131	H. M. Wilson	Field expenses	46.62
30	132	......do.	......do	8.60
30	133	......do	Traveling expenses	43.60
30	134	.... do	Field expenses	100.15
30	135	L. D. Hopson	......do	33.84
30	136	Geo. T. Quinby	......do	237.05
30	137	J. B. Williams	......do	48.49
30	138	Rich Shumway	Services, June, 1889	50.00
30	139	Goldman & Co	Field supplies	27.97
30	140	Frank Harrison	Field expenses	4.00
30	141	R. S. Tarr	......do	5.25
30	142	A. J. Wiley	......do	39.33
30	143	Geo. T. Quinby	......do	8.60
30	144	W. A. Farish	......do	119.71
30	145	F. H. Newell	Traveling expenses	58.65
30	146	......do	Field expenses	44.12
30	147	Robert Robertson	Services, June, 1889	75.00
30	148	R. P. Irwin	.....do	50.00
30	149	W. A. McKenzie	Field supplies	7.00
30	150	L. H. Shortt	Field expenses	4.75
30	151	George E. Curtis	......do	75.97
30	152	E. S. Nettleton	Services, May, 1889	186.81
30	153	J. J. Rogers	Field material	22.75
30	154	E. S. Nettleton	Services, June, 1889	329.70
30	155	Joseph Werlen	Forage	12.00
30	156	S. H. Bodfish	Field expenses	45.98
30	157	Wall & Pursel	Field material	230.00
30	158	Edward F. Vincent	Services, June, 1889	10.00
30	159	E. S. Nettleton	Traveling expenses	21.15
30	160	W. W. Sargeant	Services, June, 1889	16.00
30	161	W. L. Wilson	......do	20.00
30	162	J. A. Green	......do	5.00
30	163	J. W. Nelson	......do	4.50
30	164	L. H. Friend	......do	5.00
30	165	A. W. Ralston	......do	2.33
30	166	S. H. Bodfish	Traveling expenses	83.25
30	167	E. S. Nettleton	Field expenses	63.20
30	168	W. W. Montague & Co	Field material	72.14
30	169	R. W. Neil	......do	82.25
30	170	James Smiford	Field supplies	17.45
		Total		18,004.92

Abstract of disbursements made by John H. Renshawe, disbursing agent U. S. Geological survey, during the fourth quarter of 1889.

1889.				
Apr. 1	1	J. H. Hagerty	Care stock, etc	$50.00
1	2	Starkweather & Funk	.....do	13.00
2	3	Pay-roll	Services, April, 1889	902.90
May 6	4	J. H. Hagerty	Care stock, etc	56.44
18	5	Starkweather & Funk	......do	13.00
18	6	Chas. U. Simons	Storage	14.12
30	7	H. L. Baldwin, jr	Services, May, 1889	136.20
31	8	Van H. Manning, jr	......do	85.20
31	9	......do	Field expenses	46.33
31	10	Fred J. Knight	......do	80.15
31	11	Alfred H. Brooks	Services, May, 1889	60.00
31	12	E. L. Chipman	Traveling expenses	10.22
31	13	Geo. T. Hawkins	Services, May, 1889	102.20
31	14	C. T. Reid	......do	50.00
31	15	William J. Peters	......do	119.20
31	16	Basil Duke	......do	60.00
31	17	H. B. Blair	......do	136.20
31	18	M. R. Avery	......do	50.00
31	19	W. E. Lackland	......do	50.00
31	20	S. Chester Reed	......do	50.00
31	21	Wm. H. Herron	......do	85.20
31	22	G. O. Morgan	Horses	270.00
31	23	Van H. Manning, jr	Traveling expenses	44.74
June 3	24	Jno. D. Black	......do	10.50
3	25	Wm. H. Herron	......do	30.00

Abstract of disbursements made by John H. Renshawe, etc.—Continued.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
June 8	26	Fauth & Co	Instruments	$460.50
8	27	H. L. Baldwin, jr	Traveling expenses	27.75
13	28	do	Field expenses	275.87
13	29	R. M. Towson	Traveling expenses	11.00
13	30	Geo. H. Lamar	do	13.00
13	31	B. Peyton Legare	do	47.35
14	32	F. Howard Seely	do	13.00
15	33	A. L. Skiles	Hotel bill, etc	42.50
15	34	Wm. H. Griffin	Traveling expenses	13.00
15	35	Van H. Manning, jr	Field expenses	52.00
19	36	C. T. Reid	Traveling expenses	34.02
19	37	William J. Peters	do	40.52
19	38	C. T. Reid	do	24.99
19	39	William J. Peters	Traveling expenses	23.98
25	40	do	Field expenses	12.05
25	41	do	do	43.00
25	42	do	do	31.40
26	43	Fred J. Knight	do	177.32
29	44	C. T. Reid	Services, June, 1889	50.00
29	45	John H. Renshawe	Traveling expenses	123.06
29	46	William J. Peters	Services, June, 1889	115.40
29	47	L. M. Hoskins	do	18.00
29	48	do	Traveling expenses	5.93
29	49	William J. Peters	Field expenses	88.68
29	50	Van H. Manning, jr	do	73.50
29	51	do	Traveling expenses	7.89
29	52	E. L. Chipman	Services, May and June, 1889	67.73
29	53	Van H. Manning, jr	Services, June, 1889	82.40
29	54	H. L. Baldwin, jr	do	131.90
29	55	Wm. H. Herron	do	82.40
29	56	Alfred H. Brooks	do	60.00
29	57	H. B. Blair	do	131.90
29	58	Basil Duke	do	60.00
29	59	M. R Avery	do	50.00
29	60	W. E. Lockland	do	50.00
29	61	Geo. T. Hawkins	do	98.90
29	62	S. Chester Reid	do	50.00
29	63	H. L. Baldwin, jr	Field expenses	337.24
29	64	Walter N. Beecher	Buckboards	183.75
29	65	W. B. Moses & Son	Office furniture	127.00
29	66	Starkweather & Funk	Care stock, etc	13.00
29	67	H. L. Baldwin, jr	Field expenses	92.72
29	68	Pay-roll	Services, May and June, 1889	56.45
29	69	Fred J. Knight	Traveling expenses	31.89
29	70	do	Field expenses	45.60
39	71	Jno. H. Renshawe	do	27.17
29	72	H. L. Baldwin, jr.	do	31.50
29	73	E. Sinclair	Three wagons	232.50
29	74	S. J. Meeks	Repairs	60.00
29	75	H. L. Baldwin, jr	Field expenses	1.50
		Total		6,456.86

Abstract of disbursements made by A. O. D. Taylor, jr., special disbursing agent U. S. Geological Survey, during the fourth quarter of 1889.

1889.				
Apr. 1	1	T. Nelson Dale	Pay for March, 1889	$150.00
1	2	A. O. D. Taylor, jr	do	103.30
1	3	A. Prescott Baker	Rent for March, 1889	50.00
1	4	Richard Bliss	Bibliographical work	21.30
1	5	Raphael Pumpelly	Office expenses	86.59
2	6	Providence Telephone Company	Telephone rent	11.50
13	7	Raphael Pumpelly	Pay for March, 1889	344.40
13	8	J. Eliot Wolff	Pay to March 30, 1889	175.00
13	9	W. Beals, jr	Services, February 19 to March 13, 1889.	7.20
13	10	do	Incidental expenses	2.10
20	11	Raphael Pumpelly	Traveling expenses	153.21
20	12	do	do	118.46
24	13	William J. Swinburne	Coal and wood	164.85
May 1	14	T. Nelson Dale	Pay for April, 1889	150.00
1	15	A. O. D. Taylor	do	98.90
1	16	H. L. Smyth	Traveling expenses	42.58
1	17	A. Prescott Baker	Rent for April, 1889	60.00

Abstract of disbursements made by A. O. D. Taylor, jr., etc.—Continued.

Date.	No. of voucher.	To whom paid.	For what paid.	Amount.
1889.				
May 1	18	Richard Bliss	Bibliographical work	$23.70
3	19	J. A. Williams	Traveling expenses	2.75
3	20	......do	Services	22.80
10	21	Newport Gas-Light Company	Gas	4.76
10	22	J. Eliot Wolff	Pay for April, 1889	57.69
13	23	Raphael Pumpelly	......do	329.70
24	24	The Scovill and Adams Company	Photographic supplies	17.75
31	25	Raphael Pumpelly	Pay for May, 1889	340.60
31	26	T. Nelson Dale	......do	150.00
31	27	A. O. D. Taylor, jr	......do	102.20
31	28	A. Prescott Baker	Rent for May, 1889	50.00
June 1	29	Richard Bliss	Bibliographical works	24.00
25	30	J. Eliot Wolff	Traveling expenses	10.90
29	31	Raphael Pumpelly	Pay for June, 1889	329.70
29	32	T. Nelson Dale	......do	150.00
29	33	A. O. D. Taylor, jr	......do	98.90
29	34	A. Prescott Baker	Rent for June, 1889	50.00
29	35	Providence Telephone Company	Rent of telephone	11.50
29	36	Newport Water-Works	Water	9.00
29	37	Langley & Sharpe	Tin map case	2.75
29	38	The Scovill and Adams Company	Photographic supplies	4.25
29	39	W. & L. E. Gurley	Repairs to instruments	4.80
29	40	Newport Transfer Express Company.	Freight and cartage	18.08
29	41	Adams Express Company	Express charges	54.56
29	42	Richard Bliss	Bibliographical work	24.60
29	43	C. H. Codman & Co	Photographic supplies	3.10
29	44	J. M. K. Southwick	Hardware supplies	15.92
29	45	J. Eliot Wolff	Pay to June 29, 1889	50.00
29	46	Western Union Telegraph Company.	Telegrams	4.04
29	47	Edward Stabe	Traveling expenses	9.10
29	48	H. L. Smyth	......do	11.35
29	49	L. J. Carmalt	......do	9.05
29	50	Raphael Pumpelly	......do	72.95
29	51	......do	Office expenses	56.98
29	52	John Pumpelly	Rent of instruments	65.00
29	53	James MacKinlay	Rent of rooms	40.00
29	54	H. L. Smyth	Field expenses	29.26
29	55	Raphael Pumpelly	Traveling expenses	24.90
		Total		4,016.03

Abstract of disbursements made by Arnold Hague, special disbursing agent U. S. Geological Survey, during the fourth quarter of 1889.

1889.				
Apr. 5	1	E. J. Owenhouse	Storage	$15.00
30	2	Pay-roll of employés	Salaries, April, 1889	626.40
May 15	3	Jos. Hart	Services, March 1 to April 30, 1889	90.00
31	4	Pay-roll of employés	Salaries, May, 1889	722.20
June 29	5	E. J. Owenhouse	Storage	15.00
29	6	Pay-roll of employés	Salaries, June, 1889	701.40
29	7	E. & H. T. Anthony & Co	Photographic supplies	14.07
29	8	Jos. Hart	Services, May 1 to June 23, 1889	79.50
29	9	Pay-roll of employés	Salaries, June, 1889	85.00
		Total		2,348.57

Abstract of disbursements made by Fielding Burnes, disbursing agent U. S. Geological Survey, during the fourth quarter of 1889.

1889.				
Apr. 30	1	Pay-roll of employés	Services, April, 1889	1,301.90
May 3	2	P. H. Christie	Forage	5.00
				1,306.90
		Total		560,170.37

ANALYSIS OF DISBURSEMENTS.

Under the following heads appear the total expenditures under the various appropriations for the U. S. Geological Survey:

1. Salaries, office of the Director	$35,007.50
2. Salaries of scientific assistants	66,082.44
3. Skilled laborers and various temporary employés	14,999.67
4. Topography	190,511.76
5. Geology	89,412.44
6. Paleontology	34,988.41
7. Chemical and physical researches	15,636.61
8. Preparation of illustrations	14,694.85
9. Mineral resources of the United States	7,661.12
10. Books for library	2,633.91
11. Irrigation	88,541.66
Total	560,170.37

RECAPITULATION.

		Geological Survey.	Salaries, office Director.	Total.
Appropriation fiscal year ending June 30, 1889		$569,700.00	$35,540.00	$605,240.00
Expended as per detailed statement herewith		525,162.87	35,007.50	560,170.37
Bonded railroad accounts settled at U. S. Treasury:				
Freight	$318.25			
Transportation of assistants	1,919.81			
		2,238.06		2,238.06
Balance on hand		42,299.07	532.50	42,831.57

DEPARTMENT OF THE INTERIOR, UNITED STATES GEOLOGICAL SURVEY.

PAPERS ACCOMPANYING THE ANNUAL REPORT
OF THE
DIRECTOR OF THE U. S. GEOLOGICAL SURVEY
FOR THE
FISCAL YEAR ENDING JUNE 30, 1889.

GENERAL ACCOUNT

OF THE

FRESH-WATER MORASSES OF THE UNITED STATES,

WITH A DESCRIPTION OF

THE DISMAL SWAMP DISTRICT OF VIRGINIA AND NORTH CAROLINA.

BY

NATHANIEL SOUTHGATE SHALER.

CONTENTS.

ILLUSTRATIONS.

GENERAL ACCOUNT OF THE FRESH-WATER MORASSES OF THE UNITED STATES WITH A DESCRIPTION OF THE DISMAL SWAMP DISTRICT.

By N. S. Shaler.

Part I.

INUNDATED LANDS.

PREFATORY NOTE.

In the Sixth Annual Report of the Director of the Geological Survey I have presented the results of certain observations upon the marine marshes of New England. Since the completion of that report I have been much engaged in the study of the marshes of the Atlantic coast and other similarly inundated lands east of the one hundredth meridian. As these morasses are scattered over about one-half of the territory of the United States, occupying an area exceeding 100,000 square miles in extent, and exhibit much variety in their important features, it will be a considerable time before any general report on these areas will be completed. I propose, therefore, in order to make public the conclusions which seem to be of economic or scientific value, from time to time to present the principal results of my inquiry in detached memoirs on particular areas of these marshes. In these communications I shall endeavor not only to discuss the features of the districts which are described, but also to set forth such general conclusions as may have been attained concerning other districts, particularly as regards the classification of the areas. Therefore in the following report I undertake to give a classification of such morasses as I have observed in the region east of the Cordilleras.

CLASSIFICATION OF SWAMPS.

The formation of swamps in any district depends upon conditions which retain upon the surface a sufficient quantity of water to prevent the complete decay of the vegetable matter which may be accumulated upon it. In any ordinary forest, although the rate of deposition of vegetable matter may be and generally is greater than in any marsh area, there is no progressive accumulation of this carbonaceous material; the organic waste is freely exposed to the air in the forest bed, thus becoming oxidized and being returned to the atmosphere in the form of carbon dioxide. Thus in the upland Appalachian forests, south of the glacial belt, the woods have been growing for geological epochs which extend back probably to the Triassic period.

At present the rate of deposition of carbonaceous matter from decayed roots, fallen leaves, boughs, and bark (which scales off from the trunks and branches), as well as the seeds of the trees, amounts probably to sufficient material to produce, if it were preserved, as much as one-tenth of an inch each year over the whole surface occupied by woods. Thus if the matter accumulated as it does in the swamp, ten inches of carbon would be laid down upon the surface in a century. One thousand years would produce over 8 feet of such material; 100,000 years would give a thickness of 800 feet! Thus if the carbon of our ancient forests remained where it fell, as it does to a great extent in our swamps, the accumulation of vegetable matter would assume an enormous thickness. The fact is, however, that the contributions to the soil bed of any one year are returned to the atmosphere within a few decades and there is no increase in the forest mold.

Where for any reason the forest bed is more than usually wet, the process of interstitial decay is partly arrested, the accumulation of peaty matter begins, and in many cases this process leads, by considerable additions of the swamp deposits, to the destruction of the trees which occupied the area. The accumulation of peaty matter will continue until the gradient of the district rises and a more complete drainage is effected. Thus, owing to the drying of the upper part of the marsh, the further thickening of this material is arrested. In general, however, in all regions occupied by woods, the natural gradients are sufficient to keep the land dry enough to prevent the formation of swamps.

We thus perceive that swamps are developed wherever there is a condition of embarrassed drainage which serves to retain a sufficient amount of the water to prevent the complete decay of the vegetable waste which accumulates on the soil as a result of the entire or partial death of the plants which occupied the district. The development of the swamp area is in all cases self-limited. This limitation, whether it be in vertical thickness of the deposit or in its horizontal extension. is determined by the form of the surface on which swamps develop, or by the limitation in the growth of the plants, which is brought about by the impossibility of the roots of the growing plants penetrating through these peaty accumulations to the under soil. I purpose to discuss these considerations in the subjoined classification with reference to the limitation of the swamp areas brought about by the several above-mentioned conditions.

The most important conditions which determine the development of swamps arise from the relation between the rain-fall of a district, the gradients by which that rain-fall descends to the sea, and the temperature of the given district. Thus in an arid region very gentle gradients, say those of less than 5 feet to the mile, will fail to develop swamps, while in a moderately humid district such areas are almost always converted into marshes. Where the rain-fall of the country, though considerable, is irregularly distributed through the year, the period of dryness may permit the desiccation of nascent swamps and consequent oxidation of their carbonaceous material and thus prevent the development of marshes which otherwise would occupy the area. This is particularly the case where the growing season, say the summer and autumn, is very dry, though the winter and spring may be excessively humid. The period of drought commonly leads to the destruction of all the accumulated vegetable matter formed during the season when the plants are not growing. The further south the given region may be the more likely is the heat and dryness of the arid time of the year to desiccate the surface. Consequently, in southern regions a smaller declivity of surface will insure the absence of swamps than is necessary in northern countries, where both regions have the same annual amount of rainfall.

In these variations in the conditions which determine the formation of swamps the shape of the land is generally of most importance; next the rain-fall of the district as affecting the amount of desiccation, and consequently the character of the plants which inhabit the area and the escape of the water through the air; and lastly, the annual temperature, which serves to affect in a measure the dryness of the air and also the nature of the vegetation.

I intend to consider the distribution and classification of swamps with reference to the above-named categories of physiographic conditions. As the result of my inquiries it has appeared impossible to introduce any single classification of swamps which will adequately designate their several characters in a way to make it of any value to the student; therefore I am compelled to adopt this tripartite system.

CLASSIFICATION OF INUNDATED LANDS BASED ON PHYSICAL CHARACTERS.

The most satisfactory general classification of inundated lands which I have been able to make is exhibited in the following table. We have at the outset the fundamental division of such lands into those which are visited by salt-water or are beneath the surface of the sea and those which are formed above the ocean level. To the former of these groups I propose to give the name of *marshes*, and to apply to the latter the name of *swamps*.

Table of classification of inundated lands.

Marine marshes	Above mean tide	Grass marshes.
		Mangrove marshes.
	Below mean tide	Mud banks.
		Eel grass areas.
Fresh-water swamps	River swamps	Terrace.
		Estuarine.
	Lake swamps	Lake margins.
		Quaking bogs.
	Upland swamps	Wet woods.
		Climbing bogs.
	Ablation swamps.	

The inundated lands which I have observed in this country and in Europe are, in general, clearly divided as regards the character of the surface into three groups—those which may be termed marine, those which are formed in fresh-water basins, and those which are formed above the level where there is permanent standing water. The marine marshes, excluding the class of mud flats and of sea-weed deposits below high tide, are again divisible into two groups: grassed marshes and mangrove marshes. The former of these fall into the category of the open salt marshes which exist generally in the regions north of the tropics, and which are characterized by the fact that their physical conditions do not permit the development of any timber growth upon them. Such morasses are always occupied and generally formed by the organic waste of a number of species of phenogamous plants, mostly belonging to the group of grasses which can flourish only where they are from time to time, in the high state of the tide, subjected to overflow. Generally their range of height is such that all ordinary tides bring the salt-water about the roots of the plants, while the high tides suffuse them altogether. Their conditions of development are so equated with tidal phenomena that they may be alternately bared and suffused by the salt-water.

South of Fernandina on the North American coast and thence throughout Florida, as well as in most other tropical regions, we find an extensive growth of certain plants which attain the form of trees, and which can by their physiological functions so reconcile themselves to salt-water that they grow freely in tidal areas. This group of plants, to which we give the name of *mangroves*, in all this southern section occupies the position which in more northern districts is attained by the grassed marshes. The roots of the plants freely develop below the level of the salt-water, their seeds are so arranged that they readily take root in the shallower parts below the level of low tide, and their method of growth, by root-like processes which extend down into and implant themselves in the marine mud, enables them rapidly to advance into the water in all shallow places which are protected from the heaviest waves. A more particular description of this group of swamps will be found on pp. 291 et seq.

The partition between the marine and fresh-water swamps is often accomplished by the sand walls of beaches. As I have elsewhere indicated[1] the larger part of our salt marshes are also protected from the destructive invasion of the sea by these same walls. In the region south of Florida and in the tropics generally the mangroves create an important barrier between the waters of the sea and those of the land. The dense mass of their roots and stems entangles the decayed vegetation, the shade which they give to the area they occupy limits the desiccating influence of the sun, and the result is that they form a sort of rampart or low mole, which serves to bar in the land waters. Where, as in southern Florida, these land waters rest upon limy materials, they gradually dissolve the substratum and bear it in the state of solution to the sea. Thus in time it may come about, as in the mainland of Florida near the Keys, that the area within the mangrove belt is a little higher than the interior district. As the strip of mangrove gains on the sea the inland part of the growth dies because of the lack of contact with the salt-water, which appears essential for the development of the plant; as the mangroves disappear the higher land they form is exposed to the solvent action of the swamp waters and the vegetable matter of which it is composed decays; thus the barrier produced by the growth of these peculiar trees continually advances in its development on the sea-face and disappears on the land side.

Above the level of the tide, save in dead seas and about certain salt springs, peaty accumulations are developed in fresh water. In this group the morasses are divided by the topographic circumstances of their situation into four somewhat distinct groups—lacustrine swamps, corrosion spring swamps, fluviatile swamps, and erosion plain swamps.

The distinction between these classes is tolerably clear. The lacustrine swamps have in all cases originated through the previous presence of lake areas which have been altogether or in part closed by the growth of vegetation. The formation of these basins depends upon a great variety of accidents. They may have been produced by irregular movements of the underlying rock or by glacial excavation; or they may be depressions corresponding to an underground drainage or sink holes, the passages of which have been closed by various chances. These various circumstances of origin of depressions do not appertain to our classification and will not be further discussed.

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[1] Report on the Marine Marshes of New England, Sixth Annual Report U. S. Geological Survey, p. 353, et. seq.

Corrosion-spring swamps include a very small group of deposits formed in a peculiar manner. Where springs, such as those of the Big Bone Lick in Kentucky, convey away to the surface a considerable amount of dissolved rock materials, salt, lime carbonate, etc., the withdrawal of the matter from the rocks may be so considerable that the surface gradually sinks, forming a swampy area. Generally the rate of ablation of the district is so rapid that the local downsinking produced by the process of solution is effaced in the wide-spread lowering of the surface, but in rare instances, as at Big Bone Lick and other saline springs of Kentucky, a small area of marsh land is produced in this manner. Such deposits have no physiographic importance; they are mainly interesting for the reason that at times they afford very large amounts of vertebrate fossils.

In the central and western parts of New York State, between Syracuse and Lake Erie, are well-known extensive deposits of rock-salt lying somewhat below the general drainage of the country. In this district we have a number of swamps, some of which have considerable area and which may owe their development, in part at least, to the withdrawal of materials from the saline strata in the same manner as at Big Bone Lick in Kentucky and elsewhere. I was at first disposed to attribute the genesis of these swamps altogether to withdrawal of the material from below the surface by spring action. Further observation has led me to the conclusion that, while in some measure the swamp areas of western New York may be explained in this manner, the action is commingled with that arising from the irregular elevation of the surface since the Glacial Period. The evidence obtained by Gilbert and others concerning the rise of the old lake beaches at the north serves to show that the original surface of the country has been extensively affected by such movements. It seems pretty certain that in part, at least, these swamp areas are due to induced imperfections of drainage consequent on these changes of level.

To be classed with the corrosion spring swamps, but in a way distinct from them, are the similar but more extensive disturbances of the drainage produced where corrosion has been long continued in a mountain-built country. It commonly happens in a region of much-disturbed rocks that there are wide differences in the measure to which the underground waters leach out the constituents of the rocks. Thus it may happen that a limestone bed may be greatly reduced in volume by the efferent action of the underground waters, while the sandstone layer, or a deposit composed mainly of clay, may have resisted this corrosive action. The nature of this effect is sufficiently shown in the accompanying diagram.

Where the limestone strata of such a mountain-built district are massive, it is often easy to perceive that considerable valleys have been formed in this manner. Where the region has recently been subjected to extensive glacial action this corrosive influence is not usually conspicuous; or where the sea has recently acted upon the surface of the land, it may even be wanting; but in certain cases it is an important feature in determining the attitude of the surface. Thus in northern Georgia considerable areas have their streams in the condition indicated in the diagram (Fig. 2). The limestone beds have so far corroded as to form broad valleys occupied by sluggish

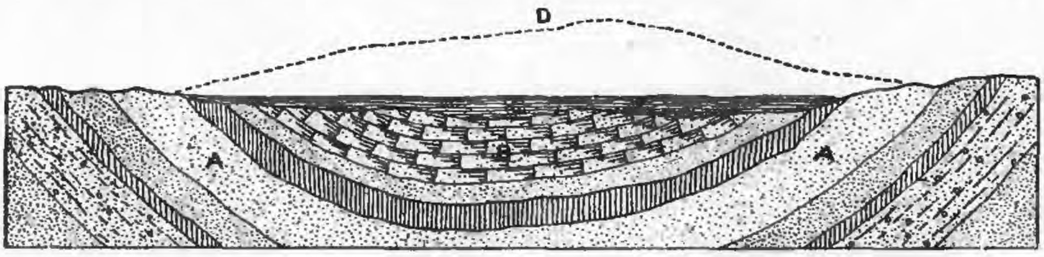

Fig. 2.—Diagram showing imperfect drainage produced by solution of strata. *A*, non-soluble strata of slate and sandstone; *B*, soluble strata of limestone; *C*, swamp deposit; *D*, surface of country before leaching had developed conditions favorable for growth of swamp.

streams discharging their waters over ridges of less corrodible rock, which, owing to their resistance to interstitial decay, afford barriers. The banks of these streams are often so marshy that a considerable area of land near them, though not actually swamp-like in its nature, is too wet for tillage.

The extent to which the surface has been lowered by the process of leaching out that has taken place in the underlying beds can sometimes in such regions be approximately determined. Where, as is frequently the case in northern Georgia, a bed of iron ore exists in the limestone, the ore being formed by the replacement of the origi-

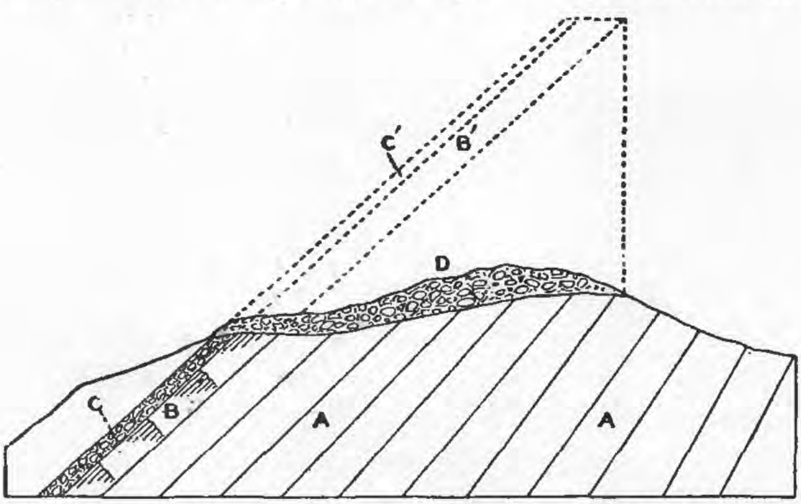

Fig. 3.—Diagram showing evidence of ablation. *A*, inclined strata; *B*, limestone capped by iron ore (siderite); *C*, iron ore layer; *D*, secondary deposit of ore; *B′*, old portion of ore; *C′*, old portion of limestone.

nal lime through the infiltration of ferruginous matter, and where the limestone bed had a certain measure of inclination, we may often determine, at least approximately, the elevation of the surface when it last escaped from the sea. The waste from the iron ore occurring as angular fragments or as rearranged material in the form of pipe ore, generally produces a low ridge in the valley, as is shown in Fig. 3. The shape of this ridge and the distribution of the rearranged ore give a basis on which to determine the original position of the outcrop.

The group of plain swamps depends for its existence on the fact that, wherever a considerable area has very gentle declivities, the circumstances of climate being favorable, the embarassment to drainage brought about by the vegetable coating is apt to be such that the escape of the rain-water is less easy than on a surface of ordinary inclination. If completely bared of vegetation, water may go with sufficient freedom to the sea over surfaces of very slight inclination; but the presence of even a very thin coating of vegetation somewhat restrains the outflow of the rain by the effect which is exercised through the waste of decayed plants, and so retains a portion of the water on the land. With such increase in moisture the growth of grasses and mosses is still further favored; the original forests, if still existing, are likely to be expelled by the change of condition, the ground being too wet for the trees, and thus the region is gradually brought into the condition of a high-lying swamp.

The formation of these plain surfaces, and their consequent imperfect drainage, may be brought about in a variety of ways, where, in a region underlaid by tolerably horizontal rocks, even if the height above the sea be considerable, the presence of a hard layer acting as a topographic determinant, resisting both the cutting action of the streams and the general solvent action of waters, may bring an extensive area to a nearly horizontal attitude. If the climatal conditions be fit this area may become more or less swampy. (Fig. 4.)

FIG. 4.—Diagram showing effect of resisting horizontal layer in producing imperfect drainage. *A*, soft strata; *B*, hard layer, topographical determinant; *C*, swamp determined by hard layer.

In other cases the plain area may be produced by the processes of base levelling which go on near the levels of enduring shores. The ground, gradually worn down by the action of overground and underground water, may finally retain too little slope to overcome the obstructing effects of the outflow of water produced by the vegetation. It may be observed that as soon as the area is covered by swamp, the extreme carbonation of the waters which pass through the morass tends to increase the leaching effect of the underlying beds and further to lower the level of the surface.

The direct cutting effect of the sea operating during the ordinary oscillation of the continent within a height of a few hundred feet of the sea-level, has on many shores tended to hasten this process of base levelling which is effected in a large part by the land waters. The nature of this action is well seen in the great eastern bench of the United States, which extends along the shore from the Gulf of St. Lawrence to the southern Appalachians. From the Bay of Fundy to the southern extremity of the Appalachians, the mountain-built district of the Atlantic coast has been very extensively degraded by marine action, operating at heights from the present sea-level up to a thousand feet or more in altitude. This action is well marked in the erosion of the extensive dislocations which lie to the east of the Blue Ridge, and to which I have given the general name of the East Appalachians. (Fig. 5.)

FIG. 5.—Diagram showing general relations of Atlantic coast shelf.

Another feature leading to the formation of plains suited to swamp growth is found in the very level surfaces formed where sedimentary deposits accumulated in lakes or on the sea floor are afterwards brought into the condition of dry lands either by the drainage of the lakes or by the elevation of the sea floor. These deposits are generally constructed on a surface which has previously been base-leveled by erosion, but the actual details of topography are in the main due to sedimentary action. To such conditions we owe the very gentle slope of the plain country extending from New Jersey to the Rio Grande. The slope of these surfaces often does not exceed a few feet to the mile, an amount so slight that the embarassing effect of the vegetation may readily be sufficient to retain enough water to produce morasses. (Fig. 6.)

These gentle slopes of elevated sea bottoms generally pass below the level of the sea and are directly continuous with the submerged portion of the coast shelf. The effect of this condition is to cause very shallow water for some distance from the shore. Soon after the coast has assumed its new place upon the change in the attitude of the continent in a time of a heavy storm the ocean waves break at a distance from the shore. Along the line where the surges are converted into breakers a broad, low mound of marine sands is always formed. In the course of time this ridge rises above the surface of the water and forms a barrier reef, confining between its position and the main land a narrow strip of sea, to which we may apply the name of lagoon. The water of this lagoon strip, originally shallow, is gradually reduced in depth by the growth of organic forms, by the contributions of mud brought from the land by the rivers, and also in many cases by wind-drifted sands which occasionally blow from the crest of the sand reef. If the shore remain unchanged in height, a relatively brief time serves to reduce the lagoon to the condition of marshes in which the ordinary salt-loving grasses flourish, and which, in the tropical or subtropical belt, rapidly become occupied by mangrove swamps. Extensive marshes of this character have been formed in the region from New York southward since the coast assumed about its present position. It is likely that even the larger part of these embayed waters would have been covered by vegetable growth, and thus brought to the condition of morasses, but for the fact that this region appears generally to have been subjected to a gradual depression since the time when the lagoons were first formed.

Morasses of this character are liable to a peculiar class of accidents dependent on the varying conditions of access of land and sea waters. When the passages leading seaward through the barrier beach are in good part closed the included waters may become generally fresh. When, by the varying chances of marine action, the sea has tolerably free access to the embayments, these waters may be quite salt. Such transitions are unfavorable to the growth of the groups of plants which have become reconciled alike to salt and fresh water. I attribute the failure of plants to obtain possession of a large area of mud flats in the lagoons and bays of the region south of Cape Hatteras to abrupt transitions in the character of the water which covers their surface.

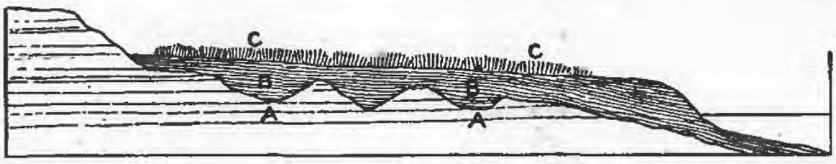

FIG. 6.—Diagram showing effect of new sediments in destroying old drainage. *A*. old rocks; *B*. newer strata; *C*, swamp.

The division of fluviatile swamps is, to a certain extent, related to the group of base-level swamps or those formed by the reduction of the land surface to near the level of the sea. The swamps formed along rivers are, however, in certain respects, clearly distinct from those formed along the base leveled lowlands, though they often occupy a part of that territory. Fluviatile swamps generally depend for their development on the alternating floods and low water which characterize all rivers whatsoever. In the time of flood, when the stream overflows the margins of the alluvial plain, the vegetation which, in the natural state of a valley is luxuriantly developed near the bank, arrests the movement of the waters as they flow off from the stream, and by diminishing the speed of their movement permits the coarser sediments at once to descend upon the plain. In this manner the margins of all alluvial plains near the stream become higher than the portions toward the escarpments of the valley. (Fig. 7.)

As the summit of the lowest alluvial plain, owing to the conditions of its construction, is everywhere at about the same height above the stream-bed, the consequence is that this marginal barrier is very extensively developed, being breached only where tributary rivers join the main stream. Even where these tributary streams cross the detrital plain they are likely to produce marginal moles parallel to their own courses and so to inclose the waters of the "back swamps," as they are termed in the Mississippi delta section. The contained waters of these back swamps often cover very large areas. When the stream falls to its lower level they commonly break through the material and form more or less permanent lines of escape. These channels are, however, generally narrow, and their paths, being much occupied by timber, are liable to the same blocking action

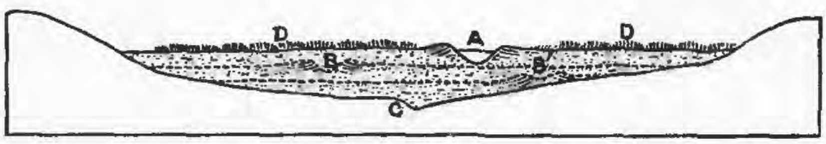

FIG. 7. Diagram showing general structure of alluvial deposits. *A*, existing new channel; *B,B'*, ancient river channels, now buried; *C*, river channel before alluvial deposits were formed; *DD*, swamps.

which constructs the mole. Each season they are more or less closed up with drift timber and sediments, so that the back swamp territory is never completely drained. Within the limits of the United States we have only one river, the Mississippi, which exhibits the phenomena of lacustrine swamps in an extensive way, but all the streams which have considerable deltas show more or less of the action.

DELTA SWAMPS.

The foregoing account of the fluviatile swamps is sufficient to describe, in a very synoptic way, the condition of all delta accumulations. The phenomena exhibited by the Mississippi delta on account of the magnitude of that stream, as well as of the conditions which determine its form, make it necessary to state the circumstances of that area of inundated lands in a more definite manner and in more detail than has been given to delta structure in general.

The deltas of the rivers in the southern part of the United States, at least between the Rio Grande and the Delaware, present certain peculiar features which are due to the condition of the continent before these alluvial accumulations were formed.

By reference to any good map which shows in some detail the characteristics of these estuarine districts it will be perceived that the rivers of the Southern States all escape into acute reentrants, formed by low, cañon-like incisions in the table-lands of the southern plain. Where the rivers are large and powerful, considerable amounts of mud have been conveyed into these bays more or less occluding their original basins. At the same time the action of the waters on the generally incoherent rocks which form the shores of the indentations has led to the considerable extension in the superficial area of the basins and a proportionate shallowing of their depth. The result of this process has been that, at the present time, the remaining parts of these basins are everywhere shallow. Where the rivers which enter the basins, as in the case of the Delaware and Susquehanna, convey little sediment on account of the physical conditions of the country whence they flow, the deltas are indistinct. As we advance southward and pass beyond the region of glaciated soil, which singularly resists the erosive action of rivers, the quantity of sediment perceptibly increases. Thus the streams which flow into Albemarle and Pamlico Sounds have noticeable deltas; generally the delta-like accumulation increases in volume as we go southward until, in the Mississippi reentrant, the detrital deposit is so considerable that it has filled the recesses of the original bay which, at the close of the Glacial Period, extended from the Gulf to the junction of the Ohio and Mississippi, and perhaps for a certain extent up those branches of the main stream. Indeed, as is well shown by a map of the delta district, the alluvial deposit has extended a considerable distance beyond the mouth of the original gorge, a feature which is found in no other river in North America.

It may be remarked in passing that, while in the Old World all the principal streams have true deltas, those of the Rhine, the Rhone, the Danube, and the Nile, as well as all the great rivers of Asia, projecting beyond the mouths of the valleys in which they are found, only the greatest of our North American streams has extended its delta beyond the reentrant trough in which it began to accumulate. The bearing of this observation will appear in the considerations which are now to be presented. (Fig. 8.)

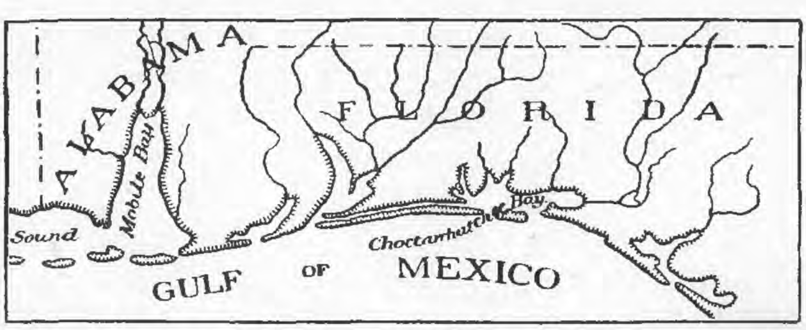

FIG. 8.—North shore of the Gulf of Mexico from the Choctawhatchee Bay to Mississippi Sound.

The facts that all the streams of the Atlantic coast south of New York enter the ocean through reentrant bays, and that, in a word, the greater portion of the deltas along our shore are accumulated in reentrants, can be explained only on the supposition that the regions about the mouths of these streams, and probably, also, of the continental area occupied by the rivers, has recently been at a much higher level than it now occupies. The evidence of this fact is as follows, viz: The banks of the southern table-lands which bound these streams are usually steep, preserving their declivities despite the considerable erosion which has acted upon them. The erosive work done by the streams during the time when the country was more elevated had been more or less modified and extended by the action of waves before the bay was occupied by the delta accumulations. The banks of the main bays universally converge as we ascend their channels. Where the principal tributaries come into the bays we have branches of these wide valleys extending some distance up the path of the tributary streams. Thus, in the case of the Mississippi delta, there are embranchments of the old bay extending up the Yazoo, the Arkansas, the Red River, the Ohio, and the Upper Mississippi. From much study of these reentrants I am forced to the conclusion that they are in their nature the canyon-like excavations effected in soft strata by the action of streams when they flowed at a higher level. In no other way can I explain the peculiarities of their formation.

This view is substantiated by tne porings which have been made below the level of the deltas. In all cases such borings indicate that the gorge, occupied by the bay or by the alluvial accumulations which have been deposited in it, has in very recent geological times been occupied by much greater depths of water than we now find there. Thus, at New Orleans and points above in the delta district, borings indicate that the delta accumulations have a depth of several hundred feet. This accumulation could not have been made except with a deep gorge in existence, which had gradually been encumbered by the alluvium as its bottom subsided with the downsinking of the continent. (Fig. 9.)

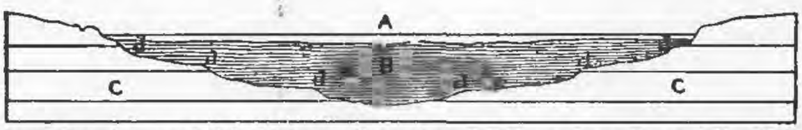

FIG. 9.—Diagram showing probable history of reentrant deltas of southern Atlantic coast. *A*, present level of sea; *B*, recent silt; *C C*, Tertiary and Cretaceous beds excavated by river while surface was higher; *d d*, old river benches.

The process of growth of the delta of the Mississippi can be traced more completely than that of any extensive alluvial formation which has yet been made the subject of study. The problems connected with the accumulation of the vast deposit which composes that delta are extremely complicated. I shall note only such of them as distinctly bear upon the swampy nature of that area.

To comprehend so much of the problems of delta history as pertain to our inquiry, the student should visit the growing extremity of the Mississippi delta where it projects into the Gulf of Mexico. He will there observe that the waters of the stream discharge through a number of passages, walled in on either side by low mounds of alluvium, which confine the stream for a score or two of miles in advance of the main delta. There is an obvious tendency of these walled ways of the river to depart from a direct course towards the open sea and to turn to the right and left of their main direction. (Fig. 10.)

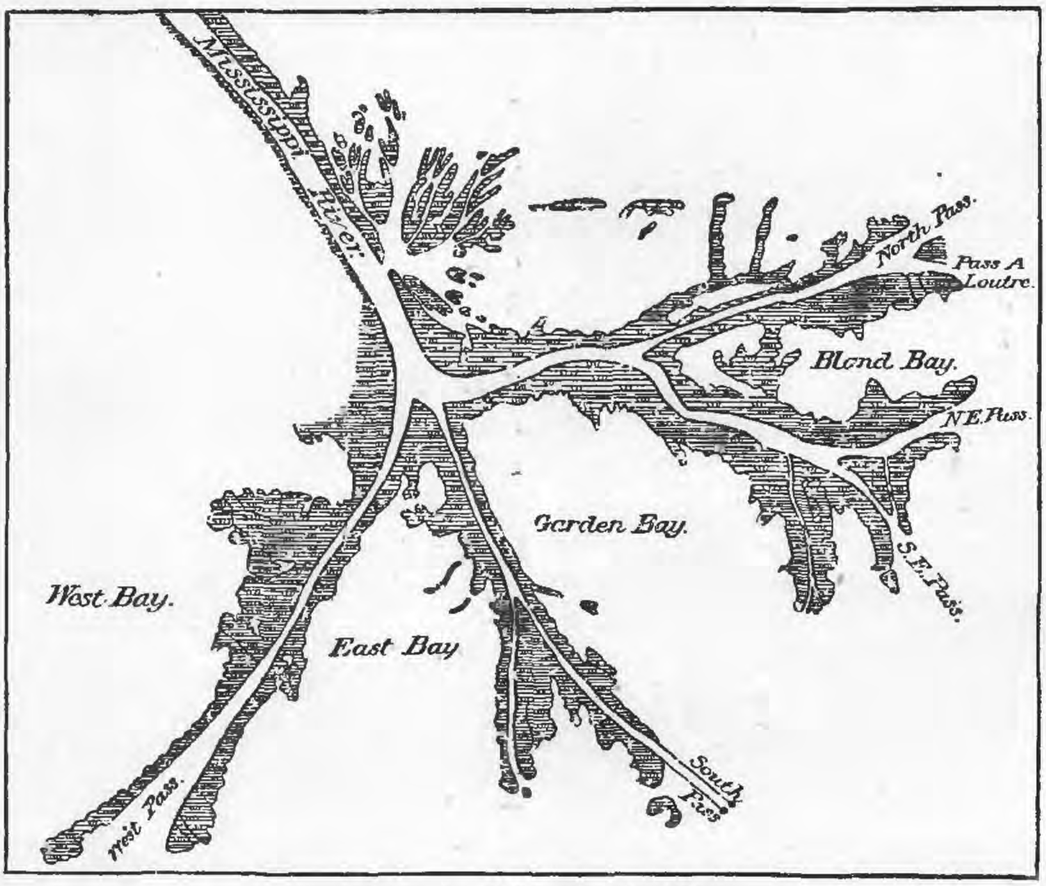

FIG. 10.—Mouths of the Mississippi River.

It happens, apparently by chance, that one of the passages from the Mississippi River to the gulf proceeds directly seaward, the others inclining strikingly to the right and left. This lateral curving of the discharge channels is probably in part due to the oscillating movement which causes all rivers in delta regions to take a varying but more or less tortuous path. In some measure this is doubtless owing to the effect of sea waves, in accumulating obstructions at the outermost point of the river course. The partly submerged banks bounding the stream near the sea are produced by the settling of the heavy sediment, which occurs in times of flood, immediately on the passage of the waters out of the open channel. Where, as at the outermost point of the river channel, the sea waves beat against this in times of heavy storm, they tend to push the waste over the wall and into the stream, and thus to produce a deflection of the current away from the run of the waves. When such a change in direction is instituted by this or other causes, the tendency of the stream is to continue the further construction of its parallel walls in the new direction. Moving laterally, it tends to come against the sides of the neighboring walls of the bay, at least until the delta has been pushed beyond the limits of the reentrant. At present this limitation is not encountered, and the streams of the Mississippi delta are free to move laterally until in some time of flood they effect a breach in one of the bounding walls, making a cut-off or shorter path to the open sea; then the construction of the stream ramparts begins again and continues until it is in turn interrupted by a similar accident. (Fig. 11.)

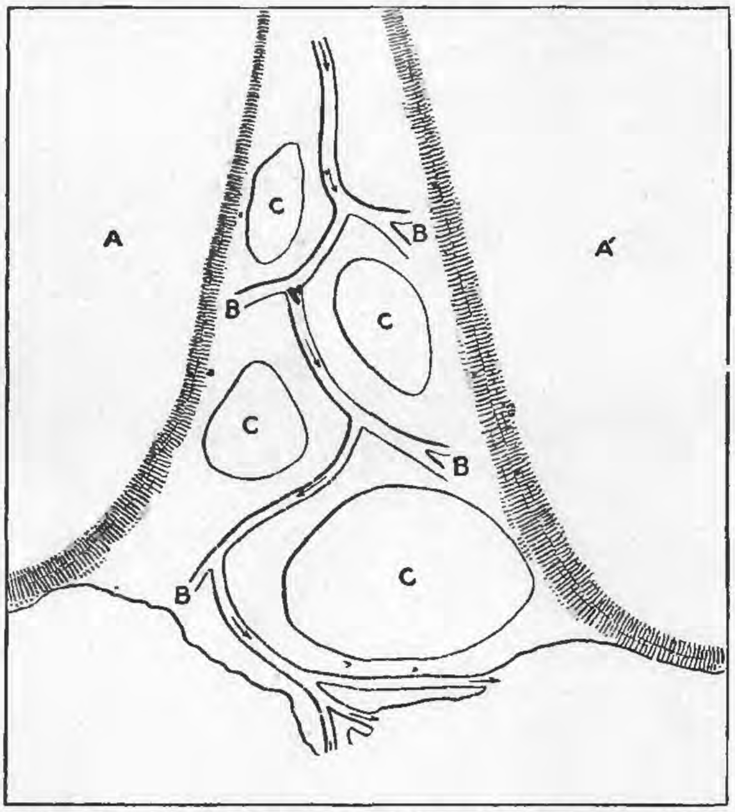

FIG. 11.—Diagram illustrating the structure produced by successive changes in the delta exits of rivers. *AA*, table land; *BB*, old exits now closed; *CC*, old fluviatile lakes now in part effaced by alluvial deposits.

An examination of the delta region within the walls of the ancient bay shows, though somewhat obscurely, that this lateral swing of the stream has been characteristic of all the development of the delta. It has doubtless frequently occurred at the successive seaward margins of the delta in a manner in which we can now see it in the present front of the alluvial deposit. In this manner the alluvial mass is made to consist, in large part, of a number of slightly elevated double ridges, the banks of the ancient stream, and deep troughs, more or less rapidly effaced by the process of deposition, in which the streams originally lay. We naturally find that these curved ramparts of the old river channels are best preserved in the lower part of the delta. We see that Lake Pontchartrain, Lake Borgne, German Lake, and the other large inclosed basins of water in the lower part of the delta, apparently owe their origin to the embankments formed in the shallow sea by these curvings of the delta mouths.

After their formation, these shallow basins, inclosed by the stream's walls, are subjected to a still further effacement by the occasional penetration of flooded waters into their area, as well as by the considerable growth of vegetable and animal life upon their sides and bottoms. It is therefore natural that these distinct indications of the effects derived from the changing positions of the river mouth are found only in the lower and newer parts of the delta. Farther up the stream this originally imbricated disposition of the ancient mouths has been progressively effaced by accidental changes of the river course, as well as by the general accumulation of sediments,

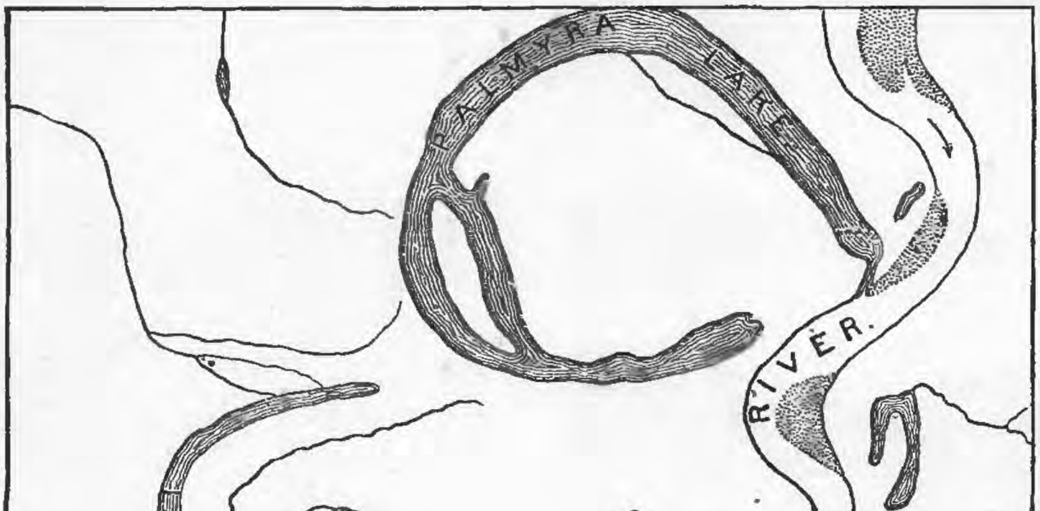

FIG. 12.—Ox-bows of the Mississippi River.

which has come about since the delta was pushed far to the seaward. In this upper section of the delta the topography seems to be mainly determined by the oscillation of the river to and fro over the alluvial plain, movements dependent on the embarrassment of its current, arising from the quantity of the debris borne down from the higher country where the stream had a steeper flow. (Fig. 12.)

In its course through the alluvial plain the river by its swinging is constantly forming great curves in its course, ox-bows, as they are commonly termed, which in time are cut through at their necks, leaving the ancient path of the stream in the form of a crescent-shaped lake which rarely, except in times of high water, maintains any free connection with the main stream. At such periods of flood the muddy waters penetrate into these basins, lay down great quantities of sediment, and so these remnants of the old river are rapidly filled nearly to the level of the high water. At the same time the trees, cotton-wood, cypresses, and willows, as well as a host of annual and herbaceous plants which love such positions, grow rapidly and accumulate their vegetable waste, helping to efface the lake. This vegetable matter, derived from rooted plants, is more or less mingled with drift-wood, a portion of which floats in from the main stream. Under certain accidental conditions the old abandoned channel may be quite blocked by these accumulations of vegetable matter, which in time become more or less floored over with ordinary alluvial material.

A dissection of the Mississippi delta would doubtless show a number of these remnants of the old channel filled to the depth of many feet with such accumulations of woody matter. The low-lying condition of this region has prevented the disclosure of any such drift-wood accumulation in distinct sections. For the purposes of illustration, I may note that in other countries such lacustrine deposits of drift-wood occasionally occur. The most notable example of this class of deposits which I have seen is found in the upper portion of the valley of the Arno, known to geologists as the Val d'Arno lignite deposits. At that interesting locality an ancient bend of the river has become entirely filled to the depth of sixty or seventy feet with drift-wood, the chafed and rounded fragments of floating timber, and the whole has been covered by a layer of ordinary silt and converted into a coarse lignitic mass which is now extensively quarried for fuel.

The effect of these accumulations on the level of the older and higher parts of the delta demands attention. The immediate result arising from the formation of these ox-bow cut-offs is to elevate the general level of the region near the stream. Each of the moats, as these remnants of the old channel may be termed, has a relatively high border on either side, and these remnants of the river embankments, when numerous and much entangled as they are because of the wanderings of the main channel, help to elevate the general surface to a considerably higher level than the portions of the delta at some distance from the main stream. The resulting topography consists of irregular strips of land rising from three to six feet above the general plane of the country, with intervening belts of swamp, which swamps partly occupy irregular interspaces between the parallel ridges of the old moats and in smaller part the crescent-shaped depressions which lie in the places formerly occupied by the moats. In the upper part of the delta this topography, due to the swingings of the stream, replaces that which is shown in Fig. 11. This latter figure should be compared with Fig. 12.

When the river in its successive oscillations has formed many of these cut-offs the more ancient of them become considerably suffused if not entirely concealed beneath the ever increasing accumulation of silt which takes place near the main stream. When in this manner the river is made to occupy a higher level than first characterized it, the current tends to break through the belt of elevated land on either side of the path and form a new channel known as a bayou. Breaking through the slightly elevated border of silt which bounds its path, the river finds its way to the belt of low-lying back swamps and there forms a new channel which may continue for a considerable distance toward the sea before the waters rejoin the main bed of the stream. In certain cases, especially in the lower part of the delta, these diversions of the stream may not rejoin the main channel but may form independent mouths at the delta front. Where, however, in its course to the sea the river in its longer channel encounters a strip of elevated land made in the delta by a tributary river coming in on the same side as a bayou, the effect may be to divert the stream back to the main channel. Along the path of the bayou, the process of sedimentation proceeds to construct the lateral ramparts of the stream, with their short slope to the current and their long glacis-like extension towards the lowlands on either side, and so in time the chapter in the history of the stream is repeated.[1]

Where a considerable tributary joins the main stream we find a portion of the delta, the character of which, both as regards the mechanical and chemical condition of the sediment and the structure of the area, is determined by an interaction between the alluvial work of the main river and that of tributary floods. If the tide from the tributary is strong and bears much silt, it tends to force the main stream away from the side on which it enters, and to urge its curve against the opposite bank. Thus in the case of the Mississippi, the Red River, being a powerful stream, has in a manner tended to force

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[1] The names which are applied to the several topographical features with deltas are as yet not determined. For convenience, I propose to transplant into this field of nomenclature two terms derived from military science. The ox-bow cut-offs have already received in New England, and especially along the valley of the Connecticut, the name of *moats*, for the reason that the first settlers of that country came from Britain at a time when they were familiar with this element of defensive work. I propose hereafter to use the term *moat* in place of the obscure paraphrase "ox-bow cut-off."

The slopes from the banks of the streams towards the swamps on either side I shall term the *glacis*, for the reason that it in structure closely resembles the slope which is constructed in front of the ditch in an ordinary fortification.

the current of the Mississippi against the high land on the east side. The rivers entering the delta on the east are small in volume and do not bear much silt for the reason that they come from low and densely wooded districts. It seems probable that we may thus explain the fact that the Mississippi River, in place of inclining as it should do by the law of the earth's rotation to the west, tends for a part of its course to make its way against its eastern margin.

The extension of a delta such as the Mississippi normally takes place in two directions by the building out of the accumulation into the sea and by the lateral increase in the area of deposits. Where, as in the present condition of the Mississippi, the floor of the delta region seems tolerably steadfast, there being no considerable oscillation of the continent now in process, each extension of the river mouths into the sea tends to bring about an increase in the heights of the silt plain all the way up to the head of the alluvial accumulation, and this for the simple reason that the longer the course of the waters before attaining the ocean-level the less rapidly they flow and the higher the floods mount. The effect of this action where the delta front comes against the steep escarpments of the table-land on either side is not in the course of a century conspicuous. The thickness of the delta accumulation can not increase by more than a small fraction of an inch each year and the topographical influence is therefore usually inconspicuous. Where, however, as for instance in much of the Yazoo region, the higher land slopes gently to the alluvial plain, the increase in the depth of the alluvium which will take place in the course of a few thousand years is indicated in an interesting peculiarity of the topography. We may there find a low rolling surface of uplands in the process of gradual disappearance beneath the rising mass of silt. At first the sediments deposited by the floods mantling over the table-land gradually round off, as it were smudge, the general topography. (Fig. 13.)

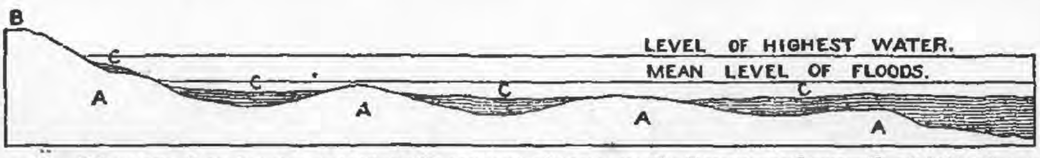

FIG. 13.—Diagram showing progressive effacement of topography by upward growth of delta deposits. *A A*, country eroded before delta began to form, suffused by successive accumulations of delta deposits; *B*, country above high water; *CC*, alluvial accumulations effacing old topography.

In certain areas where the process of suffusion of the surface has just been begun we may see the alluvial sheet having only a foot or so of thickness on top of low crests but amounting to twice or thrice that quantity in slight valleys. From this state outward into the alluvial plain, we may trace the gradual increase in the depth of the alluvium and the consequent slow disappearance of the ancient topography. The details of this depositional action are readily apprehended. The flood waters lie upon the low hills for only a few days in the year and thus deposit but a thin layer of sediment, while they occupy the lower levels it may be for three or four times as long. The result is that the deposit is thicker in the lowest lying lands and grows thinner as we ascend above their level. Moreover, the alluvial sheet is for a time extremely incoherent and is often washed by the rains from the crests toward the valleys.

In the Yazoo portion of the delta, an area of about 6,000 square miles, the levees or artificial embankments have protected the region from inundation. An extensive agriculture has considerably affected the expression of the topography. The low hills, originally slightly mantled by alluvial waste, are gradually wearing down into the valleys. The degrading influence of the plow is modifying the original topography in a somewhat rapid manner. Nevertheless, the stages of the delta growth are clearly seen in that district, and the evidence goes to show that in its natural state this portion of the delta was rapidly gaining on the more elevated country. Of course, it is to be understood that all this evidence above recounted is found within a narrow range of height. The inundation of this section in times of flood did not give the waters a depth of more than ten or fifteen feet above the general level of the country.

The height of these ancient overflows is well indicated by certain peculiar artificial features in the country. The aborigines of this region left quite a number of mounds and other works on the higher lands of the delta district. When first occupied by the whites, these mounds were used as places of refuge for the settlers and their domestic animals in times of inundation. Since the settlement of the country, numerous other mounds have been built, sometimes immediately contiguous to the tumuli erected by the Indians, in order to increase the number of refuge places. Almost every settlement in the delta, at least those founded before the ramparts had been built to fend the country against the floods, had a collection of these mounds near by. As the work of their construction was costly, they have a height which just lifts their summits above the plane of the flooded waters.

While the facts connected with the present shape of the Mississippi delta do not indicate any recent change in the general levels of this district, except so far as such changes are brought about by the gradual thickening of the alluvial accumulations within the flooded limits, some slight process of downsinking is probably going on. I am informed by Mr. B. W. Harrod that there is clear evidence of recent subsidence afforded by the existence of cypress trees on the southern border of the delta with their crowns below the present level of low water in the gulf. As these trees occur, not in the form of drift-wood, but in situ, there is reason to believe that they indicate the depression of the area by the amount of three or more feet since the plants were living.

In much of the delta country north of Memphis during the earthquake visitation which occurred between the years 1811 and 1813, extensive areas of the alluvial plain sank down to the depth of from four to six feet below the level which they had previously occupied. The only one of these districts which I have had an opportunity to observe is that now occupied by Reelfoot and Obion lake basins which lie partly in Kentucky and partly in Tennessee. My observations have satisfied me that this district of subsidence occupies the field originally covered by one of the larger moats of the delta. At the time when this earthquake occurred, the old channel of the river included within the moat swamp had been filled with vegetable matter and alluvium. The violent motion which occurred during this earthquake led to the compacting of the mass and the consequent subsidence of the surface by jarring the materials which were doubtless in part decayed. This subsidence was sufficient to kill the cypresses, the gums and other marsh loving trees which occupied the area, and to reduce it to the condition of a lake.

Similar subsidences to that above described occurred at various points on the western side of the Mississippi River during the same period of disturbance. Although I have not closely examined this section, what I have seen of the subsided districts has led me to the conclusion that they also occupy the seat of former channels which had been converted into moats and filled with vegetable waste in the manner which I have supposed it to have occurred at Reelfoot and Obion lakes. At present the process of refilling these depressions by the growth of vegetation and occasionally by the incursions of drift-wood is going on and within another century it is likely that the considerable lake area developed by the disturbances in the early part of this century will have been in good part effaced. (Fig. 14.)

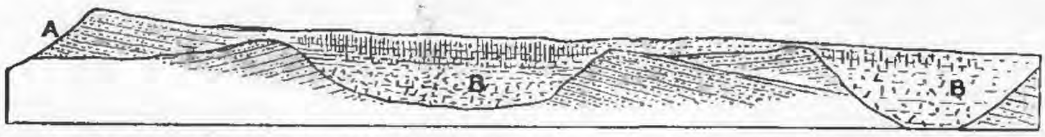

FIG. 14.—Diagram showing abandoned beds of a river. *A*, existing channel; *B*, old moats—abandoned beds of the stream.

The result of the somewhat complicated geographic processes above described is to a certain extent to diversify the topography within that part of the Mississippi delta. A considerable portion of the district has its surface above the level of all but the greater floods. By far the larger portion of its surface, however, is within the limit of height occupied by the ordinary inundations.

Although my observations have not been sufficient to make the matter clear, so far as they have gone they point to the conclusion that no general change of level due to continental movement is now going on in the Mississippi delta district. There can be little doubt, however, that the last general movement in this section has been a depression, for the reasons which are given at the outset of the section of this report which treats of the Mississippi delta. I have failed to find any evidence of elevation in the district. Such evidence would probably be patent if it existed, for the reason that we should then have alluvial deposits subjected to erosive action. It is possible that evidence of a very slight amount of elevation might be concealed by the upward growth of the delta accumulations due to the progress of the river mouth out into the Gulf of Mexico, but an elevatory movement thus masked could not have amounted to more than a few feet.

It is likely that this upward growth of the alluvium of the delta has increased since the occupation of the northern portions of the Mississippi basin by European races, and this for the reason that the process of culture increases the speed by which the flood waters find their way downward and consequently raises the height of the inundations. Moreover, the process of tillage naturally leads to the discharge into the stream of larger quantities of detrital material than were borne into it during the earlier times when the surface was in its natural state. The floods probably rise higher than of old and discharge more sediment than they formerly did over the surface of the alluvial plains.

CLASSIFICATION OF INUNDATED LANDS BASED ON THE CHARACTER OF THE VEGETATION.

The division of swamps as determined by the character of the vegetation to a great extent depends upon the variety of the climatal conditions to which different parts of the land are subject. Almost all land areas except those which have been affected by recent subsidence have for evident reasons a sufficient drainage slope to discharge their rain waters. The principal exceptions are found where the sea has constructed barriers of sand which embarrass the discharge of the waters, where the fluviatile swamps have been created by the excess of deposition along the margin of a river, or where the vegetation through alteration of climate or increasing dominance of particular species of plants has diminished the ease with which the water escapes from the land.

In tracing the effect of vegetation in embarrassing drainage and developing swamps, we shall begin our inquiry with the true forests which, with a certain measure of embarrassment of the drainage, become at times more or less affected by an excess of water. The swamp condition may prevail for a part of the year only or be continued in a permanent manner. The greater part of our trees are intolerant of any excess in the quantity of moisture about their roots. Some species, however, have by their organic experience become reconciled to such conditions. The variety in this measure of adjustment is an interesting feature in our larger plants. The range in the measure of this tolerance to permanent wetness exhibited by our forest trees is the more interesting when we consider the conditions under which our trees have developed. Probably all our land plants have been derived from forms of vegetation which were originally developed in marine or fresh-water areas. The strictly aquatic forms of vegetation, the sea-weeds, are entirely reconciled to complete inclosure in water, save certain of the higher forms which have developed the habit of dwelling between high and low tide; they are continuously surrounded by the medium in which they dwell and take their sustenance from the water through all parts of the surface.

In the plants of higher structure we find that the body becomes divided into two portions—an upper part, which is more or less intolerant of water, and a lower or root section, which demands for its functions a certain, though it may be slight, amount of exposure to such water. In many of the lower forms of phenogamous plants, as well as in most of our cryptogams, the conditions of the organism permit the permanent exposure of the roots to water. As we rise in the scale of plant organization towards the higher forms of the several groups which constitute our non-elaborated plants, the tolerance to continued wetness about the root diminishes. The roots demand moisture for their functions, but they require in general that the moisture, during the growing season at least, be held interstitially in the soil, and not in excessive quantity. They demand an alternation of extreme wetness and of moderate dryness, such as come to ordinary soils by successive rains and droughts. The greater part of our forest trees can not accommodate themselves to any soil where at least a part of their roots is not above the permanent water level.

The larger the organic assemblage constituting the tree the more intolerant on the whole the plant is of permanent moisture. Thus in our American plants there are some scores of species of herbaceous growth attaining a height of from 1 to 10 feet, which can dwell in tolerably swampy conditions, while the species of large trees, which can tolerate an equal amount of wetness, are very much more limited. Thus among the oaks only two or three species are moderately tolerant of swamp conditions. The other forms of the quercus family can not abide in morasses. The same variety in the amount of this tolerance in related species is seen in various other groups. One species of maple and three of gum endure tolerably swampy conditions. For further consideration of this problem see the second section of this report.

In no ordinary upland forest, even where the slope of the surface it occupies is of moderate declivity, do we find any considerable amount of permanent moisture. The dry seasons, which are a marked feature in all parts of North America, serve to desiccate the soil and give the roots their required access to the air during the growing period. Although the ground may be sodden with water during a part of the year, the inundation comes at a time when the functions of the plant are dormant. If now, in such a forest area, the regimen of rains is changed, depriving the wood of its time of dryness, or if, by any alteration of the base level of erosion or other conditions which determine the outflow of the water, the forest becomes more permanently moist, the delicate physiological adjustments of the plants may bring about a change in the character of the timber. This change may arise most readily and probably comes about most frequently from the migrations of various plants. The retention of moisture in the soil is to a very great extent determined by the character of the undergrowth which occupies the area. In an ordinary open wood that has a small amount of undergrowth the annual fall of leaves, twigs, and trunks may be no more than is taken away by the processes of decay. If, however, some species of swiftly growing plants extend into the wood and contribute a large amount of vegetable matter to the forest mat, the depth of the zone of decay may be increased. Its spongy character may serve to retain a sufficient amount of moisture to weaken and finally to destroy the original forest trees.

The extension of particular species of undergrowth may be brought about in a variety of ways. All our plants are in a state of singularly delicate adjustments. Each tree retains its place by virtue of very unstable equations with the plant and animal life about it. Thus the multiplication of our squirrels is leading to the destruction of certain species of oak, particularly the white oak, the nuts of which are devoured by these rodents. Particular species of insects diminish the vitality of certain trees by attacking the roots, leaves, or other essential parts of the plant. Again, some of our herbaceous plants, such as the common reed, vary greatly in the measure of energy with which they extend over the fields they occupy. Where, as in many cases, moving out from the open swamps, they obtain foothold in a wood, they carry the moist conditions which favor their development in their advance to the new ground. Their close-set, fibrous roots and the tangle of decayed vegetation which they rapidly accumulate, create swamp conditions which are not tolerated by the larger trees. So, too, our species of water-loving mosses, particularly sphagnum, under favorable conditions, advance upon the forests and gradually destroy the timber growth.

An alteration in the amount of rain-fall in the direction of increased precipitation may have a like effect in destroying a forest. It is a fact well known to gardeners that trees tend to dry the soil and a paucity of undergrowth can often be attributed to the desiccation brought about by the arboreal vegetation. But a slight increase in the rain may accumulate so much water in the forest-bed that the trees in their growing period can not evaporate it from the surface and in this way the ground may be made fit for lowly vegetation, which will speedily increase the water storage in the forest-bed.

Instances in which the gradual invasion of forests by swamp-making vegetation has destroyed the original growth of trees are abundant in the northern section of this country. Throughout the section north of the parallel of 43° cases of this sort may readily be observed. Thus on the sea-board of the State of Maine, near Eastport, I have noted a number of instances in which the growth of sphagnum invading the forests has brought the surface to such a wet condition that even the most water-loving trees are unable to maintain their foothold. They may be seen in all stages of deterioration. Well out into the swamp we may find the roots and crowns of the trees, the upper portions having entirely disappeared by decay. Near the margins are trees only recently killed by the access of water. Still farther towards the border of the swamp we find others in all states of degradation. Similar phenomena may be found from point to point in northern Michigan and Minnesota, serving to show that for some centuries at least the swamps have been making headway against the forests in their contention for the possession of the surface. (Fig. 15.)

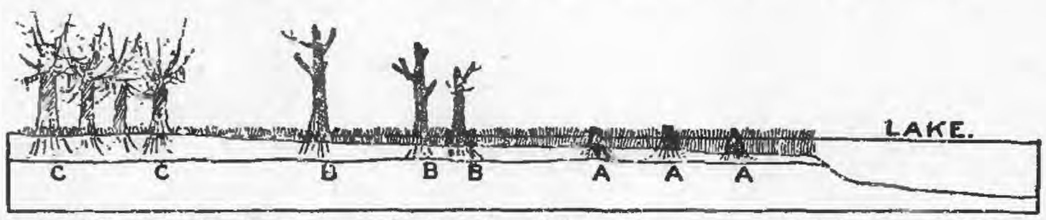

FIG. 15.—Diagram showing progressive invasion of forest by swamp. *AAA*, stumps of trees preserved in swamp; *BB*, dead trees with branches standing; *CC*, forest stunted by swamp growth.

EFFECT OF CERTAIN PLANTS ON THE FORMATION OF MORASSES.

We shall now proceed to consider the groups of plants which in various sections have the most important influence upon the development of swamp conditions. At present my studies have not enabled me to assign a satisfactory weight to the several species, genera, or families of plants in the development of morasses. Certain general points, however, are fairly well determined, and these will now be presented. In the northern section of the United States, speaking generally of those regions in which the mean annual temperature is below 55° F., the water mosses, especially the species of sphagnum, are by far the most important swamp-breeding plants. This is due in part to the fact that sphagnum can tolerate water more perfectly than any other of our important palustrine forms of plants, and in part to the peculiarity of its habit, which enables it to grow rapidly and form a thick sheet of vegetation without any of its roots being embedded in the under soil; they may remain pendant in the water. Owing to the rapid growth of its entangled shoots and to the very close-set character of the mesh which it forms, sphagnum is capable of retaining water in the fashion of a sponge. The particles of water are so inclosed by the filaments of the plant that evaporation takes place slowly and the water is readily drawn up from below by capillary attraction to replace that which goes away in the air. The result is that in regions characterized by a short summer and a considerable amount of rain-fall this plant frequently extends upward from the original level of the swamp, carrying the marsh condition to higher lands.

In northern Europe and elsewhere the species of sphagnum often develop luxuriantly on slopes having a declivity of as much as 5°, so that the bog may rise to the height of some scores of feet above the level of the water in which it originates, and may ultimately come to have many times its original horizontal extent. Within the limits of the United States the summers are generally so hot and dry that the climbing bogs due to sphagnum growth are of inconsiderable extent and rarely have an inclination of more than 2°. The American instances of these climbing bogs which I have observed are mostly limited to the eastern portion of Maine, near the shores of the Bay of Fundy. Faint traces of the same mode of growth are observable in certain areas of New Hampshire, and in a yet slighter measure in the northern part of Michigan and Minnesota. Even as far south as the swamps of Virginia and Carolina the sphagnum grows weakly above the level of permanent water, but it does not form a sufficiently thick mat to induce a permanent marshy character on the surface. I have never seen the coating of humus produced by it with a thickness of more than six inches in that part of the country.

Although this sphagnous growth in the swamps of North America is much less important than in the wet lands of the Old World, this group of plants has a considerable value in the development of swamps in all the region north of the Potomac. Its value as a peat-producer is, throughout the section within the glacial belt, probably greater than that of all the other water-loving plants. It is, indeed, in the numerous small lakes of the glacial area—pools having an original diameter of less than a mile—that these plants perform most of the work which is done by them within the United States. In such limited water basins the waves produced by the wind have relatively little power. The growing pond lilies and rushes protect by their leaves and stems the shores next the shallow bottom from the impact of the waves. Thus sheltered, the sphagnum grows apace, and by the continued supply of waste which it gives to the bottom still further diminishes the depth of the water next the shores which it occupies. (Fig. 16.)

As the sphagnum grows from its first lodgment on the shore outwardly towards the center of the lake, the mat it forms floats upon the water and constantly contributes the waste of its dead stems to the peaty accumulation which takes place upon the bottom of the basin. In this way, providing the pool be not originally deep, it requires but a few thousand years to close over the surface and reduce the original expanse of water to the condition of quaking bog. In this state the basin is covered by a continuous sheet of sphagnum dense enough often to afford a lodgment to many other aquatic plants, the mass continually thickens, and the sheet sinks gradually towards the bottom of the water. In time the bog, which for a period consists of humus on the bottom separated by a certain depth of water from the sphagnum on top, becomes quite solid. The

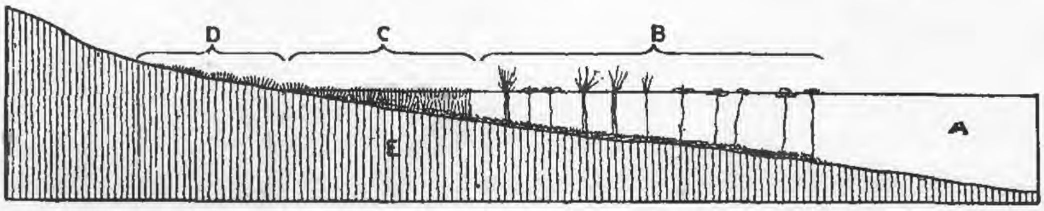

FIG. 16.—Diagram showing first stages of swamp growth around margin of lake. *A*, basin of lake; *B*, zone of lilies and bushes; *C*, place of beginning of sphagnous growth; *D*, climbing bog; *E*, disintegrated peat on which lilies and bushes are rooted.

further growth of the bog, which at this stage is usually occupied by an abundant growth of water-loving trees, serves to bring a certain amount of pressure upon the partly decomposed humus lying below, and so the mass is reduced to the state of compact peat, the lower parts of which mainly consist of sphagnous growth and the remains of water lilies and rushes, while the upper part, owing to the advent of the forest to the area in the later stages of the bog accumulation, contains more or less matter composed of the remains of the shrubs and trees. (Fig. 17.)

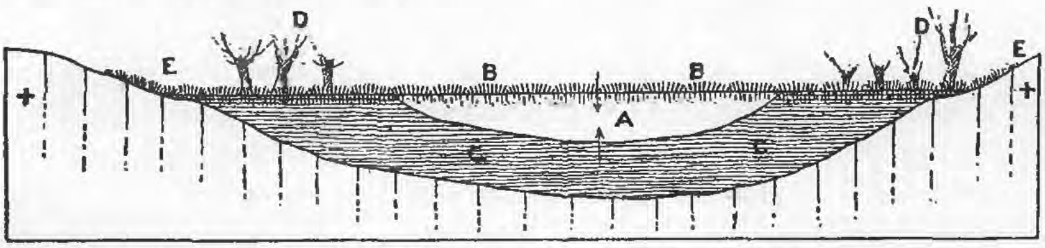

FIG. 17.—Diagram showing conditions of lake connected with quaking bog. *A*, remaining portion of water area; *BB*, living sphagnum; *CC*, peaty mass derived from disintegration of surface layer of living plants; *DD*, solid part of swamp bearing near shore trees, further out bushes; *EE*, climbing bog, often absent; ++, original level of water. The arrows indicate direction of growth of the upper and under layer of peat.

The greater heat and more frequent droughts of the region south of the Potomac and the Ohio—in general we may say south of the parallel of 39° or 40°—while they make the extensive growth of sphagnum impossible, serve to favor the development of certain other groups of plants which have an important influence on the development of swamps. These southern swamp-making plants belong in the main to the genus *Arundo* (our common cane), to species of the grape, to the bald cypress and juniper among conifers, and to dwarf palmetto and species of mangrove, the last two being limited altogether to the southern part of the United States. The importance of these several groups, as well as the regions which they affect, vary greatly. By far the most noteworthy of those mentioned is the common cane which abounds throughout the Southern States in all the marshy districts except those affected by salt water. To this group we shall now give attention.

The species of *Arundo,* though scantily appearing in favored stations north of the Potomac, do not take on any considerable development until we enter the swamps of Virginia. Indeed, the northernmost point at which they considerably affect the conditions of wet land is the Dismal Swamp district of Virginia and the Carolinas. (See Pl. XVI.) In that district the cane does not attain its full measure of development. It is rare indeed that the stems ever reach an altitude of more than fifteen feet or a diameter exceeding half an inch. Nevertheless, certain features connected with their habit of growth and with the circumstances of their decay cause them to have an important influence on the development of marshes even in this relatively northern part of the field occupied by them. Their roots are very tolerant of water, preferring to grow in a position where they lie altogether in the humus which is wet throughout the growing season. In such positions the stems are often so closely planted that there will be from 75 to 100 within the space of a square foot. The leaves as they are shed fall down and become compacted in the interspaces between the shoots, often forming a mat so close that water encounters much friction in passing through it, and this mass of leaves extends to the height of a foot or more above the surface of the ground. The dead stems prostrated by the wind also serve to complete the entanglement. On a surface densely occupied by cane or cane-brake, as it is termed, the interstitial friction is often so great that the surface of the water will rise upward in the direction of the drainage to the amount of several inches for each hundred feet of distance. The slope of the swamps occupied by these cane-brakes may thus become so sharply inclined that, as regards their slope, the conditions remind us of the quaking bogs in the more northern country.

If the cane-brakes of the southern swamps were as continuous as the sphagnum sheets of the North their influence on the wet lands would be even greater than that of the above-mentioned mosses. The fact is, however, that throughout the Southern States the distribution of the cane is extremely peculiar, and is subjected to various limitations even in the regions where it most abounds. It does not flourish beneath dense forest; it will not grow in permanent lakes or in free streams, and even where the conditions apparently best suit its development it is liable to sudden destruction from unknown causes. It appears likely that the plant develops in the manner of ordinary forest trees, the individuals attaining maturity and then perishing at times without leaving seed in the ground or young plants to take their place. Whatever be the cause, the fact is evident that the cane is usually scattered in a patched manner over the surface of the swamps where it grows. It is not unusual to find a cane-brake terminating abruptly with a wall of vegetation, scarcely a trace of the species being found beyond the limits of the sharply defined bound. Rarely indeed do these patches of cane exceed a hundred acres in extent, and in no case have I found a continuous area of this vegetation covering as much as a square mile of surface. It is probable, however, that with successive and interrupted growths the plant may occupy a large part of the field on which it appears at any one time in the form of scattered patches.

Where the growth of cane has anything like a continuous character, it is generally found in the condition of strips bordering the streams which traverse a swamp district. In this marginal form it often extends for a distance of some miles. In such positions it is important in its influence upon the growth of the swamps for the reason that it serves to create a barrier between the open streams and the morasses on either side, thus retaining the swamp water sometimes at a height of a foot or more above the level of the channel, into which, but for the cane, it would find ready egress. Although the cane can not attain its full development under a dense forest shade, it readily finds a lodgment in woods of an open character and often destroys the timber by the increased wetness which it brings about. Wherever the woods are blown down or destroyed by fire, the cane is apt to occupy the deforested area. Its sudden development in such positions in the form of stripe-like fields extending across a plain country may often greatly affect the drainage of a large district.

The various species of rushes which abound in different parts of the United States have a considerable effect on the development of swamps, although much less effective in barring the paths of outflowing waters than the reeds for the reason that they are of less height and never grow as closely together. Still, from the fact of their wide distribution they have no small effect in retaining the water on the surface of slightly inclined lands. In general the rushes differ from the cane in their distribution in the fact that they are more tolerant of water about their roots in the growing season; on account of their relatively small size, they are comparatively inefficient in forming barriers to water movement; yet they contribute a considerable amount of carbonaceous matter to deposits of peat. In the fluviatile swamps, rushes have a relatively small importance, owing to the fact that they do not readily tolerate a considerable range in the height of the water. I have found them best developed and most important as an element in swamps in northern New York about the borders of Lake Ontario. Around other parts of the Great

Lakes, as well as the water basins which have anything like an equal stability in the height of water, this group of plants has a considerable influence in swamp-building.

The plants next in importance are the grapes and the common species of the genus smilax, commonly known as the green-briar. Where either of these plants grow luxuriantly, they wrap over the other vegetation of the swamp, forming a mass of stems which are not at all supported by the stock through which the nutriment is drawn from the soil. In time their weight bears them down to the earth, as well as the plants they rest upon. In this way they form a tangle which resists the outflow of the water directly by the network of the stems and indirectly by the mass of leaves and other debris which they hold in their embrace.

The most conspicuous instances of this action which I have found occur in the plain lands of the Yazoo district in the Mississippi Valley, where a species of the grape locally known as the muscadine grows with exceeding luxuriance. The weight it imposes on the vegetation is often sufficient to break down trees several inches in diameter, bringing their branches in a confused mat to the surface in which position the debris serves to retain water on slopes of noticeable declivity. In some cases this creeper invades even the canebrakes crushing the stems to the earth and forming a dense spongy mat, which in times of flood water receives a large share of alluvium. In this way by the commingled sediment and the organic matter derived from the vegetable growth many of the low mounds rising from one to three feet above the general surface of the delta may have been produced.

The dwarfed palmetto contributes in some districts in a considerable measure to the restraint of the drainage. Its fan-shaped leaves, which are never elevated more than two or three feet above the surface, are often a square foot or more in area, and when they fall to the earth they contribute to the resistance which the water meets in its way down gentle declivities. The leaf remains for a long time undecayed, and thus is still more effective in hindering the drainage. This species is abundantly developed from southern South Carolina around the coast belt of inundated lands to the Mississippi delta. Up the west side of that delta district it extends to about the twenty-fourth parallel of latitude, or within a hundred miles of Memphis, Tennessee.

It may be remarked, in passing, that this is the northernmost extension attained by any member of the group of palms within the United States. This species will withstand a temperature which sometimes goes as low as 10° F. It is thus, perhaps, the most capable of enduring cold of any member of the order of *Palmaceæ*. Its extreme northern extension on the eastern side of the Mississippi delta is doubtless in part to be attributed to the relative proetction against low temperature secured by the wide belt of swamp land which lies to the northwest of the Yazoo district.

MANGROVE SWAMPS.

The group of mangroves is on all accounts the most singular and in many ways the most important of all our swamp-breeding plants. The mangroves have an eminently peculiar habit in that they flourish only in positions where their roots may come in contact with salt water. Phenogamous plants are generally extremely intolerant of the effects exercised by the waters of the sea; few of our arboreal or even shrubby plants can flourish with the sea water in free contact with their roots. The mangroves have, however, by a curious process of specialization become an essentially marine group. Although they are developed in a stunted form in water which is nearly fresh, yet so far as I have been able to observe they attain the vigorous growth which will enable them to drive out contending species only in stations where their roots are permanently bathed in salt or brackish water. The life habit of this form is so peculiar, and the plant has such an influence on the history of the coast-line marshes and swamps, that I venture to give in some detail the results of observations which I have made upon the species in Florida.

The modification of the mangrove, with reference to the peculiar work it does in the formation of morasses, is so singular that it will be necessary to trace in general the life history of the species. It may be said at the outset that the tree has an extremely varied height, the adult form ranging from an elevation of five to sixty feet. The seeds, in considering which we shall begin the account of the peculiarities of structure, are remarkable both for their size and form. They are fusiform bodies, having a length of from five to ten inches and a diameter from a quarter to half an inch. They contain a remarkably large share of nutriment especially devoted to certain peculiar needs in the growth of the plant. At the end of the seed from which the roots are thrust, hooklets are developed, from three to six in number, which have a length of from one-third of an inch to an inch, and are recurved towards the upper end of the seed. These hooklets are apparently in their nature roots, which are developed before or immediately after the fall of the seed. I have not seen the seed upon the tree, but I have found them where they had fallen, and am informed by local observers that these hooklets are developed before the seed falls. (Fig. 18.)

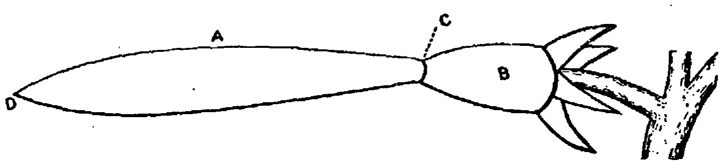

FIG. 18.—Diagram showing seed of mangrove. *A*, seed; *B*, fruit; *C*, seed drops off at this point; *D*, root end of seed.

It is worth while to note the fact that the seeds of the mangrove attain an unusual measure of development before they are detached from the parent tree. It is to the relatively great development of the embryo that we owe the peculiar form and great size of the whole structure. In fact, in this plant the seed, by attaining a considerable measure of its growth before leaving the parent, avoids some of the difficulties which would otherwise arise in the conditions of its germination. By a great development of the embryo, it attains the remarkable length which makes it easier for the young shoot to rise to the surface of the shallow water.

Owing to the fact that mangroves generally stand amid the water, a large part of the seed when dropped from the tree comes into command of the currents produced by the tides or winds. While floating, owing to the differences of weight at the two extremities, they lie in a nearly vertical attitude, the basalar or root end downward, and the upper or the sprout end not much below the surface of the water. In the course of their journey with the tidal or other currents, it happens that many of these seeds catch on the bottom by the grapnel-like arrangement before described. As soon as the seed becomes fixed, roots are thrown out from the base, which attach it more firmly to the bottom and stimulate the further development of the plant. The young tree then shoots rapidly upward, apparently being able by the store of nutriment contained in the seed to grow even under water for the height of a foot or more, until it attains the surface. As soon as it rises above the water it puts forth leaves, which enable it the better to perform that part of the functions of the plant which pertain to the atmosphere. These first leaves appear even when they are for a time exposed to being covered by the tide.

As soon as the leaves are formed, the plant grows rapidly; it shoots upward until the stem is just above the level of high tide; as the seed stem grows to the surface of the water rootlets essentially like the grapnel roots come up from the sides of the seed extending upwards and downwards at a high angle, attain the bottom and serve to support the stem against movement by the action of the waves; then the true crown is formed and the growth of the trunk as distinguished from the root section begins. From the crown shoot off long, slender, root-like processes somewhat resembling the stolon of a strawberry plant, only there is no bud at the extremity. These shoots commonly have a diameter of about an inch; they sometimes grow horizontally, but more often in a slightly ascending position for the distance of from three to five feet. Roots are thrown off from these stolons at a sharp angle, and grow downward through the water until they fix themselves on the bottom. They often have to traverse a distance of from six to eight feet before they touch the sea-floor. Having become rooted, a new crown is usually formed near where the root leaves the stolon or branch. From this new branching point another stem ascends and other runners are put off. (See Fig. 19.)

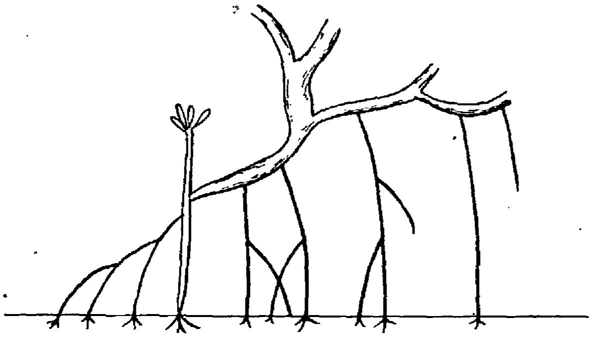

FIG. 19.—Diagram showing method of growth of mangrove.

Under favorable circumstances the mangrove spreads with great celerity. Estimating the rate of growth of the trees as well as possible from the annular lines of increment and from the testimony of observers, I am inclined to think that by these successive runners and branches the trees may advance over the sea-floor at the rate of twenty or thirty feet in a century.[1] The advance of the mangrove bushes upon the sea is limited in part by the deepening of the water, which, with the extension of the wood from the shore, may become so profound that the runners can not attain to the bottom, and in part by the action of the waves which toss the elastic runners about in such a fashion that they can not gain a foothold. There is yet another cause of the limitation, which is due to the fact that certain fishes, particularly the species called the mullet, which abounds in Florida waters, have formed the habit of feeding upon the growing extremities of the roots as soon as in their descent they attain the surface of the water. It seems to me likely that at the present time the action of the mullet is the most considerable of all the influences which resist the extension of this interesting plant.

As soon as the mangrove is established along the shore its growth begins to serve in the formation of a barrier to the escape of the land waters. The roots below the level of the crown check the flow of the currents and bring about a deposition of sediment. On these roots a good many marine animals and plants find attachment. In certain places the oysters seek such foundation and develop in considerable quantities, adding by their shells to the deposits of waste. The leaves as they are shed are also apt to find a lodgment in these close-set branches of the trees below their crowns. In certain places much driftwood lodges in the interstices of the root growth. The result is that in the end a low mole is built along the swampy shore

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[1] For the diagrams, Figs. 18 and 19, I am indebted to my friend Mr. Ralph M. Monroe, of Cocoanut Grove, Fla.

which, although having a height of not more than two or three feet, forms a tolerably effective barrier to the escape of the rain-water towards the sea.

The mangrove presents us perhaps with the most interesting case in which a plant has become highly specialized with reference to peculiar conditions. When we consider the evidently rigorous contest which goes on within our forests between the several species struggling for a place to develop, it becomes a matter of surprise that the strip of shore along our fresh and salt water basins is so rarely taken possession of by forms especially adapted to such situations. Of the many thousand species of trees in different parts of the world only a few genera have by any system of modifications been provided with the means of maintaining themselves with their roots below the level of permanent water. Of all of these the mangrove appears on the whole to be the most remarkably specialized with reference to its peculiar station. The adaptation consists not only in the structural features already detailed, but in the physiological modifications which enable the living plant to endure the salt-water. It appears to me that these facts illustrate in an interesting way how seldom in the chapter of accidental variation peculiarities occur which permit forest trees to occupy a position in which they clearly would have a singular advantage over their competitors. A careful consideration of this problem promises to throw some important light on the Darwinian hypothesis; but further discussion of the matter can not be undertaken here.

One of the important consequences arising from the free growth of the mangrove in the regions south of the Carolinas is found in the total change as to the character of the morasses in that area which are affected by tide water. North of the mangrove belt the tidal marshes have the same general character which they exhibit throughout the more northern regions of the continent. They are in the form of grassed plains covered at high tide, and quite destitute of all perennial branched vegetation, neither trees nor bushes flourishing upon their surface. Within the mangrove district this type of treeless marshes disappears. The surface which would be occupied by such areas is everywhere bordered by the mangrove growth, which serves in the manner before indicated to bar out the salt waters from their access to the land at high tide, and thus to permit the fresh-water plants to occupy the field which otherwise would be characterized by vegetation of a marine nature.

The mangrove fringe which borders the coast in southern Florida has in some parts extended the swamp area over wide districts which but for this growth would still be occupied by the shallow salt waters. In a considerable measure the everglade district has been converted from a shallow sea into marshes by the growth of this peculiar vegetation. The coral reefs to the south and east of the shore fend off the heaviest surges, while the waste of the reefs broken up by the waves serves, along with the remains of animals and plants, to shallow the water near the shore. Over these shallows the mangrove is rapidly advancing; the low shore-encircling mound, largely composed of calcareous matter which they produce and which fends off the sea waters from the inner growth of the swamp, composed of saw-grass and other plants which are intolerant of salt-water, is gradually taken into solution by the swamp water and borne away to the sea. The quantity of this calcareous matter dissolved by the waters of the everglades is remarkable. Not only does the water taste of lime, but in the season of drought, when the swampy lakes have shrunk five or six feet below the flood level, the bottoms of the dried-up pools exhibit a layer of calcareous sediment, forming a crust of from a tenth to a fourth of an inch in thickness.

The effect of this solvent action is not only to destroy the elevation formed by the mangrove belt, but also to efface the old coral reefs which lie within the everglades. This action is distinctly seen in the western or everglade face of the Miami Reef. These disintegration processes are diagrammatically shown in Fig. 20.[1]

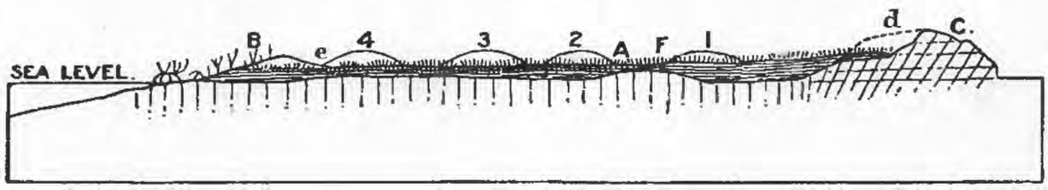

Fig. 20.—Diagrammatic section through Everglades, showing the effect of growth of mangroves on shore line. *A*, general surface of everglades; *B*, mangrove strip with attendant mound; *C*, Miami reef; *d*, bench excavated by everglade waters; *e*, dissolved portion of mangrove fringing mound: *F*, old reef destroyed by solvent action of water; 1, 2, 3, 4, successive portions of mangrove barrier.

THE EFFECT OF GLACIAL ACTION IN PERTURBING DRAINAGE.

The effect of glacial action on the surface of the land is produced in a variety of ways which we will now consider.

Where a glacial sheet rests upon the land it has, except in its period of decay, a motion over the surface; by wearing away the deposits on which it rests it quickly becomes armed with blocks of harder rock which are fixed in the lower part of the ice and shoved forward. These fragments moved by the glacier become instruments which serve to rend the rock beneath. They rapidly wear out and are replaced by other fragments which they have disrupted from their beds. Beneath most glacial sheets there is a system of water-currents—the so-called subglacial streams supplied by the water rendered molten in part by pressure and in part by various frictions which the movement of the ice brings about. It is evident in many cases that these streams act with much violence and so serve to aid in the

[1] For a further account of this solvent action of the swamp waters in the Everglade district see "The Topography of Florida," by N. S. Shaler, Bull. Mus. Comp. Zool., Harvard Coll., vol. 17, No. 7, March, 1890.

disintegration of the surface. The rate of wear of subjacent rocks beneath the glacier is extremely variable and depends upon a variety of circumstances. In the main it is determined by the resistance of each particular field to erosion which the glacier brings upon it. As this measure of resistance varies much, according to the constitution of the rock and its consequent changes in hardness, the glacier rapidly converts the surface on which it works from its original character given by river action in which the surface everywhere declines to the sea to a warped surface, a somewhat irregular system of depressions and elevations, which in a way measure the energy with which the erosive forces have operated and the resistance which the rocks have opposed to their action. Thus where the given area is occupied by stratified rocks in a horizontal position the relative uniformity in resistance which deposits of this character afford may cause glacial wear to take place with something like uniformity over a wide field. Where, on the other hand, the rocks have been much metamorphosed and upheaved by mountain-building action, variations in the resistance is much greater and in all cases such a surface is cast into a very irregular mold.

The deeper the depression which the ice has carved in a surface in general the more energetic is the erosion which it effects. The cutting power of the ice depends on the depth of the overlying section which presses upon any particular part of the surface beneath the glacier. Whatever be the irregularities of the floor of a glacier, its upper part either is level or else presents a uniform declivity in the direction of flow. Therefore, for a time at least, in the formation of an excavation the deeper it becomes the more it tends further to deepen, and this increase continues until the ice finds some difficulty in escaping from the trough owing to the height of its bounding walls. Owing to these conditions the pits which are excavated in any glacially worn surface of rock often have a surprising depth. They are generally basin-shaped, so that if the glacier disappeared without leaving any considerable coating of waste upon the surface a large portion of the given area is covered by water retained in these crateriform depressions. If the waste left upon the surface by the disappearance of the glacier is great in amount the depressions may be partly filled by detritus, but in large measure they will remain in the form of water basins. To this cause we owe a large part of the water area which becomes the seat of swamps in regions where glacial action has recently been operative.

While the excavatory action of the ice is one of the principal causes of the irregularities of the surface in glaciated regions, it is by no means the only influence exerted under such circumstances which acts to create conditions favoring the development of swamps. The debris or comminuted materials produced during a glacial time are probably even more effective in laying the foundations for the future development of morasses. While the glacier is in motion over a surface a large part of the waste removed from the rocks is by the rolling motion of the ice and various accidents which beset its lower part carried up into the frozen water for some distance, perhaps for hundreds of feet above the level of the ice. The quantity of this material thus taken up into the glacier is often very large. When the ice comes to melt away, this mass of débris sinks down upon the surface and forms the irregular sheet of drift now commonly known by glaciologists under the name of "ground moraine." If this sheet were of uniform thickness it would not have any peculiar effect in increasing the variety of superficial forms; but in fact the accumulation of this debris from the ice is extremely irregular. In some districts, particularly where very hard rocks occur or those which have few joints and which therefore give way but slowly under the influence of the ice, the amount of debris may be extremely small. In other cases it may be very large, and thus when the ice melts away a sheet of extremely irregular thickness, varying it may be from nothing to the depth of one hundred feet or more, is accumulated on the surface. As might naturally be expected, this irregularity in the distribution of the drift ground moraine creates many closed basins which become the seat of lakes. (Fig. 21.)

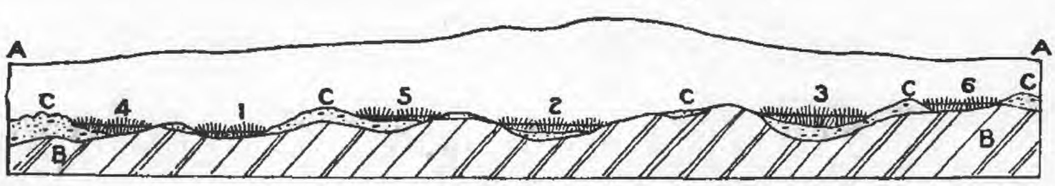

FIG. 21.—Diagram showing effect of glacial erosion on an area underlaid by rocks having a varying resistance to ice action. *A A*, preglacial condition with continuous inclined surface unfavorable to growth of swamps; *B B* warped surface induced by glaciation; *C C*, drift deposits; 1, 2, 3, swamps formed by depressions of bed rock; 4, 5, 6, swamps formed by barrier of drift.

As the glacial front travels across the country it pushes before it a large amount of material. When for a time its advance is arrested, this accumulation remains in advance of the ice as a frontal moraine. The accumulation is further reinforced by large amounts of matter brought to the given line by the steadfast movement of the ice or carried out to the front of the glacier by the subglacial currents. In this way in many parts of this country the walls of debris are left which dam across the paths of streams and generally obstruct the natural drainage of the country. A good many extensive areas of swamps owe their origin to this cause. Generally, however, the area of swamp lands thus brought into existence by morainal walls is small, for the reason that these frontal ridges are at numerous points breached by the openings formed at points where the numerous subglacial streams emerged from beneath the ice. In all the moraines which I have seen having an aggregate frontage of perhaps one hundred miles these breaches are rarely more than three or four miles apart, and in most cases they afford tolerably open paths for the egress of the waters. There are, however, some interesting examples where barriers of this description have served to retain swamps. The largest single marsh area in Massachusetts appears to owe its existence to such morainal barrier. This is the Great Cedar Swamp, lying to the north of Taunton, in Bristol County, Mass. We have at this point in the towns of Taunton and Raynham an obscure morainal ridge, rising in its highest point to about one hundred feet above the sea, and extending in a nearly east and west line for the distance of some miles. This accumulation blocks the path of a considerable set of streams and retains their water at a sufficiently high level to cover several thousand acres of land with marshy accumulations. (Fig. 22.)

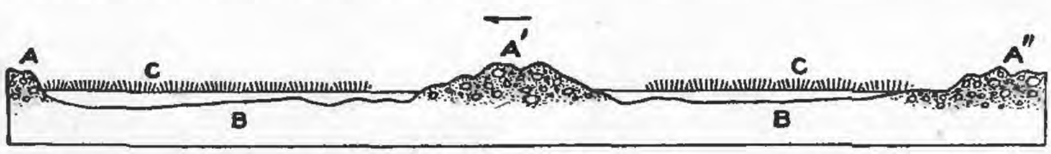

FIG. 22.—Diagram showing effect of moraines in forming swamps; *A, A', A''*, frontal moraines formed in succession from left to right; *B B*, frontal aprons of moraines; *C C*, swamps created by morainal obstruction to drainage. The arrow shows direction of the glacial movement.

In northern Michigan, where the frontal moraines are very numerous, they serve to retain the water on many extensive areas. In this region the effect of the morainal dam is clearly enhanced by other classes of glacial debris, the kame deposits and frontal aprons, the influence of which will now be considered.

The origin of kame deposits is still a matter of controversy. It is likely that they were formed either beneath a glacier or on the floor of a water basin immediately in front of the ice wall. The latter appears to me for various reasons (which will not be discussed here) the more probable explanation of most kame areas. These kame deposits when extensive most frequently appear as very irregular masses of stratified sand and gravel formed near the front of a shoved moraine. Owing to their normal irregularity of shape they inclose a great many water basins and thus produce a large number of small swamps. Moreover, as the accumulations of this description commonly lie somewhat parallel to the true moraines, the effect of their masses is to enforce the obstruction of the drainage which

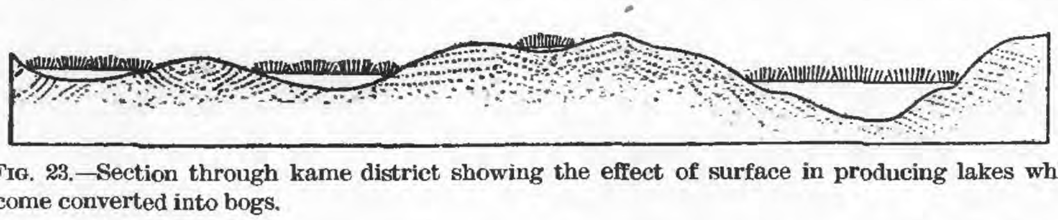

FIG. 23.—Section through kame district showing the effect of surface in producing lakes which become converted into bogs.

the shoved moraines produce. Thus the morasses of Bristol, Plymouth, and Barnstable Counties, Mass., which are among the most extensive in New England, are mainly due to the obstructive effect of these kame accumulations on the drainage. (Fig. 23.)

Besides the frontal moraines and kames our great moraines have almost invariably beyond their lines, in the direction towards which the ice moved, extensive accumulations of detrital matter in the form of plains or gently inclined surfaces sloping away from the morainal front. To this class of deposits I have applied the term "frontal apron." This plain region has normally a width of from one to six miles and surface very nearly horizontal. Most commonly this surface inclines gently backward towards the moraine for the distance of a mile or more from the front. Then from indistinct summits it declines at the rate of three or four feet to the mile away from the morainal accumulation. I have no question that the greater part if not the whole of these deposits were formed beneath the surface of a water area. Along the coast it is evident that this water was the water of the sea. In Wisconsin and Michigan where these morainal aprons are well developed, it may be that they were formed in fresh-water basins, an extension of the Great Lakes of the Northwest. The reader may find a discussion as to the method of formation of these aprons in my report on the geology of the island of Martha's Vineyard, in the Seventh Annual Report of the U. S. Geological Survey. Owing to the peculiarly level character of these frontal aprons, they favor the development of swamps. When occupied by vegetation they are generally the seat of wet woods, save in those cases where the materials are so porous as to permit the ready passage of the water.

Where the morainal accumulations are crowded close together, the frontal apron connected with one moraine frequently extends to the foot of the next moraines to the southward. Thus it comes about that in northern Michigan we have line after line of these successive moraines, the frontal aprons of which have become the seats of swamp building. (See Fig. 22.)

Besides the effects above noted, there are certain other less important influences of glaciers which deserve attention. Though they do not serve to create as large swamps as those produced in the ways above described, they lead to the formation of very numerous small morasses. In all glaciated regions, both in North America and Europe, masses of till occur which have the form of regularly arched

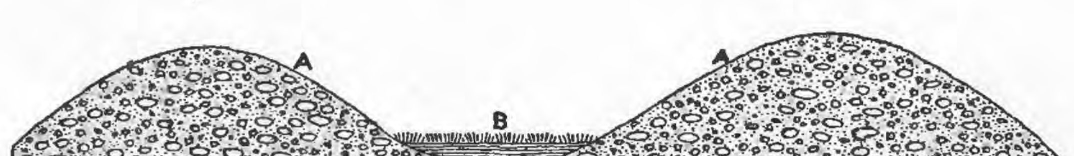

FIG. 24.—Diagram showing swamps developed between drumlins. *A A*, drumlins; *B*, swamp.

elevations commonly known as lenticular hills or drumlins. These hills are often crowded together in the same field, their bases being more or less confluent. In the cavities between the hills we generally find small swamp areas, and where a belt or field of drumlins lies across the general path of the drainage these elevations sometimes produce barriers to the flow of the waters and thus create tolerably extensive morasses. About one-tenth of the small bogs in New England are produced by these singular accumulations of bowlder clay ; but the total area of this class of swamps is probably not in all more than one-hundredth of the whole extent of this class of deposits. (See Fig. 24.)

Where kames are abundant, especially where they assume the ridge-like character to which the term "serpent-kame" is commonly applied, the irregularities of the surface lead to the formation of many small marshes. Probably one-half of the bogs in glaciated districts may be attributed to these irregularities in the distribution of the kame materials. Where the material composing these kames is of a somewhat compact nature, retentive of water, each of these depressions is at first the seat of a small lake which, owing to its inconsiderable size, is quickly closed over by vegetable growth. Thus, although there are probably at the present time over 5,000 kame lakelets in existence in New England, it seems probable that when the glacial sheet first passed from this country there were several times as many such basins as now remain unclosed. (See Fig. 25.)

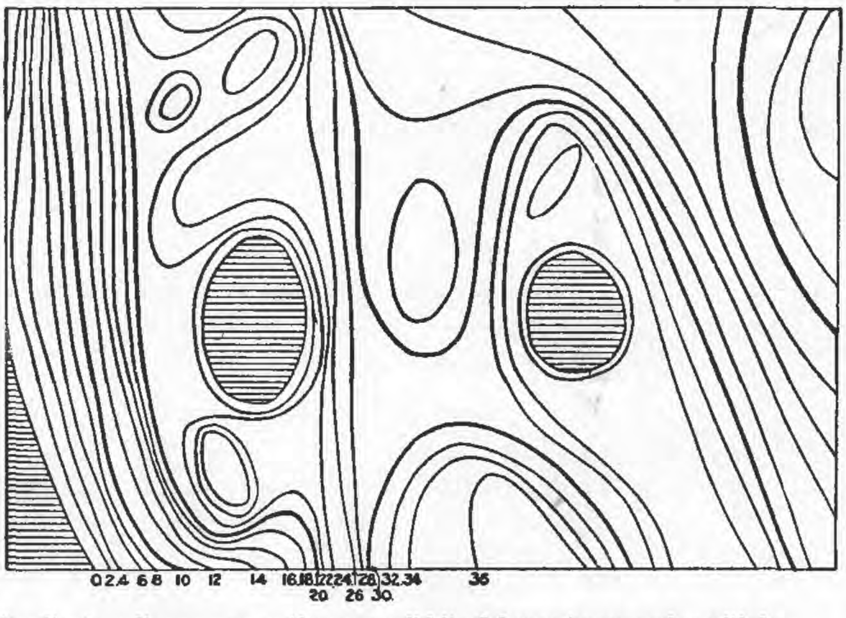

FIG. 25.—Contour lines representing a small bit of kame topography with kame ponds.

There is yet another though uncommon way in which glacial action produces depressions in its detrital deposits which may become the seat of swamps. When the ice sheet disappeared large masses of the glacier, which were heavily weighted with stone and other debris torn from the subjacent rocks, apparently remained in the valleys, and were flooded over by the vast quantities of water-drifted sands which spread across the surface of the country. In the course of time, though slowly, these buried masses of ice melted away, allowing the surface to descend into a pit-like form. Many of the water basins of New England, as for instance the well-known lake Cochituate, near Framingham, Mass., have been formed in this manner, as is indicated in the diagram. (Fig. 25.) It is possible that some of the kame kettles which are found scattered over the frontal aprons of the moraines in New England and elsewhere are to be explained in this manner, though the most of such depressions are doubtless to be accounted for by the action of whirling waters near their escape from the subglacial streams. (Fig. 24.) Last of all, among the glacially formed swamps, comes a small group of morasses which have neither physiographic nor economic importance, and are interesting only on account of the peculiar circumstances of their origin, viz, the glacial col swamps where the continental glacier overrode the divide between the head waters of two streams, the torrent sections of which radiated from the common ridge which separated the drainage areas. It often happened that the elevation between the heads of the adjacent streams became worn down, so that in place of a sharp divide separating the two valleys we have a continuous trough extending up from either stream-valley, and terminating in a small piece of imperfectly drained ground whence the sources of the two streams flow in opposite directions. In all cases where I have been able to examine valleys of streams, the head waters of which were included within the glacial belt, and the tributaries of which flow north and south from the crest line, I have always found that they were one or more glacially eroded cols of this character.

The most striking examples of these river-divide swamps which I have had an opportunity to examine are found at the head of the Genesee River in Pennsylvania, where the digitated small tributaries of that stream head against similar brooks belonging to the Alleghany system of waters. At the joint head of these streams there are three or more of these low passes, each occupied by a small area of swamp which discharges its waters both to the north and to the south. In one of these lies the most southerly situated glacial lake known to me in the Appalachian district. This small basin, which bears the name of Rose Lake, and which has an area of about six acres, owes the impounding of its waters to a slight accumulation of morainal matter across its natural exit. Larger specimens of the same class of divide swamps occur where the tributaries of the Mississippi head against the upper waters of the Red River of the North. Indeed, they appear to be common wherever the conditions above described occur.

It should be noted that cols of this description, sufficiently planed down to contain swamps, are likely to be formed only where the ultimate tributaries of the rivers flowing away from the divide lie in the path of the ice movement, and in about the same meridian. It is to be assumed that when the glacial sheet attacked the surface there was a low point in the crest where the heads of diversely flowing streams lay against each other. The ice, guided in its movement by the valleys on either side, and having its cutting energy somewhat increased by the progressive contraction of the valleys towards their head, has cut away the dividing ridge and planed it down to the form of a continuous groove. Where the original valleys did not head against each other I have in no case found the summit of the trough eroded in this manner.

As soon as a region recently occupied by a glacial envelope becomes repossessed by vegetation, the water-loving plants begin to efface the innumerable lakes which commonly occupy the area. Where the basins are, as is generally the case, less than half a mile in diameter and of no great depth, the process of occlusion goes forward with great rapidity. The mosses, principally species of the genus *sphagnum,* seize upon the shore and extend their sheet of interlaced shoots across the surface of the basin. They afford a foot-hold for many annual and perennial plants so that the sheet thickens and settles at once towards the bottom, while at the same time the accumulation of mucky matter, separated by decay from the superficial layer of plants, sinks to the bottom of the water, and is more or less commingled with the waste of diatoms and other plant and animal forms which dwell within the lake. The speed with which the small basins are closed is due to the fact that in such contracted areas the waves of the lake are not strong enough to destroy the sheet of vegetation which extends out from the shores. In the larger water areas the waves break up this marginal growth as rapidly as it is formed. In such basins it is not until the water next the shore is made shallow by contributions of waste drawn from the marginal plant growth that the mosses can do their work. When the suitable depth is established the lake becomes occupied by species of lilies and other plants which diminish the energy of the waves and so permit the more efficient growth of the swamp vegetation. Moreover, in large lake basins, the ice in the winter season, expanding under the influence of accessions of temperature, presses against the shores with great energy, and thus tends to shove back and destroy the marginal growth of plants. In the smaller basins, though this action is of some importance, it is not sufficiently serious to interfere with the extension of the bog materials from the shore towards the center of the area. The sheet extends rapidly over the surface of the lakelet converting it into a quaking bog, that is, a water basin covered with a sheet of vegetation, long before the depths of the pool are filled in with vegetable matter.

We thus see that to glacial action we owe a more wide-spread disturbance of the drainage conditions than can be attributed to any other geological cause. Though the morasses thus produced are generally small, the aggregate effect on a region is of great importance. Probably near one-half of the swamp areas redeemable to agriculture in North America are to be attributed to the disturbance of the drainage produced by the last Glacial Period.

From these several causes and others of slight importance which it is not necessary to notice here, the extensive ice sheets of the Glacial Period greatly perturb the drainage of the land. The consequence is that within the limits of the United States there are very numerous marshes varying in extent from an acre to tens of thousands of acres which owe their origin to glacial action.

THE ECONOMIC USES OF MORASSES.

The economic value of morasses is a subject of such magnitude that it can only be briefly treated in this memoir. The practical uses of such fields, considered from the point of view of human interest, may be divided into two groups, first, the resources afforded by the swamps in their natural state, and second, the advantages which may be won through the drainage of these areas.

In their natural state our morasses afford certain valuable products which deserve attention. First among these we may reckon the large supply of timber which is obtained from certain marshy districts. In this country the New England and some more southern swamps furnish large quantities of white cedar. In the Dismal Swamp of Virginia (see Plate VIII) and thence southward along the sea-board and in the interior district within the delta of the Mississippi, the swamps yield large quantities of juniper and cypress timber. In such areas the growth of the several species of trees which flourish in such situations is rapid and the wood is commonly of a valuable quality. With a proper system of planting a part of our eastern and central swamps can be made profitable nurseries of timber. The Dismal Swamp is particularly adapted to the growth of the juniper, nearly one-third of its surface affording conditions suitable for that timber tree. This species of tree affords valuable wood and grows with rapidity. The same is the case with the kindred cedar of our New England swamps. It seems to me quite possible that a considerable part of our fresh-water morasses may advantageously be used for forest culture, because they generally lie near to deep water and can be made accessible to transportation by very cheap canals.

The peat of our American bogs has been but little used for fuel. Only in certain peculiar situations, as for instance on Block Island, at the mouth of Long Island Sound, has the use of this fuel ever been long continued. In New England and in Canada repeated efforts have been made to convert peat into a more compact and serviceable source of heat by various modes of mechanical treatment. None of the methods adopted have proved commercially successful; though the amount of money and mechanical skill devoted to the end has been great, the failure in all cases has been complete A similar failure has attended all European efforts having for their objects the improvement of peat for fuel. From some studies of the project which I made about twenty years ago, I came to the conclusion that with ordinary labor at $1.50 per diem it would be possible to make serviceable fuel at the cost of about $5 per ton. The difficulty, however, is not altogether found in the cost of the treatment of the peat or in the nature of the product, at least as far as the production of heat is concerned, but in the popular prejudice against some of the qualities of the fuel. Peat is generally very ashy; it has a peculiar odor and the fire made from it is not lasting. It is impossible in this report to give a review concerning the history of peat fuel; such a review would, however, show that the prospect for utilizing this material in the United States is very small.

A large use of peat is found in agriculture. In New England and the other regions of the United States where small peat bogs formed in the depressions brought about by the Glacial Period are numerous, the farmers generally resort to such deposits for material to be used in their compost heaps. This substance when used is of value on account of the absorbent properties which it possesses. It serves, moreover, to add vegetable matter to our glacial soils which, owing to the recent nature of their formation, commonly lack a sufficiency of decayed woody materials. Long experience has on the whole warranted this practice of using peat for fertilizing purposes. It should be noted, however, that there is a great difference in the chemical constituents of peat. Where the material is mainly formed of decayed moss it contains relatively small amounts of lime, potash, or soda. On the other hand, where the peat, as is frequently the case, is composed in large measure of the decayed leaves and stems of upland vegetation, which have been swept to the pools by streams, it is much richer in such materials. When formed in this manner it often affords of itself a valuable fertilizing agent.

An important use of our swamps has within half a century been brought about through the artificial propagation of cranberries. This species of plant requires for its best development conditions in which the field it occupies may be periodically flooded with water. To attain this end it is generally necessary to strip an ordinary bog of its vegetation by cutting away the upper layer of turf and removing it from the soil. On this artificial surface a coating of sand from three inches to a foot in depth is placed in which the cranberry plants are rooted. Then by convenient dams the surface is made ready for flooding at the required times. It is the common opinion that the cranberry plants send their roots through the sand and obtain nutriment from the underlying peat. The fact appears to be that they develop in the main within the sand, obtaining little from the underlying humus, as is indicated by the fact that the plants grow about equally well in situations where there is no peat beneath the sand layer. The annual flooding with swamp water appears to be sufficient for the nutrition of the plants. At present probably over 100,000 acres of our northern swamps are devoted to this agriculture and the industry is rapidly extending.

The above-described form of tillage has an especial importance for the reason that it makes avail of areas which have hitherto contributed nothing to the economic interests of the country and gives employment to a large amount of labor. On the average an acre of cranberry bog requires the expenditure of about $300 in the preparation of the ground and an annual outlay of about sixty days' labor for the care of the plants and the harvesting of the crop. In the district of Cape Cod, Massachusetts, where cranberry culture has been most developed, the effect on the economic and social conditions of the population arising from the distribution of money in districts which were formerly almost without agricultural resources has been very great.

Within the glaciated districts of the United States the small marshes formed in the manner before described frequently contain considerable deposits of iron ore of the variety commonly known as bog ore. The chemical reactions which produce these deposits demand our attention only so far as is necessary to understand the general conditions under which such ores occur. Wherever the glacial waste is derived from crystalline rocks, as is the case throughout a large part of the glaciated district of North America, the soil waters penetrating downward into the more or less open drift deposits come in contact with ferruginous matter. The quantity of iron generally in the form of magnetite contained in the glacial waste is surprising. From samples of such debris taken from all the New England States I have come to the conclusion that on an average between 1 and 3 per cent. of the weight of the drift materials consist of this substance. The rain-water percolating through the soil becomes considerably charged with carbon dioxide, or carbonic acid gas, as it is commonly termed. This enables the passing water to take up a considerable part of the iron oxide. Entering a swamp these waters, by a somewhat complicated reaction which takes place on the contact with vegetable matter, lay down a portion or the whole of the contained iron and then flow away to the sea. In this manner our morasses in the glaciated district have become seats of extensive iron deposits. Almost every swamp has a greater or less amount of such bog-iron ore. Sometimes where the drift materials near the pond are very sandy the deposits consists of a mere ferruginous stain coloring the beds immediately under the bottom of the basin. In other cases, where the drainage is through gravels or clays of a less siliceous character, the bed of bog iron may be a foot or more in thickness.

In northern Europe, within the limits of the region occupied by the continential glaciers during the last ice age, these bog-iron deposits have long been extensively worked as sources of the supply for iron furnaces. In New England, especially during the last century and the first decades of this, the bog-iron ores were extensively exploited; of late years, owing to the discovery of cheaper ores nearer to the sources of fuel supply, resort to these sources of iron has been to a great extent abandoned. The aggregate quantity of these iron ores in the New England district and in the Northwestern States is probably very great. I am inclined to believe from inquiries I have made that in New England alone the total area of the bog-iron deposits exceeding a foot in thickness probably amounts to more than sixty square miles, and it may be several times this area. These bogs probably contain more than 100,000,000 tons of the ore. It is quite possible that within New England there may be 500,000,000 tons of such ore deposits. Within the limits of the glaciated field of the United States there is probably several times this amount of bog-iron ore in existence.

It must not be supposed that this ore has anything like the value which appears to be indicated by these large figures. Although the ores of this description are of excellent quality for certain purposes, they are generally very phosphatic and therefore are not at present of much value save for the production of foundry iron. Moreover, the deposits of bog ore are generally covered to a certain depth with peaty matter and the drainage which has to be accomplished before the wet beds can be won is often costly. Nevertheless, I am of the the opinion that in some conditions it will prove profitable to win these beds, at least in those cases where it is proposed to reduce the swamps in which they occur to agricultural use. When the so-called basic system of working iron ores by which the phosphatic material is eliminated from the iron comes into general use, it is probable that this group of deposits will have more value than at present. In any event they constitute a very important reserve in the iron resources of this country.

These bog-iron ores are most commonly developed in small marshes. Where the morass is of a large area they are frequently wanting, while in the neighboring swamps of limited surface they may

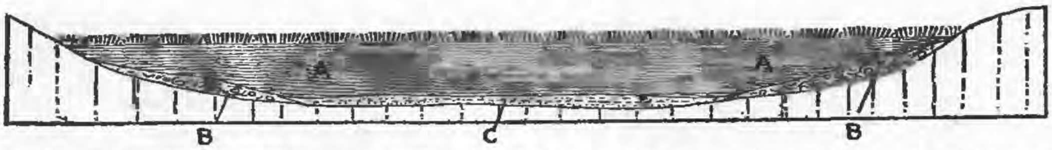

FIG. 26.—Diagram showing normal position of bog-iron ore and infusorial earths. *A*, peat swamp—occluded lake; *BB*, normal position of iron ore; *C*, normal position of infusorial earths.

abound. This difference is probably due to the fact that where the marsh is large the proportion of chalybeate waters which find their way into the basin is relatively small, while in the less extended body the proportion of ferruginous material may be much more considerable. I have also observed that the bog-iron ores are thickest near the margin of the swamps and at the point where the waters enter the basin and are often wanting in the central portions of the morass. This point is of some importance where the observer is endeavoring to determine the total quantity of iron ore in a particular area.

Another element of commercial value is found in the diatomaceous earths which are deposited in the open waters of the swamp areas. As is shown in Fig. 17 a portion of the swamp area is apt to remain for a considerable time inclosed by the bog growth, which in all cases extends from the margins of the basin towards the center. In this open water certain species of low-grade plants and animals rapidly develop and contribute their remains to the bottom. These forms, principally belonging to the group of Diatoms, afford the infusorial earth, which is now valued in certain arts. This material when of economic value appears as a gray or whitish, slightly compact, material, which when dry is of very little weight in proportion to its bulk. Its principal economic use is for making protecting envelopes for boilers and steam-pipes designed to retain the heat of the vessel. The material serves this purpose because it is very porous, containing exceedingly numerous and finely divided particles of air. The quantity of this infusorial earth in our swamps is considerable. Owing, however, to the fact that deposits of this nature are rarely formed near the shores of bogs, the presence of the substance is apt to escape detection. Only in the rare cases where bogs are drained to their central part are such deposits revealed to the eye. It is my purpose in the further prosecution of these inquiries into the condition of our swamps to make a careful study of these infusorial earths. At present I am able only to affirm their frequent occurrence in the larger morasses of the New England district. I am inclined to believe that they will be found to afford a resource of some economic value.

There is another important element in the deposits formed in our swamps which deserves attention. All our bog deposits show by chemical analyses that there is a process in action in such fields by which phosphatic matter is accumulated in materials laid down on the floor of the morass. The general history of these phosphatic deposits appears at present to be about as follows : Among the numerous groups of organisms which develop in the swamp areas we find an abundance of small crustaceans. These take from the water a certain measure of lime phosphate, which for a time is built into their bodies and on the death of the individuals is contributed to the silt which accumulates on the floor of the morass. In the mud of the swamps this phosphatic matter is again partly or altogether dissolved and is either diffused through the deposit or gathered into nodular form. Where, as in the northern parts of the country, the quantity of lime phosphate contained in the rocks about the swamps is small the phosphatic material may serve only to enrich the soil forming on the bottom of the pond, making it more fit for the uses of agriculture. In other regions, as for instance in the sea-board of South Carolina, where the underlying rocks contain a considerable portion of phosphatic matter, this material may become aggregated in nodular form. I am at present of the opinion that the extensive deposits of nodular phosphatic rock, which are mined in South Carolina, in the main owe their formation to this work, which goes on within the natural laboratory of the swamp accumulations. I have discussed this problem in a more extensive way in the introduction to the report[1] on phosphate deposits, prepared by my assistant, Dr. R. A. F. Penrose, jr. The matter will be subjected to further discussion in subsequent reports concerning the geologic and economic features of our swamps. In this preliminary sketch it can only be referred to in the most general way.

Our swamps have an important economic value from their effect on the flow of the streams into which they discharge. They act as natural reservoirs of the rain-water, storing it in times of much rain and pouring it out slowly into the streams. They thus bring about the relative steadfastness of the flow which is characteristic of all rivers which rise in swamp districts. The larger part of the New England streams which have value as water powers owe a considerable share of their value to the storage of rain-water in swamps. This natural storage is often increased by the construction of artificial dams, which increase the depth of the water retained in the morasses converting them for the time into lakes. Although this process of damming up the marshes has been of considerable importance to our manufacturers by insuring a larger and more permanent flow of water to the mill-wheels, it seems likely that the influence of such artificial reservoirs has been decidedly unfavorable to the health of the country. Some observers have attributed the recent rapid extension of malarial fevers in Connecticut, Rhode Island, and Massachusetts to the action of these dams which, when deprived of their water in times of droughts, bare large areas to decay, especially in the summer and autumn seasons.

By far the most important economic question concerning our morasses relates to the character of the soils which are obtained when they are unwatered by artificial drainage. On this point the evidence obtained from both this country and Europe, particularly from the latter, is conclusive. It is in effect as follows: The land obtained for tillage by draining swamp areas is generally of a very fertile nature and singularly enduring to the tax which husbandry puts upon it. When first drained the swamp areas are usually unfit for immediate

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[1] Bull. U. S. Geological Survey, No. 46.

use as tillage fields. The layer of peaty matter commonly has a considerable thickness. It must be removed by decay or by fire. Where possible this result is best obtained by flooding the district for a year or more to such a depth that the plants which cover it are altogether beneath the surface during the growing season. If after two years of such condition the area is quickly drained it is commonly possible to burn away the vegetable matter and make the surface ready for the plow. For a year or two the arable value of the area is small, for the reason that it is necessary to give the atmosphere time to exercise its influence in completing the processes of decay in the soil, which are but imperfectly carried on while the area is covered with water. The soil is said to be "sour" and "cold," but commonly through two or three plowings and consequent exposure to the air this evil is remedied.

Our swamp areas owe their fertility in large measure to the presence of phosphatic deposits which are formed in more or less abundance beneath all palustrine districts. Frequently there is also an increase in the amount of the lime, potash, and soda arising from the swamp growth. The only deleterious element deposited in the swamps is iron. In our New England marshes there is often considerable amounts of this substance, quantities so great as to be injurious to agriculture. Frequently this layer of bog-iron ore is limited to the shores of the swamp or to points near by where springs enter the morasses. Before deciding on a drainage project, it is important to determine the area occupied by the ferruginous matter and the thickness of the deposit. This in general may be ascertained by probing a swamp with a rod; if the ferruginous layer be, as commonly, not more than an inch or two in thickness, it is not likely to prove a serious hindrance to agriculture. If, however, the bog is underlaid by as much as six inches of iron ore, it would probably prove unsuited for the purposes of tillage. In general it may be said that our swamps, especially those which occur in sandy districts will, when properly drained, afford extremely fertile land. It may be remembered in this connection that quite one-fifth of the most fertile fields in Great Britain and Ireland have been won in such bog districts. During the time of the Saxon kingdoms, England was to a great extent occupied by morasses which have since been cleared away. The sites of these bogs are now indicated by the great and persistent fertility of the soil they once occupied. The same is true of a large part of northern Germany and the valley of the Po in Italy. Probably not far from one-twentieth of the tillable land in Europe was inundated and unfit for agriculture in the eighth century of our era.

In the United States the large amount of cheap Government land long afforded to settlers on our frontier abundant fields to be had almost for the asking. This stage in the development of the nation has now passed by. About all the ground immediately fit for agriculture has passed into private hands. As yet there are larger portions of the country untilled, but they consist of lands of a lower grade than those which were opened to settlers even down to the close of the eighth decade of this century. At the rate of increase of our population it will soon be necessary either to resort to lands of inferior fertility or to make avail of the vast areas which can be won to tillage either by drainage or irrigation. There is still a large store, probably somewhere near 100,000 square miles, yet to be won from inundated fields, and perhaps nearly twice this amount from the regions where irrigation methods may be applied.

The arid but irrigable lands are in the main remote from the seashore, and therefore commercially at a disadvantage as far as our greater cities and foreign markets are concerned. A large part of the swamp lands are situated near the Atlantic coast or in the immediate neighborhood of the greater rivers, and on that account are well placed for conveniently marketing their products. It seems to me that a large portion of the great area occupied by our morasses may be quickly made serviceable to our population by simple engineering expedients. The cost of irrigation is probably on an average somewhat less than that of drainage; but when we consider the better access to large markets, it is an open question whether the drainable lands do not contain the most important part of our agricultural reserves. Estimating the drainable area at a total of 100,000 square miles, it seems to me likely that the aggregate value of the district measured in terms of production will be not less than that afforded by the fertile lands comprised in the States of Ohio, Indiana, and Illinois.

AREA OF INUNDATED LANDS IN THE UNITED STATES WHICH ARE WINNABLE TO AGRICULTURAL USES.

In the table given below I have essayed a computation as to the area of lands now occupied by morasses or shallow lakes which can by simple engineering processes be won to agricultural use. The results are but approximations to the fact, but they represent the result of much study in the field and are based on data afforded by existing maps.

In classifying the lands under the head of morasses, all areas have been brought into the category in which the natural declivity is insufficient, when the forest growth is removed, to reduce the soil to the measure of dryness necessary for agriculture. Wherever any form of engineering work is necessary to secure this desiccation, the area is classified as swamp. There is no doubt that the corrections obtained through actual survey will considerably change the areas given in this table. It is believed, however, that in most cases the correction will serve to increase the estimate as to the extent of the inundated lands in each State. The object of preparing this table is rather to indicate the importance of these winnable lands to the agricultural interests of the country than to afford precise statistics as to the areas in question. Such statistics can be obtained only when the topographic maps of the country are in hand and the extent of each important area of morass has been carefully computed.

It will be observed that, in order to give a better general idea of the area of inundated lands, I have generally expressed the estimates as between certain limits. In arranging the several States in the table, it has appeared best to adopt the grouping of the areas which is in general that accepted in other descriptions of this nature. Thus the New England States are placed together as are also those of the Gulf district and of the Northwest.

LIST OF APPROXIMATE AREAS OF INUNDATED LANDS IN THE SEVERAL STATES.

In the New England States, the northwestern States, and Florida considerable areas of shallow, drainable lakes are included in this estimate:

	From—	To—		From—	To—
	Sq. miles.	*Sq. miles.*		*Sq. miles.*	*Sq. miles.*
Maine	3,000?	5,000?	Arkansas	8,000	10,000
New Hampshire	500	700	Tennessee	1,000	1,500
Vermont	300	500	Kentucky	300	400
Massachusetts	500		Missouri	2,500	3,500
Connecticut	100?		Texas	2,500	4,500?
Rhode Island	30		West Virginia	30	
New York	2,000	3,000	Ohio	1,000	1,500
New Jersey	900?		Indiana	1,000	1,500
Pennsylvania	300?		Illinois	3,000	4,000
Delaware	50?		Michigan	6,000	9,000
Maryland	400?	600?	Wisconsin	3,000	6,000
Virginia	1,400	1,800	Iowa	300	500
North Carolina	3,500	4,000	Minnesota	5,000	7,000
South Carolina	2,500	3,000	Dakota	500	1,000
Georgia	3,500	4,000	Nebraska	300?	500?
Florida	28,000	30,000	Kansas	200?	300?
Alabama	1,500	2,000	Total	105,210	131,200
Louisiana	14,000	16,000			
Mississippi	8,000	10,000			

The States of the Cordilleran group from the eastern face of the Rocky Mountains to the Pacific are not well enough known to me to be made subjects of even the most general computation. It is probable that the total area of soil which may be won from inundation by ordinary engineering devices in this field does not altogether exceed 10,000 square miles. I am inclined to think, however, that it will amount to somewhere near this total.

It should be observed that in this computation I have included the salt-water swamps and mud-flats where they lie in positions such as would make them reclaimable in the northern part of Europe. I have also included the areas of alluvial lands subject to inundations in the tillage season to such an extent that agriculture is unprofitable until the land is drained or diked. A portion of the area included in these computations is not drainable by gravity, but will require the use of mechanical means, such as wind-mills, to maintain the measure of dryness necessary for tillage. These districts in which pumping would be required do not exceed 5,000 square miles in area. I have estimated such districts only in regions so near to our large cities that the surface can be used for garden crops and thus would repay a large expenditure for the construction and maintenance of drainage systems.

PART II.

GEOLOGY OF THE DISMAL SWAMP DISTRICT OF VIRGINIA AND NORTH CAROLINA.[1]

The Dismal Swamp is the northernmost part of the characteristic swamp country which borders the southern Atlantic coast. It belongs altogether to that group of inundated lands where the lack of drainage is due to an original deficiency of slope, combined with the flow-retarding influence of vegetation on the movement of water from the land.

Although swamps of a similar character are imperfectly developed in the region north of the Potomac, they do not take on a conspicuous aspect until we pass southward of that stream; and this for the reason that the surface of the country north of it is considerably higher than in southern Virginia and the Carolinas, and has developed a stronger topography. The streams are sufficiently incised to permit almost everywhere the ready drainage of the water despite the obstructing effect of vegetation. Moreover, in the region north of the Potomac, the ordinary cane and the other plants which obstruct drainage make but a scanty growth.

The principal determining cause which has led to the formation of the Dismal Swamp is found in the character of the surface on which the marsh accumulation rests. The whole of this coast from New York southward has the form of an ancient sea-bottom more or less modified by river action, the measure of the modification being determined by the average height to which the sea-floor has been elevated above the level of the ocean and the steepness of the slope toward the sea. In New Jersey the plain is tolerably elevated and the slope from the interior towards the shore is steep enough to insure a swift discharge of the water. In northern Virginia the height of the plain is somewhat reduced and the slope proportionately

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[1] The literature concerning the Dismal Swamp is extensive but of an extremely fragmentary character. As it is proposed in connection with the work on inundated lands of this country to prepare a general bibliography of the subject, it does not seem worth while to undertake any work of this nature in connection with the present report.

It gives me pleasure to acknowledge my indebtedness to many intelligent persons dwelling about the Dismal Swamp for important information which is embodied in this report. I am also indebted to Mr. W. R. Atkinson, topographer of the survey, for much assistance which has been rendered apart from his services as the chief surveyor in the preparation of the accompanying map. I am also indebted to Mr. Collier Cobb, of North Carolina, for information concerning the submerged forests on the Albemarle Sound, and for diagram, Fig. 36.

diminished. From the James River southward, the elevation of the plain at equal distances from the shore is still further lowered, the incisive action of the streams having yet further reduced it, leaving parts of the surface in the form originally belonging to the sea-bottom. In this condition the surface for a considerable distance from the coast rises at an average rate of about eighteen inches to the mile. It is not a perfect inclined plain, for it is cast into slight elevations and depressions in a manner that reminds one of the ocean after a time of great storm, when the waves have fallen to a height of two or three feet, retaining at the same time their original horizontal amplitude. Within the limits of a square mile the variations in the surface of this inclined plain amount to not more than two or three feet. There is no distinct order in the elevations, but in general their major axes seem parallel to the existing and former shore lines.

Turning to the field in which the Dismal Swamp lies (See Pl. VI), we find that on the west, in the Dismal Swamp district, this billowy plain is sharply bounded by an escarpment formed by the sea when the surface of the continent was about 28 feet below its present level. This old sea-bench, to which I shall give the name of the Nansemond shore-line, extends from near Suffolk, Va., where it is rather obscurely indicated, having been somewhat effaced by erosion, southward with extreme distinctness of front to Albemarle Sound. A more detailed description of this escarpment will be given in the section of this report especially devoted to the matter of ancient sea-margins in this district.

The eastern boundary of the swamp district is determined by certain low elevations, apparently dune-like in their nature, which lie in the county of Princess Anne, east of the railway extending from Norfolk to Elizabeth City. This latter system of elevations, which attain a height of only a few feet, serve in a measure to retain the swamp waters upon the surfaces on which they lie. They are, however, of relatively small importance compared with the effect produced by the vegetation of this district. Although a large part of the area occupied by the swamps of this section of the shore is

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Description of Map.—The accompanying map is an incomplete topographic sketch of the region occupied by the Dismal Swamp. It represents the present condition of surveys which are in progress, and, although unfinished, it is likely to be helpful to the reader. Its most regrettable deficiency concerns the peripheral swamps; these are inadequately delineated, except on the eastern side of the main canal, where they are tolerably well represented.

The contour lines of five feet give a fair idea as to the general form of the surface occupied by the main swamp. These contours show, also, in a very clear manner, the character of the old sea-margin which forms the western boundary of the principal swamp area. Along this line the location of the contours is very much more definite than in the central portions of the morass. It is particularly to be regretted that the tributary swamps lying at the west of this bench are not delineated.

The green color indicates the unreclaimed swamp area; the conspicuously timbered districts are outlined by wavy lines, concave towards the forests.

without distinct marks of subaerial erosion, the surface, as will be seen by the map, is considerably divided in the region next the sea by the curious, fiord-like indentations which characterize the whole of our southern coast, but which are more marked in Virginia than elsewhere. It will be observed in the several maps that these indentations extend for some distance into the inundated areas, where they terminate rather abruptly within the wide field of swamp deposits. It will furthermore be observed from soundings indicated on the map, together with the sections which are intended to afford an idea of their form, that these streams are deeper in most instances than the open waters of the great bays into which they discharge. Thus, in Albemarle Sound, the water is in most cases not half as deep as it is where the branches of the sound penetrate into the swamp district. The meaning of this topographic feature will be discussed below.

GENERAL CHARACTER OF THE BEDS BELOW THE LEVEL OF THE DISMAL SWAMP.

It is difficult to obtain any satisfactory information concerning the beds below the level of this district for the reason that the unaccented topography fails to reveal good natural sections and the artificial cuttings, such as well and ditches, extend only to a trifling depth. On the northern border of the swamp deposits composed of stratified sand, containing occasional beds of shells, are exhibited from point to point. The following species determined by Dr. W. H. Dall, paleontologist of the U. S. Geological Survey, indicate in a general manner that the beds are of Pliocene age. Of the twenty-nine species which appear in my collection, a list of which is given below, twenty-four according to Dr. Dall belong to living forms, and five are extinct. The extinct species are found in the so-called Pliocene of Florida and South Carolina and Virginia. There can be no question that the deposit is of preglacial age.

LIST OF SPECIES FOUND IN BEDS EXPOSED BY A ROAD-CUTTING NEAR THE JERICHO CANAL, TWO MILES EAST OF SUFFOLK, VA.

Crepidula convexa, Say.
Turritella apicalis, Hp. (var.)
Scalaria clathratula, Adams.
Eulima sp.
Turbonilla interrupta, Totten.
Liomesus Stimpsoni, Dall.
Anachis avara, Say.
Ethalia sp. fragm.
Cadulus carolinensis, Bush.
Ostrea virginica, Gmel.
Pecten eboreus, Conr.
Pecten exasperatus, Sby.
Leda acuta, Conr.
Yoldia limatula, Say.
Nucula tenuis, Mtg.
Arca incile, Conr.
Cardium islandicum, Lin.
Crassatella undulata, Say.
Eriphyla lunata, Conr.
Mactra congesta, Conr.
Abra æqualis, Say.
Tellina tenta, Say.
Tellina modesta, Verrill.
Lucina crenulata, Conr.
Gouldia cerina, Ad.
Callista convexa, Say.
Chióne albida, Gmel.
Dosinia elegans, Conr.
Balanus sp.

Traces of this same deposit occur for a few miles south of Suffolk and I suspect the existence of similar beds near Elizabeth City. From certain comminuted fragments taken from the bottom of the main Dismal Swamp Canal, it seems to me not improbable that the beds were touched at several points in making that excavation. I am therefore disposed to believe that the foundation rocks beneath the swamp district consists mainly of the beds indicated by the foregoing list of fossils.

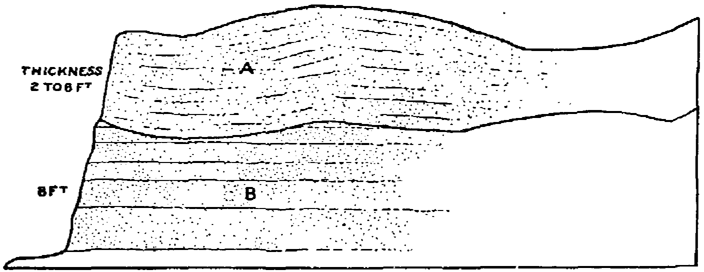


FIG. 27.—Diagram showing relations of fossiliferous sands near Suffolk, Virginia. *A*, upper sand, no fossils observed; upper surface slightly eroded, bedding somewhat irregular; *B*, lower sands with fossils noted in list; upper surface distinctly and sharply eroded.

It is evident that the strata of Pliocene age which underlie the swamp were accumulated in shallow but quiet water. This is shown by the character of the species as well as by the fact that many of them are delicate forms, yet have suffered no wear from the action of currents. The deposit in which these fossils occur has apparently suffered no other dislocation than that which attended its elevation above the ocean, which has brought it to a height of about 35 feet above the present sea-level. As the species are of a littoral nature, we may assume that the total elevation required to bring them to their present position may not have exceeded 100 feet. It may have been somewhat less. It is evident, however, that the surface of these beds was for a time at a higher level than that to which they now attain, as is shown by the fact that they are deeply incised by streams which have created a tolerably accented topography, the elevations of which have been obscured by subsequent accumulations in a manner indicated in the diagram. (Fig. 27.)

This irregular form of the surface of the Pliocene strata is only proved for the region about Suffolk. Faint traces of the same series of beds at other points lead me, however, to the conclusion that it is probably characteristic of the whole field. The character of the surface must have been given to the Pliocene beds at a time when they were more elevated above the sea than they are at present. After the erosion of this surface came the subsidence which formed the terrace in which the Nansemond bench is excavated, which lies considerably above the level of the Dismal Swamp. This, as is shown in section, Fig. 28 (see beds marked *A*), requires a subsidnece of more than 50 feet after the Pliocene deposits were carved by

DISMAL SWAMP CANAL, LOOKING SOUTH FROM WALLACETON, VIRGINIA.

streams. The bench on which the Dismal Swamp deposits lie was afterwards formed during another period of elevation when the sea lay at about 30 feet above its present level. The sands worn from the escarpment which I have termed the Nansemond bench were distributed over the new sea-floor in such fashion as to level off the inequalities brought about by subaerial or by marine erosion.

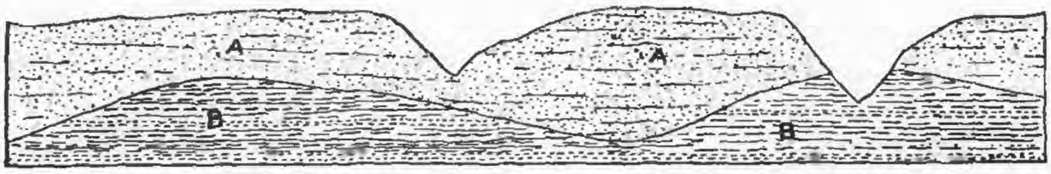


FIG. 28.—Diagram showing inferred relation of Pliocene and post-Pliocene strata in district west of Dismal Swamp. *A*, superficial sands forming surface of Nansemond terrace; *B*, Pliocene beds overlaid by more recent sands.

The true measure of the inequalities which characterize the bedrock surface of this district is not readily apprehended by an inspection of the area within the field of the swampy districts; the peaty accumulations have unquestionably done much to destroy such topography as may have existed in the region. Even on the higher level of the upper Nansemond bench, which forms the summit of the old Nansemond shore, bounding the western margin of the main Dismal Swamp, there are numerous original hollows now filled in with peaty matter of a consolidated sort on which ordinary forest trees have found a lodgment. I am informed by farmers that they frequently discover places in these fields which contain a peaty deposit many feet in depth. In some cases the accumulation is quite profound, permitting a sharp stick to be passed down to the depth of eight or ten feet. There may thus be within the limits of the Dismal Swamp a number of stream valleys which have been so encumbered by the accumulation of vegetable matter that they are no longer evident to the eye.

TOPOGRAPHY OF THE DISMAL SWAMP.

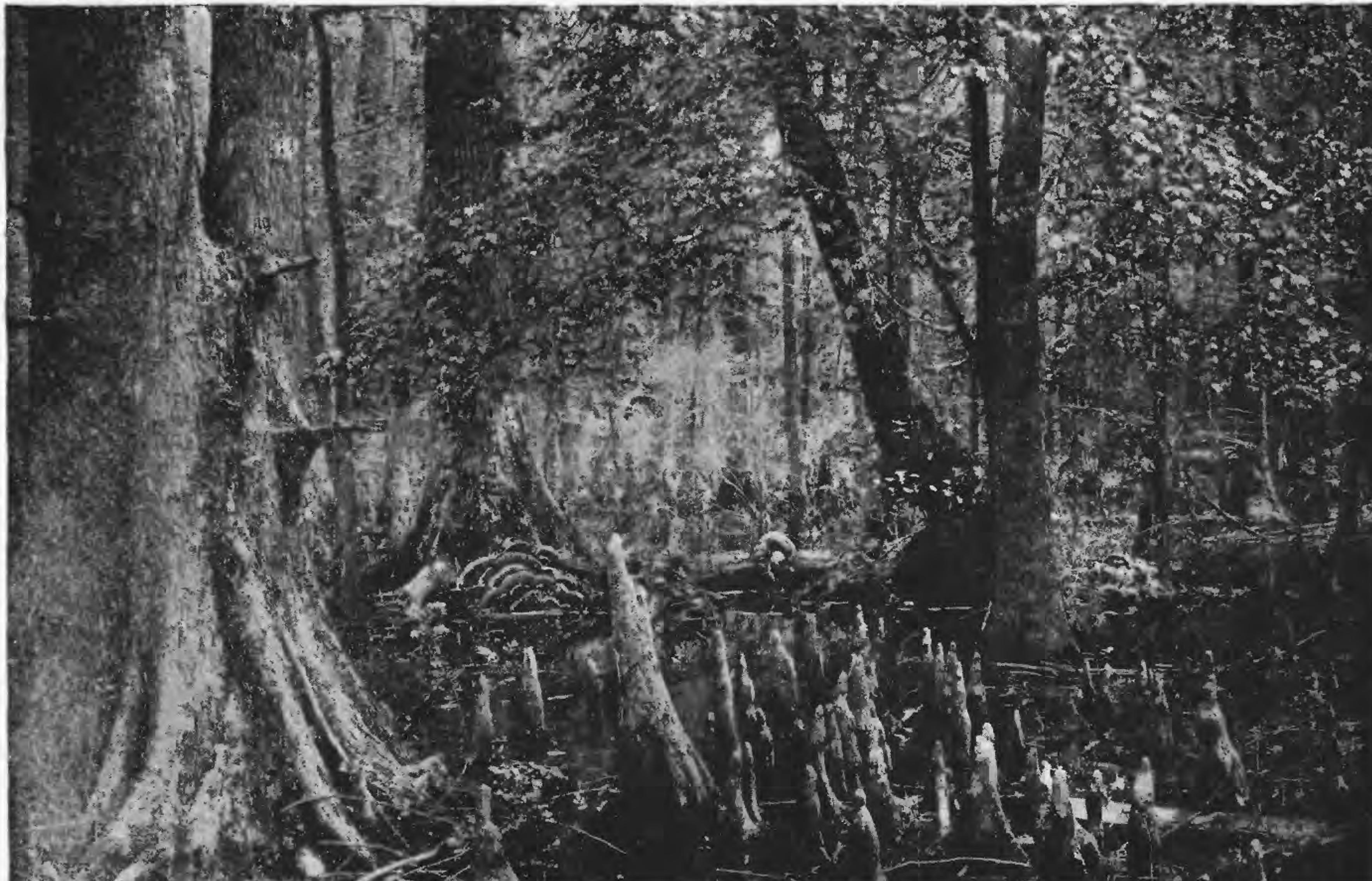
In its original condition, before this region had been affected by tillage, the area of inundated lands in the Dismal Swamp district was considerable greater than it is at the present time. If we include in the swamp lands in this part of Virginia and North Carolina fields which have been won to the plow by ditching, the original area of the morass was perhaps one-third greater than at the present time. Near its northern, eastern, and southern boundaries, the wetter parts of the swamp passed outwardly into fields where the inundations were less considerable, and in consequence the surface less incumbered by peaty matter. It appears tolerably evident that when the subjugation of the land began the swamp was extending its margins, taking possession of the lower land, the swales between the billowy elevations of the plain, and climbing up the gentle elevations between these low places. The process of artificial drainage went on rapidly until the drainage power of the small canals, dug to unwater the surface, was lost as they were extended into the swamp. The greater portion of this peripheral drainage work was finished before the middle of the present century. The lands won from the margin of the morass and from swamps more or less distinctly connected with the main area, probably amounted to somewhere near seven hundred square miles; the area of swamp lands remaining between the waters of Albemarle Sound and those of James River probably amount to not far from fifteen hundred square miles. In the last century the Dismal Swamp Canal Company constructed a canal in a general north and south direction from the waters of James River, at Deep Creek, to the waters of Albemarle Sound, near South Mills, N. C. (See Pl. VII.)

This canal was intended to afford a line of ship communication suited to the vessels of that age between the bay district of North Carolina and that of the Chesapeake. It was expected to furnish a passage for merchantmen and war vessels between these great systems of inland waters, and this expectation was realized. It was designed, moreover, to provide a means of access to the vast and then untouched forests of juniper, cypress, and pine which abounded in this field. This important water-way was one of the most considerable hydraulic works which had been undertaken in that century.

For the time when it was executed, the Dismal Swamp Canal was a costly and well-contrived work. For three-fourths of a century or more it was an important means of transit between Albemarle Sound and Chesapeake Bay. Of late its use for this purpose has been in the main superseded by another canal nearer the coast.

The effect arising from its construction through the swamp upon the general condition of the region has evidently been considerable. Its course is about at right angles to the general slope of the country. The first canal was originally designed to afford 12 feet of water and had a width of 50 feet or more; the amount of excavated material heaped upon the banks was considerable. As no pains was taken to provide channels of escape through the barrier for the swamp water coming from the west, the western dike of the canal serves to retain the waters in all that region, and at the same time to fend these waters from the region east of the excavation. The water has no doubt been retained in the part of the swamp lying west of the canal in order to keep the several ditches which feed the canal or which provide the ways of floating its timber from the recesses to the navigable depth. By a system of locks which have a total lift of 20 feet the water in the canal is maintained at a little higher level than it had before the canal was constructed.

The result of this interference with the natural drainage of the



SOUTHERN MARGIN OF DISMAL SWAMP.

swamp has been that the western section of the morass is probably rather wetter than it was before the barrier was constructed, while the section to the east of the canal, deprived of the water which originally flowed into it, has become partially desiccated. In the section to the west of the canal, within the limits of the area indicated on the map as a morass, there are probably no areas which in an ordinary season are sufficiently dry to permit tillage, though in periods of peculiar drought a large part of the surface may attain this measure of desiccation. In the section to the east of the canal the higher parts of the ground at many places are in an ordinary summer season so dry that they might be tilled without inconvenience from water. In that part of its area considerable portions of the surface have been improved by ditching, the swamp covering remaining only in the lower grounds adjacent to the sluggish streams which traverse the district. Something of this relative difference in the measure of the desiccation has doubtless come about in consequence of the barrier interposed by the embankments of the Dismal Swamp Canal. (See Fig. 29.)

At Wallaceton post-office, which is situated about midway between the ends of the canal, an enterprising proprietor has carried a tunnel beneath the waterway so as to provide drainage for a thousand acres or more to the west of the tow-path embankment. The result is that an area of not far from two square miles is sufficiently drained to admit tillage, and has long afforded admirable crops of Indian corn.

An interesting feature in the topography of the Dismal Swamp is the presence of a considerable lake occupying a tolerably central position in the part of the morass which lies to the west of the main canal. The form and position of this lake are shown on the map, and its general aspect is fairly indicated in Plates X and XI. The basin it occupies is everywhere shallow; probably in its natural state the maximum depth was not over six feet. At first I purposed to make careful study of the depth and form of the basin, but a little observation showed me that the depth of water had been much affected by retaining dams. The measure of the effect produced by the obstructions to natural drainage not being determinable, it did not seem worth while to make a careful study of the basin.

There is a tradition, which appears in its origin mythical, to the effect that this basin was formed by fires which occurred in some remote time. Intelligent local observers, in proof of this hypothesis, note the fact that, during dry seasons, patches of the swamp a few acres in extent have been seen to burn to such a depth as to form a place for the accumulation of permanent water. Not only is proof wanting to justify the supposition that Lake Drummond was thus formed, but there are good reasons why its origin must be otherwise explained. It is difficult to believe that in the course of a single dry season a forest fire could burn over an area as large as is occupied by this lake, or that the conflagation could so completely have removed the whole deposit of peaty matter. Moreover, even in the dryest season, it appears to be only the peripheral portions of the swamp which become sufficiently desiccated to burn to any depth, this central portion remaining wet at any depth beneath the surface even in the periods of greatest droughts.

If Lake Drummond were an unparalled feature in our swamp areas it might be reasonable to explain its origin by the hypothesis of an extensive forest fire in a period of great drought, but there are numerous instances in which similar lakes occur in the central portion of our greater swamp areas. I have been therefore led to the conclusion that this central lake of the Dismal Swamp was formed in the following

Fig. 29 —View showing aspect of swamp where timber is relatively dense.

way, viz: The gently sloping platform on which the Dismal Swamp rests evidently emerged from the sea in a somewhat rapid manner; the absence of any marine bench on its surface appears to be conclusive evidence of this. At first we may assume that the sterile character of the soil would have prevented the simultaneous growth of forest trees and other plants of a higher order over the greater part of the plain. The growth of such plants would naturally have begun on

DISMAL SWAMP ONE-HALF MILE EAST OF LAKE DRUMMOND.

EASTERN SHORE OF LAKE DRUMMOND.

the periphery of the district, either on the western border where the soil had already been formed, or next to the sea where the humidity would favor the growth of plants even on barren sands. I conceive that beginning on the margin the forest would advance towards the center of the field, and the fallen trees and other entanglements would serve to form an obstruction to the outflow of the water, and thus to retain the central part of the area in the condition of a shallow lake. The area of this basin would be gradually narrowed by the growth of the cypresses, black gums, and other trees which can maintain their roots beneath the level of permanent water. Notwithstanding the fact that the level of the water in Lake Drummond has been raised since the construction of the Dismal Swamp canal, the forest is still slowly gaining upon the area of the lake at several points. Leaves and drifted wood accumulate next the shore and shallow the basin so that, gradually, trees can find a foothold in what was recently open water.

If this view be correct, Lake Drummond must be considered as belonging to the type of peat-inclosed lakes which are so common in the small morasses of the glaciated area. To the same group we shall probably have to refer the numerous other lakes in the region of swamps south of Albemarle Sound. Lake Phelps, Pingo Lake, Mattamuskeet Lake, Alligator Lake, and other basins in the more southern part of North Carolina, probably belong to the same type of swamp inclosed basins.

GENERAL CHARACTER OF VEGETATION IN THE DISMAL SWAMP.

Although the physical conditions of the Dismal Swamp district are extremely uniform, the vegetation exhibits a considerable diversity in its distribution in different parts of the area. The higher land, lying not more than three feet above the lowest adjacent levels, is generally occupied by a growth of pines, altogether composed of the common species of southern pine so far as observed. These pine-clad elevations often rise so little above the surface of the swamp that the eye fails to detect the difference in level. Yet the lessened moisture due to the perceptible elevation is sufficient to give over the field to the possession of coniferous trees. The lower levels of the swamp are mainly occupied by three species of trees, which are greatly, though somewhat diversely, tolerant of water about their roots. These are the Taxodium or bald cypress, the juniper, and the black gum. The juniper occupies areas which are commonly somewhat desiccated through the dry season. The tupulo or gum, and the cypress can inhabit areas which are in most cases water-covered even during the growing season. The cypress is the most tolerant of water of these species, often attaining its best development in places where summer droughts at no time remove water far from the surface of their roots. (See Plates VIII, IX, X, and XI.; also Fig. 30.)

The peculiar tolerance of these two species to water about their bases—a feature which is somewhat sharply contrasted with the other forest trees of this country—is probably to be explained by the fact that in both forms we have provisions by which the roots are enabled to have access to air, and thus secure the aeration required by the processes which take place in their underground branches. The knees of the cypress have long been a subject of discussion on the part of botanists, and various conjectures concerning the service which they perform have been made. A study of the region in the Mississippi Valley which subsided during the earthquake of 1811, showed me very clearly that wherever by such accidents the vascular summits of these projections were brought below the level of the summer waters, the trees inevitably died. In other

Fig. 30.—Tributary swamp, a mile east of Corapeake, N. C.

cases, where by artifical dams the surface of the water had been raised in a swamp area, I found that the trees, the summits of which were suffused by the water in the summer season, were quickly killed, while others continued to live. The general results of some of these observations I have already embodied in a memoir.[1] Subsequent studies on the bald cypress in Florida, Louisiana, and elsewhere have served to confirm this conclusion.

[1] Memoirs of the Museum of Comparative Zoology at Harvard College, vol. 16, No. 1.

WESTERN SHORE OF LAKE DRUMMOND.

It is an interesting fact that the knees of the cypress develop only where the roots upon which they rest lie beneath the surface of the water during the growing season of the year. They sometimes appear above the surface of the soil which is bare of water in the summer time, but digging down to the place occupied by the roots water will generally, if not always, be found so far present in the soil that it fills the excavation.

Another important fact in this connection is exhibited in the specimens of this species which grow upon elevated land secure from summer inundation, or where the trees stand on the margin of a swamp with parts of their roots on the dry land and part beneath the water. In the case where the tree is altogether removed from the chance of inundation the roots bear no knees whatever, or at least they exhibit slight enlargements from point to point, which, though they indicate the positions the knees might occupy, never develop into such structures. On the margin of the swamp the roots which are beneath the water will bear knees, while those in the dry soil exhibit no such protuberances, or at most the slight prominences just mentioned.

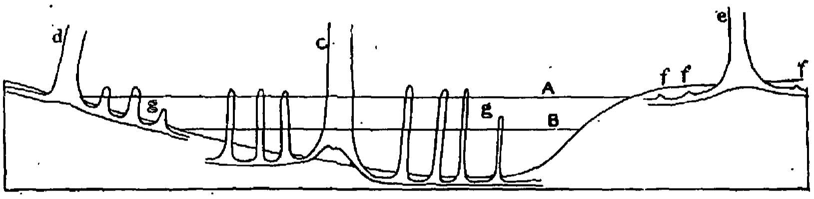


FIG. 31.—Diagram showing development of knees in Taxodium. *A*, level of water in the growing season; *B*, lowest level of swamp water; *C*, cypress with all the roots beneath water; *d*, cypress with a part of the roots beneath water; *e*, cypress with none of the roots beneath water; *ff*, its aborted knees; *gg*, knees not grown to serviceable height.

In the Dismal Swamp the knees of Taxodium never attain any considerable height above the surface, the tallest seen having an elevation of not more than three feet above the roots from which they spring. In the swamps of the Mississippi Valley, where the water of the marshes is often deeper than it is at any point in the Dismal Swamp, the knees sometimes attain an altitude of six feet or more.

The black gum contrives to secure a result similar to that attained by the Taxodium by quite another contrivance of its roots. Where this tree occupies positions in which the water remains during the summer season the roots in all cases in which I have been able to observe the facts have the habit of arching upward a few feet from the base of the bole in the manner which I have indicated in the accompanying diagrams (Figs. 32 and 33), and which is also imperfectly shown in Plates VII and VIII.

Where the region is only moderately wet, where the water in the summer season comes near the surface, the emergence of the root is accomplished by a gentle upward flexure which brings its surface a little above the top of the ground; where the water stands yet higher the whole of the root may emerge from the soil. In rare cases, where the water during the growing season stands two feet or more above the level of the roots, the flexure in that part of the tree is still more noticeable. In such cases the curves frequently assume the form shown in Fig. 33.

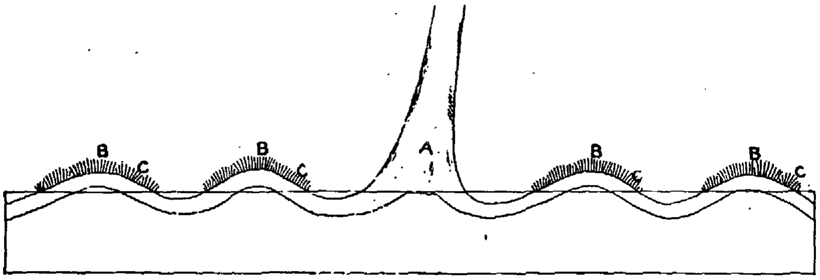


FIG. 32.—Diagram showing position of root-arches in black gum. *A*, trunk of tree; *BB*, root arches; *CC*, plants rooted in rugosities of bark, showing height of water in growing season.

It is tolerably easy to determine the depth of inundation during the growing season by a close inspection of these root-arches of the tupulo. The bark is very rugose and in the damp swamp is frequently the seat of a considerable growth of annual plants, occupying positions shown in the diagram (Fig. 32). In some cases I was able to observe this coat of vegetation on many of the root arches around the same tree. The annual vegetation was everywhere at the same height, and therefore may be taken as evidence that the roots are

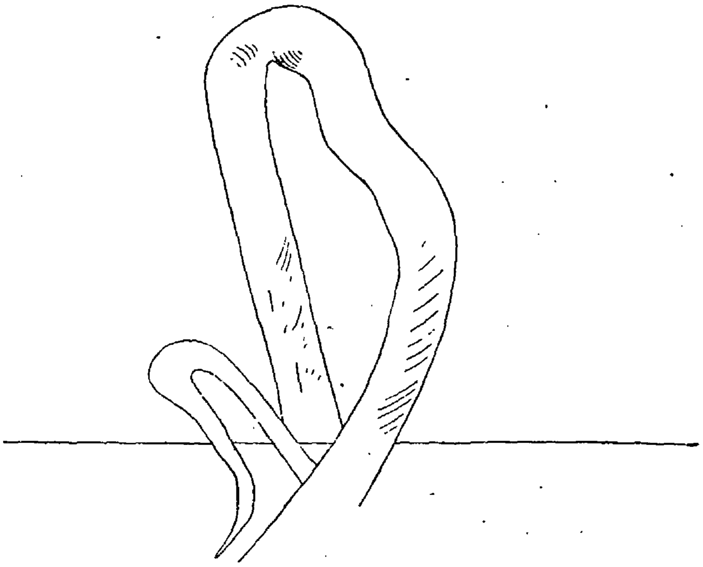
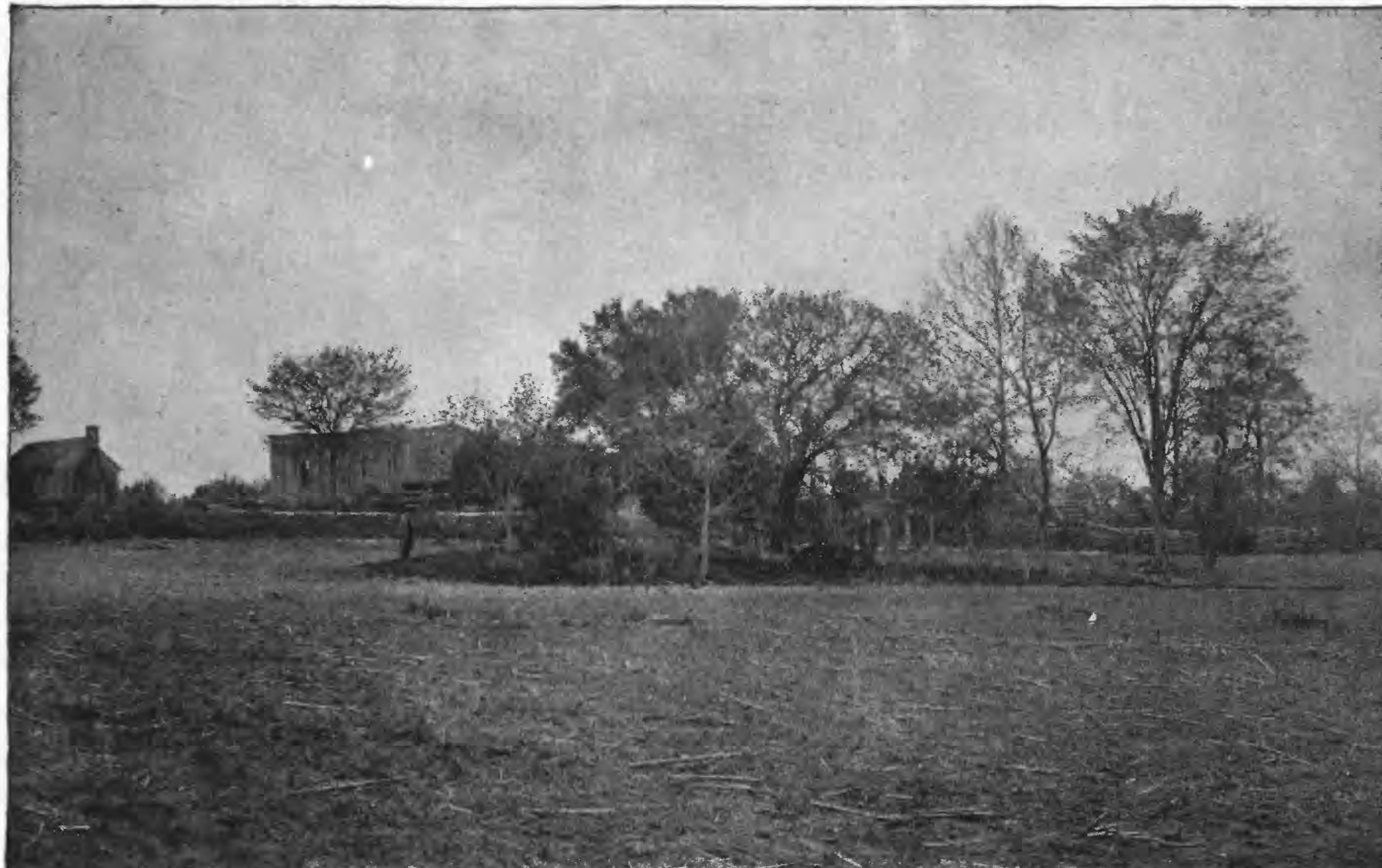


FIG. 33.—Sketch of root-arches of black gum in extreme form of development.



NANSEMOND SEA BENCH, TWO MILES SOUTH OF SUFFOLK, VIRGINIA.

deeply covered by water in the summer time, but that the knee arches rise a foot or more above the surface of the water, or to about the same extent as the summits of the knees in Taxodium.

The amount of root arching in individuals of this species as well as the development of similar knee processes in Taxodium differ considerably in the individual trees. In some forms, lying at the same height as others, which are abundantly provided with these arched processes, the flexures are almost wanting. It appeared to me, however, that in the cases where the arches are not well developed the trees are always of an inferior growth and apparently not well reconciled to their environment.

It is also a noticeable fact that the flexures of the roots do not develop in the youth of the plant, but begin to be evident after the tree has attained a diameter of a foot or more. Something of the same sort may be observed in the case of Taxodium. The older the tree the more extensive proportionately are the knee processes. A young tree an inch or two in diameter without any knees at all may often be observed growing near specimens of the same species a foot or more in diameter, all of which have abundant knee processes. It seems clear that in both of these genera the knees are features which are not developed until the plant attains a considerable size.

It appears to be a characteristic common to nearly all trees which have become reconciled to very wet soils that their trunks are much expanded at the crown, tapering from that point upward more rapidly than trees in other situations. The two varieties of gum and cypress are conspicuous for this feature. It seems evident on eye inspection—I have made no comparative measurements—that the expansion of these trees at the crown where they occupy wet situations is much greater than when they occur upon relatively dry ground. Not infrequently with gums and cypresses the diameter of the tree at the crown is over twice as great as it is at the height of ten feet above the surface and in some cases I have found the ratios as high as three to one. An eye inspection, without measurement of several other species in stations diverse as regards the amount of moisture to which they were subjected, appears to indicate that this expansion of the crown in wet conditions is a common feature of forest trees. It seems possible that the enlargement of the tree just above the level of permanent water may be due to the same physiological conditions which determine the development of knees such as occur in the Taxodium, or of sharp flexures in the roots, like those exhibited in the Nyssa. When I first observed this feature I was disposed to think that it was perhaps designed to support the trees in their somewhat insecure foothold in the soft earth of the morass. Further inspection has satisfied me that this view is untenable and that the peculiarity is more likely to be due to the cause above mentioned.

THE NANSEMOND BENCH OR ELEVATED SEA MARGIN.

As before remarked the western border of the main Dismal Swamp is well defined by a sharp elevation or escarpment which seems to have been clearly an ancient sea-margin. This escarpment is distinctly traceable from a point north of Suffolk to the southern border of the main swamp. The general trend of the escarpment is north and south. The character of the feature is tolerably well indicated by the map, by Pls. XII and XIII, and by the transverse sections of Fig. 34. In its general character the escarpment is a sharp step between the tolerably level area lying to the west of its summit and the uniform surface of the swamp to the east. The average difference of height between the base and the summit plain is about twenty feet, varying from five to fifty feet. Although the surface of the escarpment is more or less eroded by stream action which has evidently taken place since the time when the sea broke against its base, it is on the whole better and more continuously manifested than in any other marine bench which I have ever seen in this country or in Europe.

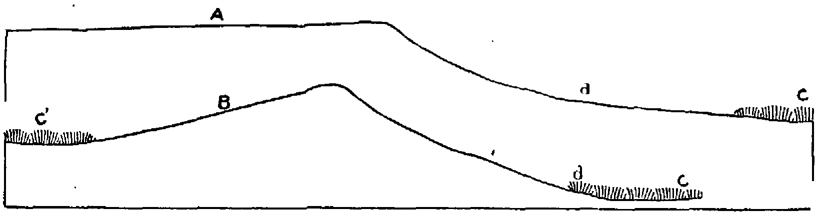


FIG. 34.—Typical sections of Nansemond escarpment. *A*, prevailing character of section through Nansemond escarpment; *B*, oceanward type of section where the back swamp extends to near escarpment; *CC*, main Dismal Swamp; *C'*, back swamp at higher level; *dd*, old beach slope.

As indicated in the general map, this escarpment is cut through by several considerable streams which drain from the swamps lying at the height of several feet above the main morass. Where these streams debouch into the eastern swamp, the distinct bench character has been in part effaced by the action of their waters as well as by the considerable amounts of detritus which they have brought from the upper to the lower level. (See Pl. XV.) At many points, however, the escarpment has an average declivity exceeding 20°, the slope at the base having the general aspect and about the angle proper to sands which have been rearranged by wave and tidal action. (See Pl. XIV.)

In the thirty miles or more of length between Suffolk, Va., and Reddick's Store, N. C., the escarpment is unbroken by promontories or outliers. At Reddick's Store, however, as is shown by the map, we have a promontory projecting a considerable distance to the eastward. This promontory lies at a slightly lower level than the main part of the plain against which the terrace has been formed. Dur-

NANSEMOND SEA BENCH, EAST CORAPEAKE, NORTH CAROLINA.

ing the time when the sea lay against the terrace, this projection seems to have been a sandy cape, the top of which rested but a little above the level of high tide.

A peculiar feature connected with this old sea-margin consists in the relative rarity, as compared with the existing shore-line, of sand-dune structures. The present shore from Cape Henry southward to Cape Florida exhibits at all points, where I have had an opportunity to study it, an abundance of these elevations formed by the action of the wind. Along the main line of the terrace from Suffolk to Reddick's Store I found scarcely a trace of wind-drifted sands—nothing, indeed, sufficiently clear to be classed among those topographic features. On the promontory at Reddick's Store above mentioned there are a few small areas of wind-blown sands, so insignificant in their development as to require close observation to detect them. None of the elevations exceed four feet in height. The absence of dune structure is indeed a conspicuous feature in all this part of Virginia. So far as my observation goes, it characterizes the southern plain from this section southward. It is evident that no portion of the great southern plain was to any extent or for any considerable time attackable by the wind after its elevation above the sea.

I find it difficult to form a satisfactory explanation as to the rarity of dune deposits in this district. It is evident, however, that one of two suppositions is required. We must conceive the country to have been characterized by westerly winds alone or accept the theory that the currents of air moving from the east during the time when this was a sea bench were of very slight energy. If in the end it turns out to be a legitimate assumption that the winds were more prevailingly from the west during the time when this sea bench was formed than at present, the fact may be important with reference to the climatal conditions of this country during the glacial time or the period immediately following the recession of the ice.

The swamps which lie west of the Nansemond escarpment are of considerable extent. The area as well as the form of these morasses has not yet been determined by surveys, nor are the heights at which they lie sufficiently ascertained to make them the subject of adequate description. In their general character they are substantially like the Dismal Swamp and their wetness is due to similar circumstances of embarrassment of drainage by vegetable growth which has produced the greater morass eastward. They lie in the detached basins of the several streams which drain them. It seems to me necessary to suppose that the valleys in which these swamps lie were excavated when the surface was more elevated than it is at present.

The extent to which these streams occupying the country to the west of the escarpment have cut down into the general level of the plain on which they lie is one of the indications that the surface of this country has been considerably higher than it is at present. At no point are these streams now doing any work of excavation; on the contrary, the swamps appear at all points to be gaining in area. It is probable, moreover, that the palustrine accumulations are considerably deeper in these western basins than they are in the main Dismal Swamp. I am inclined to think that the streams were originally carved while the region lay fifty or more feet higher than at present. This opinion is supported by the fact that where these streams traverse the escarpment they pass it in wide valleys which appear to have been in good part filled up by sand washed from the neighboring escarpment. These valleys have at some points a width of one-half a mile or more, the general conditions of these breaches in the escarpment is shown in Fig. 35.

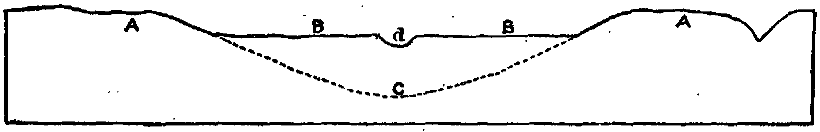


FIG. 35.—Diagrams showing condition of stream valley traversing Nansemond escarpment. *AA*, section along the margin of the Nansemond escarpment; *BB*, valley of stream draining from back swamp with wide terrace; *C*, dotted line showing conjectured slope of valley; *d*, trough of sluggish stream, now doing no erosive work.

EFFECT OF RECENT CHANGES IN THE CONTINENTAL LEVEL ON THE DISMAL SWAMP DISTRICT.

I have already had occasion to consider the principal features which afford evidence of recent changes of level in this part of the continental area. I propose now to assemble and examine in some detail the facts which indicate alterations in the relations of land and sea in this district, with the hope of determining, as far as it may be done from the evidence, the succession of events involved in the movement of the continent since the beginning of Pliocene time.

It is evident that during the period when the fossils noted on page 315 were deposited this region lay at a lower level than it now occupies. The amount of subsidence probably exceeded a hundred feet and may have been much greater. During this time the Pliocene of Nansemond County, upon which the Nansemond escarpment was formed, was deposited. This Pliocene deposit extends inward for a considerable distance, certainly beyond the Petersburg and Weldon Railway. Its contact with the previously existing land of the continent is not well known to me. It appears, however, to have been rendered obscure by recent erosion. After the deposition of these Pliocene strata the surface of the country underwent an elevation which carried this portion of the continent much above its present altitude. During this period the valleys of the rivers in this district were probably in part excavated and at the same time the general topography of the country was greatly accented by the digitating tributaries of these main rivers.

USUAL ASPECT OF MARINE BENCH ON WESTERN BORDER OF DISMAL SWAMP.

The next event in the physical history of the continent consisted in a resubsidence of the land, which appears to me to have brought the Pliocene bench again below the level of the sea, probably reducing the land to a still lower level than that which it occupied in the Pliocene time. The evidence of this movement is not very distinct. It consists of sand lying on top of the eroded Pliocene beds, in the manner indicated in the diagrams, Figs. 27 and 36.

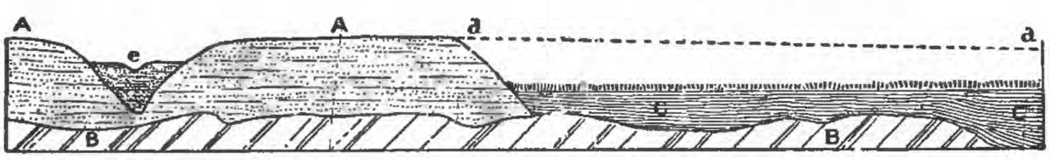


Fig. 36.—Diagram showing general relations of Nansemond escarpment. *AA*, Nansemond terrace on which the escarpment is carved, now deeply incised by streams; *BB*. pliocene strata, also showing subaerial erosion; *CC*, deposits of Dismal Swamp formed of waste from beds of *A*; *dd*, section of Nansemond terrace removed in formation of escarpment; *e*, partly filled stream bed.

These upper sands are unfossiliferous. They appear to have been derived from the erosion of Pliocene beds. This subsidence was probably not long continued, for the reason that the sands above the level of the Pliocene are not very thick and are very uniformly distributed, permitting the lower lying beds to protrude in such a manner that they frequently occupy a considerable part of the surface. Following this subsidence came another elevation which led to the formation of a new topography in the minor streams, but probably to no great change in the main channels, such as the James River or Albermarle Sound. This second elevation appears also to have carried the surface above its present level, leading to the creation of relatively deep valleys now occupied by the minor streams such as drain through the Nansemond escarpment into the Dismal Swamp. (Fig. 37.)

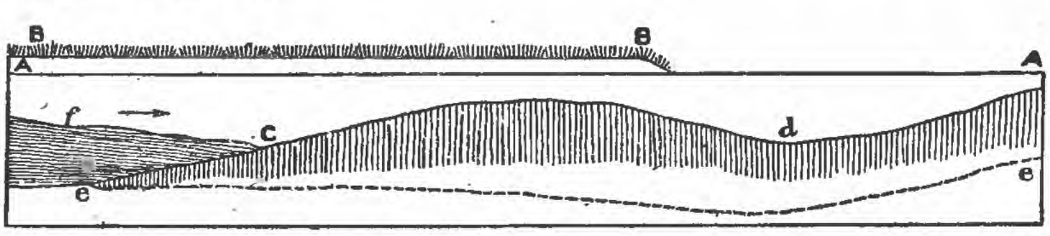


Fig. 37.—Diagrammatic section showing evidence that rivers and bays extending from Dismal Swamp were excavated while surface was at a higher level. *AA*, level of high tide; *BB*, margin of swamp near Albemarle Sound at mouth of river; *CC*. present surface of bottom; *d*, deepest water of sound, tidal channel; *ee*, probable bottom of channel during last uplift; *f*, peaty silt derived from swamp.

The next conspicuous event in the series of changes was a rise in the level of the sea against the shore while the Nansemond bench was being constructed and the material excavated from the scarf distributed over the neighboring sea floor. The length of the time during which the sea lay against the Nansemond escarpment must have been prolonged, for the scarf is extensive and the material derived from it has been removed to considerable distances. The extent to which the sea coast worked inland while this scarf was forming can not as yet be determined, but the recession of the shore probably amounted to several miles.

It appears to me necessary to suppose a reelevation of the land to a position above its present level, during which the tide-water rivers, which project from the Albemarle Sound into the plain region occupied by the Dismal Swamp, attained the relatively great depth of channel which now characterises them. I can not conceive that these channels were formed previously to the construction of the Nansemond bench, and that they retained their depth and peculiar shape while the work of cutting that scarf was going on. (See Fig. 37.) The material eroded from it would inevitably have filled those channels, which are not at present the seats of strong currents, and therefore could not have been excavated by causes now in action.

Finally, we have the last change which brought the sea to its existing relation to the shore. At present the evidence—not yet of an accurately determined nature—points to the conclusion that the coast line is in the process of subsidence. I am assured by my assistant, Mr. Collier Cobb, that near Washington, N. C., on Pamlico Sound, the crowns of forest trees standing, in their natural position, appear at remarkably low tides some four feet below high water. Various reports of an unauthenticated nature have come to me of similar evidence along the shores of Albemarle Sound.

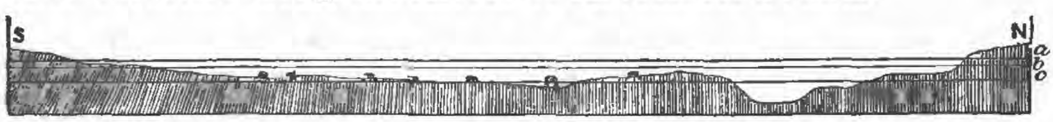


FIG. 38.—Section across Pamlico River at Washington, N. C., showing submerged stumps of Taxodium. *a*, high water mark; *b*, mean sea level; *c*, level of water during northwest gale.

It appears to me probable that the following named movements have taken place:

1. A subsidence which led to the formation of the Pliocene plateau.

2. An elevation which permitted the carving of that plateau.

3. A subsidence of the surface which deposited the non-fossiliferous sands on the eroded Pliocene surface.

4. An elevation which permitted the carving of that surface in valleys which could not have been formed at the present height of the land above the sea.

5. A subsidence in which the Nansemond escarpment was formed.

6. A reelevation during which the valleys of the streams radiating from the swamp were excavated to the depth which they now have; and finally,

7. A sinking now in process of development, which has determined the present shore line.

It seems, at first sight, almost unreasonable to hypothecate these four cycles of elevation and subsidence during the relatively short geologic time between the beginning of the Pliocene and the present period. We have, however, abundant evidence that alternations occurring with equal frequency took place during the time of the Coal Measures, also at the close of the last Glacial Period, and probably at various other stages in the earth's history. This portion of the continent was quite near to the ice front during the last Glacial Period. The effect arising from the varying weight of that accumulation as well upon land as upon the surface of the sea, through the perturbing influence of the attraction brought about by the ice cap, may well explain such frequent changes in the relation of sea and land. It is, indeed, doubtful if all the oscillations of the shore since the Pliocene have been recorded in the phenomena which I have sought to interpret.

The only one of these movements concerning which I can form any conclusion as to the speed at which the change took place is that which removed the sea from the base of the Nansemond escarpment. The last considerable accident of this district—last, at least, to be distinctly recorded—probably occurred with considerable rapidity, as there are no subsidiary benches of a distinct character below the level of that bench. It should be noted, however, that as before described the reelevation after the formation of this shore line carried the surface above its present level as is shown by the deep streams which penetrate from Albemarle Sound into the coast plain, and it may be that there were benches formed in this portion of the uplifted area which has again sunk below the level of the sea.

The foregoing interpretation of the geological history of this area must be regarded as a tentative effort to explain the changes of level in this portion of the southern plain. It will be impossible to arrive at a satisfactory conclusion as to the changes in relation to sea and land in this district until similar studies have been prosecuted in other parts of the Southern States. I have already essayed an inquiry of the same general nature in the peninsula of Florida, and propose to set forth the results of this research in a subsequent report. I may say, however, that the evidence obtained in the last mentioned district clearly points to the conclusion that similar movements in apparently the same succession occurred in that more southern district. I am therefore inclined to suppose that the changes indicated in the Dismal Swamp district occurred simultaneously throughout the southern portion of the Atlantic coast belt. It should be noted, however, that although I have for convenience spoken of all these movements as if they were due to the elevation and depression of the continent, it is by no means impossible that some of the oscillations were due to actual changes in the level of the sea and not to movements of the land. The attraction of a polar ice cap, the withdrawal of water from the sea into the glacial envelope which covered the land in high latitudes during the last Glacial Period, and changes in the elevation of the sea-floor over wide regions, most likely had a share in determining the position of the sea in the period during which we have traced the history of the Dismal Swamp district. In a word, it is probable that the position of a coast line depends upon many interacting causes and not as is commonly assumed by geologists to the oscillations of the land alone.

ANIMAL LIFE OF THE DISMAL SWAMP.

In the preceding pages I have had occasion incidentally to note some of the more important peculiarities in the vegetation of the Dismal Swamp district. The singular nature in the physical conditions in our morasses is marked in the animal as well as in the vegetable forms which inhabit their areas. Where a morass occupies but a small surface the exceptional features of its animal forms are not usually conspicuous. The larger swamps, those which are to be measured by square miles, generally have a peculiar fauna. The characteristics exhibited by the animals which occupy our morasses are usually related to the nature of the vegetation and the peculiar wetness of the earth. Thus, owing to the fact that nut-bearing trees are relatively rare, the arboreal rodents are generally absent. The inundated nature of the soil makes it unfit for occupation by the subterranean forms of that group. Thus this important order of mammals is imperfectly represented in our larger morasses. So, too, with the reptilian forms. Certain of our serpents which have accustomed themselves to dry situations are generally absent from the swamps. The predaceous mammals, such as the fox and wolf, find these marshy lands unsuited to their needs. The species of birds which nest upon the ground are also rare. The birds generally, excepting aquatic forms, are less plentifully developed in our marshy areas than in the upland districts.

I have not yet been able to undertake any systematic inquiry into the animal life of our inundated lands. My general observations, however, show that the biological conditions of these areas are such as to afford an interesting subject for research. Thus the swamps of Ohio and other States north of Kentucky contain a good many species which are otherwise limited to Tennessee and other Southern States. It seems probable that these outlying groups of southern fauna occupying northern districts will be discovered in other sections of the country.

I have already noted the fact that a number of species of trees show a singularly specialized structure which fits them to the peculiar environment which the swamps afford. It seems likely that this reconciliation with the environment will also be exhibited in the animal species which inhabit these areas. From the facts which have met my observation I am inclined to think that the fishes of our larger and more isolated swamp areas will be found to present certain interesting peculiarities.

Owing to the isolation of the swamp areas, the species have been kept from the commingling of blood which necessarily occurs in extensive river systems. Thus the smaller fishes which inhabit the pools of our swamps have secured something like the measure of isolation which characterizes the inhabitants of our caverns, and it seems likely that the species of the detached morasses may have a trace of the same specific and generic peculiarities which are to be noted in the underground world. With this brief sketch of the conditions of animal life in the swamps I will now proceed to give a few notes which I have been able to make on the fauna of the Dismal Swamp district.

Bird life is only moderately abundant, and is characterized by the general absence of the ground forms. The serpents which tolerate moist ground are of frequent occurrence, but are not known to present any peculiarities of species. The mammalian life is more peculiar than that of the other groups. The rodents are conspicuous by their absence. Bears are remarkably abundant. About two hundred are killed each year within the limits of this field of morasses. Deer are now rare, but they have been somewhat plenty. The most peculiar feature in the mammalian life is the fact that large numbers of wild horned cattle are found within the morass. These have feralized from domestic herds about the swamps. Estimates as to the number of these creatures vary considerably. I am inclined to think that there are probably about five hundred now living within this area. They are extremely wild, and when hunted are often dangerous to the sportsman. Several observant persons have reported to me that fierce combats frequently take place between the bulls and the bears. Mr. Wallace, of Wallaceton, states that he has several times heard the bellowing of the horned cattle when they were engaged in such combats. Another observer stated to me that some years ago he found a bull and a bear lying dead beside each other, both having been killed in the combat.

It is said that the bears have a peculiar habit in their assault upon the horned cattle; they spring upon their backs and rend the muscles which support the head of their prey, and thus escape the danger from its horns. The evidence as to this peculiar habit rests upon the fact that where the horned cattle have been killed in their contests with the bears the neck muscles are found divided.

I have not myself had an opportunity of seeing any of these cattle, but it is stated that they are generally of a black color and of small size. They appear to range through all portions of the swamp, but during the breeding season to prefer the slightly elevated portions where the canes abound. (Pl. XVI.) They feed mainly on the tenderer shoots of the cane, and are said to dwell generally in herds of from twenty to fifty individuals. Occasionally members of the wild herds are tolled out into the cultivated fields by offerings of salt, and are led to join the domestic cattle. The greater part of the wild cattle, however, evidently live for generations without obtaining access to saline materials, a fact which shows that salt is not really necessary to them, for within the morass they can have no opportunity whatever of obtaining it. There are no salt springs, the tidal rivers which penetrate to the swamp are all fresh, and there are no licks, such as were afforded by the slightly saline clays of the Mississippi Valley, to which the buffalo abundantly resorted.

METHOD OF DRAINING THE DISMAL SWAMP.

During the time when slaves were held in this part of the country a considerable portion of the morasses which originally constituted the Dismal Swamp was drained. This task was accomplished by the simplest engineering expedients. Ditches having a depth rarely exceeding six feet were dug wherever convenience dictated. Each farmer planned the system for his own land without any relation to a general scheme for improvement. It is evident that the work was done in most cases without even the surveyor's aid. The aggregate labor expended in this ill directed system has been great. Properly applied it would have gone far towards winning the whole of the unreclaimed swamps between the Albemarle Sound and the James River to agriculture. There are hundreds of miles of these trenches but few of which exhibit any conception of the conditions which should have regulated their construction. In any scheme for the improvement of this region the existing system of ditches will have to be neglected save in so far as they may serve for the drainage of the small patches of land for which they were contrived.

There can be no question that the whole of the swamp area of this district, excepting certain small strips near the mouths of the larger indentations which extend northward from Albemarle Sound, are readily to be won to tillage by simple and comparatively inexpensive improvements. The accompanying map shows clearly that all the important parts of this system of morasses lie well above tide-water. The average inclination of the surface is about twenty inches per mile, and this is sufficient to give a strong current to water flowing in ditches having a width on the water surface of four feet and a total depth of water of three feet. The character of the soil is very favorable for such improvements. The considerable amount of vegetable matter in the earth causes the canals which are not used for navigation to maintain their banks in good order. There are few tree trunks buried in the swamp deposits, as is well shown by the excavation of ditches contrived for conveying timber. The aggregate length of these channels is at least twenty miles. At no point in their various courses have they encountered any considerable difficulty from the trunks of trees lying prostrate beneath the surface.

The rank growth of the vegetation, particularly the roots which seize upon the banks of the canals, will save all costs for revetting their slopes.

In devising a plan for the drainage of this area, it will be necessary to take account of the existing canals; for, although these have not been contrived for the purposes of desiccation and are in certain ways unsuited to that object, the constructions are so large that it will be necessary to introduce them into the scheme of drainage works. If the principal canal, that which is now navigable to vessels, were deprived of its locks and a similar course were taken with the Jericho canal or ditch, extending from Lake Drummond to James River near Suffolk (see Pl. XVII), the result would be that a strip of land bordering on these water-ways would, provided the embankment on either side of the water-ways were cut through at a sufficient number of places to permit the exit of the water, at once become sufficiently dry for the uses of agriculture. The drainage level of the swamp on either side of the main channel would be lowered about five feet. This alone would afford a base-level low enough for the drainage of at least four miles west of the canal and about two miles east of it. The difference in the distance to which the ditches might be made effective would be determined by the slightly varying slope from the west towards the sea. Along the Jericho ditch the drainage would be less effective because of the small size and shallowness of that excavation. At present the ditch averages not more than fifteen feet of effective width with a depth of not more than three feet. The level of the water, moreover, is nearer the general level of the swamp than in the case of the Dismal Swamp canal.

If the level of the bottom of the Dismal Swamp canal were lowered to twelve feet below the present level of the water with an average width of twelve feet and an average depth of water on the new plane of four feet, it would doubtless furnish a sufficient exit way for all the swamp waters which would be drained to it from either side, and it would then be possible by branch ditches to unwater the whole of the country on the western side of its path and nearly the whole of the area to the east. At the same time the depth of the water remaining in the canal would be sufficient for all the purposes of transportation which would arise from the agricultural use of this area. Tributary ditches, starting with the depth of eight or ten feet and a width of water-way of about eight feet, should be extended with diminishing size and depth to near the western margin of the swamp. They would probably not need to be nearer together than intervals of two miles. Their average length would be about eight miles and thus the total length of this system would be about eighty miles. Smaller and shallower ditches, having a width of water-way of not more than four feet where they connected with the main channels, would need to be carried in a general north and south direction from the secondary channels so that no portion of the surface would be more than a mile from the water-way. Even smaller ditches would have to be extended across the surface so that no considerable portion of the area would be without a channel for its flood waters in the summer season. Practical experience in the district seems to indicate that with this kind of drainage channels the soil would, after it had been subjugated to the plow, remain in a fit condition for tillage. (Pls. XVIII and XIX.)

In the section east of the Dismal Swamp canal, a gentle though slight slope towards the sea would make the drainage towards the channel of that canal less easy than on the northern slope. It is probable, however, that within the range of three miles which would include the greater portion of that area the channel of the canal would, if supplemented by side ditches, afford an adequate means for unwatering the land. The region yet further to the east would have to be made the subject of an independent scheme of drainage which should discharge the waters into other main ways.

If these excavations could be accomplished only by hand labor it is doubtful if, even with the present demand for agricultural lands, it would prove profitable to undertake the drainage of this morass. But recent improvements in methods of excavation make it possible to unwater land of this description at a relatively small cost as compared with older methods of hand labor. The whole of the work can be accomplished by machine dredging, the engines being operated by steam power. In the principal ditch the ditching can be done from the usual form of boats and in the smaller channels the apparatus can be conveyed along the path of its work by means of movable tramways on either side of the ditch.

After the main works are constructed the cost of cutting away the timber and of first plowing the land will, according to trustworthy information given by various persons who have of late years undertaken such work in this district, amount to about $30 per acre. In the average present condition of the forested portions of the swamp the return for this labor in the way of timber may amount to about $60 per acre, which probably would meet the expenses of clearing the forest away and of providing the smaller drainage channels.

The area which would be won to tillage by such a system of drainage, though only a portion of this swamp district, is about 250 square miles or 160,000 acres. I am assured by various trustworthy farmers that when first won to the plow this land had a measure of fertility which will enable the tiller to reckon an annual product of from eighty to one hundred bushels of shelled maize per acre. It is, therefore, safe to estimate the money value of this area when thus improved at not less than $16,000,000.

Against this estimate of the tillage value of this region we must set such returns as it now makes in the way of timber products. I have not been enabled to obtain any accurate statistics as to the profits derived from the timber industry now carried on in this swamp. Nearly all of the original forest has been removed, culled by the woodmen, or destroyed by fire. The supply of exported timber is gathered from the growth of cypress, juniper, and pine. From all the data I have been able to procure I am led to the conclusion that the aggregate profit from the timber does not exceed $50,000 per annum, and that it may be much less than this amount. Year by year the value of this product is diminished through the occurrence of forest fires, in the dry seasons, which eradicate from large areas not only the growing trees but even their seeds. Such fires burn down to a considerable depth in the peaty matter and thus destroy the germs as well as the parent trees. On these surfaces, which include at present perhaps as much as one-tenth of the swamp area, the forest wins its way in a very slow manner. The swamps are principally occupied by annual plants. With the increase in the population around the margin of the swamp, these fires are apt to become more common. When they happen they cannot be extinguished save by heavy rains, and they make the use of the swamp, except on certain selected areas, ineligible as a nursery of timber. We thus find that if the swamp were brought to the use of agriculture at an aggregate cost of say $4,000,000, the gain to the interests of the community would be very large. On the one side of the account, we may have a revenue from the timber which is not likely to exceed $100,000 per annum ; and on the other an income from agricultural products which would doubtless exceed $2,000,000 per annum, while the cost of the improvement at the present rate of interest on money would not exceed $200,000 a year.

This region is very favorably placed for cultivating and marketing garden crops. Already the Norfolk district furnishes a large share of the garden products used by four or five million people dwelling in the cities between the James River and the coast of Maine. The greater part of the territory which now furnishes these supplies has a poor soil which can be made to yield satisfactory returns only by a costly system of fertilizing. Experiments already made within the Dismal Swamp district show that this soil is excellently adapted to the cultivation of vegetables. The annual demand for such garden crops is sure to increase apace, and there is no other field so well suited for the enlargement of this form of agriculture as the area occupied by the morass of the Dismal Swamp district. The drainage channels could readily afford water transportation to within a mile of every part of the tilled area. In a manner hereafter to be noted a large portion of the surface could, if desired, be irrigated by the higher lying waters. Nowhere else in the world is there near to great markets so large a field of land suited to garden crops which is not used for such purposes. If availed of for this form of tillage, the annual return from the land would probably not be less than $100 per acre or a total of somewhere near $16,000,000 per annum for the region which it is proposed to drain. It would, of course, be some decades before it would be profitable to bring all this vast area into such use, but after a time of service in ordinary field crops it seems to me likely that the whole of the surface would be thus utilized.

It will be seen by the description of the Nansemond escarpment or old bench that several considerable streams which cross that line have their head waters in the subordinate swamps lying in general at the height of several feet above the western margin of the swamp. (See Plate X.) Owing to the topographic conditions of these inland morasses, they could readily be converted into great storage reservoirs in which irrigation waters would be retained. I estimate that it would be possible to store in these higher swamps for the purposes of summer irrigation bodies of water having twenty-four square miles of area and an average depth of five feet, the whole of which could be used for agricultural purposes in the region east of the Dismal Swamp canal. This would afford, making allowance for evaporation, a sufficient amount of water to meet in dry seasons the exigencies of garden tillage of an area of about one hundred and fifty square miles or say about 100,000 acres. With a somewhat more costly system of storage which would not probably tax the tilled land for reservoirs to the annual amount of more than $10 per acre, the water could be husbanded and would afford irrigation facilities to the whole of this district.

It is thus evident that we have in this region a combination of the advantages for high-grade tillage such as are rarely found in any part of the world, an excellent soil, ready water communication, a favorable climate and opportunities for obtaining abundant irrigation water in times of drought. In a word, the region affords all the advantages of the best artificially unwatered soils in Belgium and Holland with a cost for the improvement far less than that required to win to agriculture the low-lying semi-marine swamps of that section.

HEALTHFULNESS OF THE DISMAL SWAMP DISTRICT.

It is a common opinion that all swamp districts are necessarily afflicted with malarial diseases. This opinion rests upon the experience which is had in the ordinary alluvial lands along the shores of rivers. The fact appears to be that in hot countries, where the level of the soil water varies much at different seasons of the year, malarious effluvium is bred. On the other hand, in regions where the soil, however wet, retains its moisture during the summer season at about the same height it holds during the winter, there seems to be no

CHANNELS CONNECTING DISMAL SWAMP WITH TRIBUTARY MORASSES ON THE WEST.

THINLY TIMBERED PORTION OF MAIN SWAMP AREA.

VIEW ON JERICHO DITCH.

SUFFOLK END OF THE JERICHO DITCH.

RECLAIMED SWAMP LAND AT WALLACETON, VIRGINIA.

peculiar liability to malaria. This supposition is well borne out by the distribution of malarial diseases in the neighborhood of the Dismal Swamp. Around the margins of that field of morasses where the summer's heat dries out a portion of the swamp area to considerable depths, so that the under earth as well as the humus material is subjected to the action of the air, a certain amount of malarial fever occurs; but in the central portions of the morasses, at a distance of a mile or more from the margin, there seems tolerable exemption from such diseases. In fact, the people who dwell in the interior of the swamp appear to be less affected by such maladies than those who live on the ordinary upland surface of Virginia and North Carolina. In this entire region of morasses, the summer droughts, however severe, serve only to dry out the upper portion of the peaty coating, leaving the lower soil still surcharged with water. The decay of the peaty matter alone does not seem to afford the conditions which lead to the development of malarious exhalations.

In the process of improvement of the swamp, which would necessarily lead to the lowering of ground water level to the average of about four feet below the surface of the true soil, there would doubtless be for a time a considerable development of malarial disease. But we may judge from our experience in the drainage work already done about the swamps that these fevers would be of a simple and non-malignant type. It is likely that the trouble would endure for but a few years until the level of the ground water was again established in the soil. The difficulty encountered from such diseases would probably be no greater than that which was experienced in the settlements in southern Indiana and Illinois, or in other similar parts of the Mississippi Valley.

THE PENOKEE IRON-BEARING SERIES OF MICHIGAN AND WISCONSIN.

BY

ROLAND DUER IRVING and CHARLES RICHARD VAN HISE.

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ILLUSTRATIONS.

THE PENOKEE IRON-BEARING SERIES OF MICHIGAN AND WISCONSIN.

By R. D. Irving and C. R. Van Hise.

INTRODUCTION.

In the midst of our preparation of the memoir[1] of which the present paper is an abstract, Prof. Irving's death occurred. This was so early in his life that, while his contributions to geology are large, his later works show that he had but fairly entered the period which would have been the most fruitful in scientific results. The original memoir was designed by Prof. Irving to be the first of a series which should in turn treat each of the important iron-producing districts adjacent to Lake Superior. To him who planned this investigation is very largely due whatever excellence this paper may have. With the junior author must necessarily rest the responsibility for its present form, since the abstract was not begun until after Prof. Irving's death. In order to make it clear to what extent it has the shelter of Prof. Irving's authority the name of its author is placed at the head of each chapter in imitation of the original memoir.

In the full work, abstracts are given of all previous publications upon the Penokee Series, but in this shorter paper no attempt is made to make quotations from the many reports which have treated more or less extendedly of the district.

To Mr. J. Parke Channing our especial thanks are due for a large amount of gratuitous work, and in particular for his detailed examination and drawings of many of the mines, and the facts contained as to the structural relations between the dike rocks and ore bodies. As mining inspector of Gogebic County, he resides in the district and has from time to time given us the results of the latest developments. To Mr. J. M. Longyear, of Marquette, Mich., we are also indebted for much assistance, including access to his very large collection of specimens of the Gogebic end of the range, made as the agent of the Lake Superior and Portage Ship Canal Company. To Mr. B. N. White and Mr. Charles Oley we are indebted for all the

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[1] Mon. U. S. Geol. Surv.: The Penokee Iron-bearing Series of Northern Wisconsin and Michigan, by R. D. Irving and C. R. Van Hise. In press.

assistance which could be given by skilled woodsmen somewhat familiar with the district. To numerous miners and mining superintendents we are indebted for many courtesies. With few exceptions, information with respect to mining properties has been freely granted to us by all. Mr. W. N. Merriam has made the greater part of the originals for the illustrations, including both photographs and drawings. Mr. George E. Luther has given valuable clerical assistance.

In a previous publication of the Survey,[1] one of the writers of this memoir has provisionally mapped under a common color all of the various areas in the Lake Superior region, the rocks of which are now regarded by any authority as the equivalent of the original Huronian series of the Canadian geologists. The provisional mapping was preliminary to a thorough study of each of these areas in the United States, with the object of determining, not only its own structure and the genesis of its rocks, but also the general stratigraphy of the pre-Cambrian formations in the Northwestern States. A portion of this map, with corrections up to date, is in this abstract reproduced (Pl. XX). The areas included in the full map are:

The Original Huronian (H).
The Marquette-Menominee Iron-bearing Schists (H_2).
The Wisconsin Valley Slates (H_3).
The Penokee Iron-bearing Series (H_4).
The St. Louis Slates (H_5).
The Chippewa Valley Quartzites (H_6).
The Black River Iron-bearing Schists (H_7).
The Baraboo Quartzites (H_8).
The Sioux Quartzites (H_9).
The Animikie Series (H_{10}).
Folded Schists of Canada, including Vermilion Lake Series (H_{11}).

This classification has reference, not only to a certain geographical separateness of the various areas, but also to certain peculiar geological characteristics which each area or group of areas displays.

In the six and a half years that have elapsed since the beginning of our present study of the older formations of the Northwest, work has been done in a number of these areas, much new material collected, and some new conclusions reached. In the case of the Penokee area, this study has progressed sufficiently far to warrant the publication of the results. Moreover, this publication is particularly called for, since this district furnishes us much the best type in the entire Lake Superior region to which to refer other series. That here displayed is particularly adapted to serve as a type because of the simplicity and fullness of its stratigraphy, and because of the absence of folds and of the accompanying changes due to pressure—which so greatly increase the difficulties of study in the Marquette-Menominee region, for instance—and because of the clear and unmistakable nature of its relations to adjoining formations.

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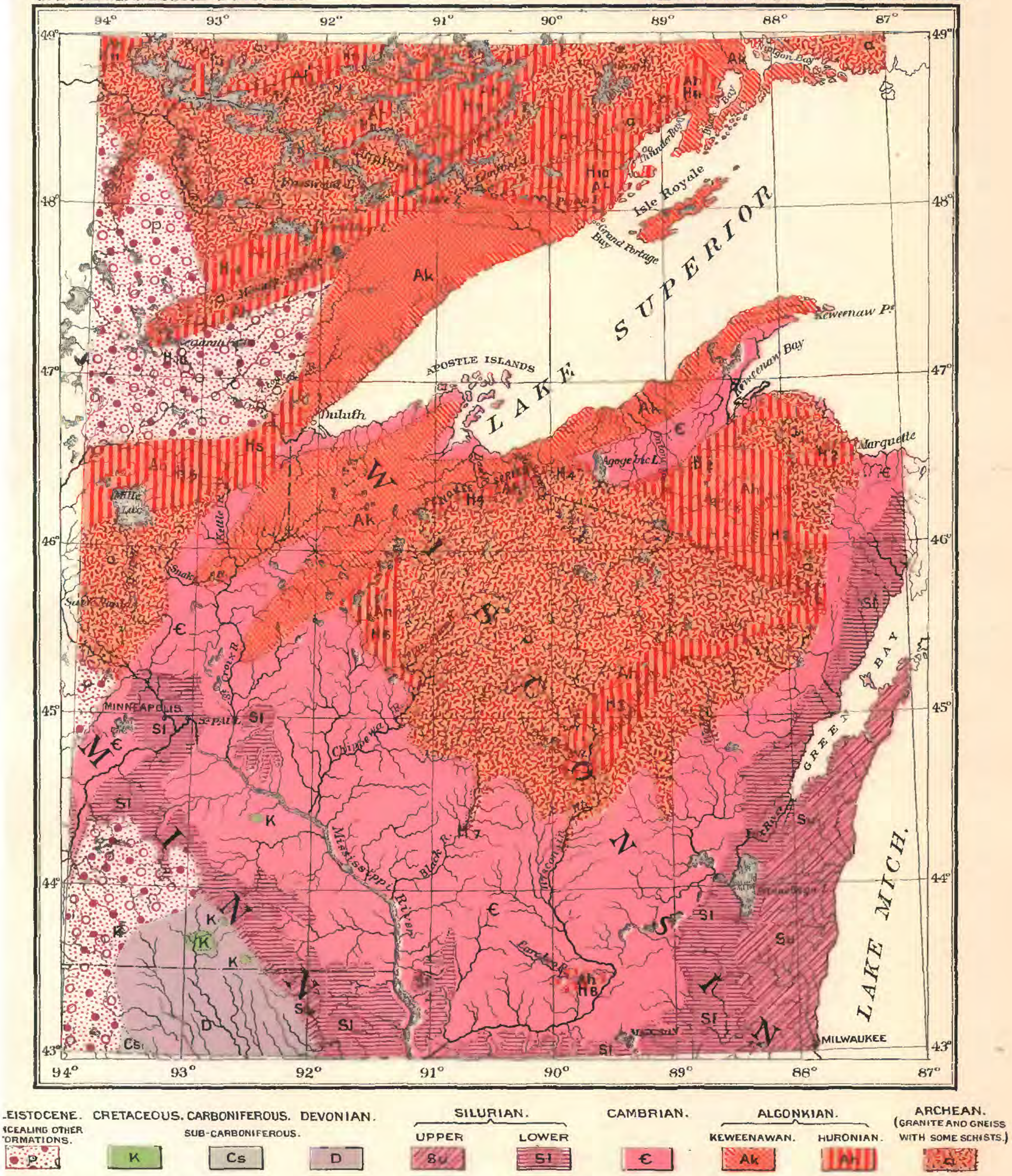
[1] Fifth Annual Report, U. S. Geol. Survey, pp. 181–241; pl. XXII., "Preliminary paper on an Investigation of the Archean Rocks of the Northwestern States;" by R. D. Irving.



PRELIMINARY GEOLOGICAL MAP OF THE NORTHWEST.

Scale $\frac{1}{4,000,000}$

The general geographical position of the Penokee belt will be understood by reference to Pl. XX. The larger scale map of Pl. XXI will serve to show more definitely the extent and position of the area whose geology is to be discussed. This belt stretches from Lake Gogebic, Michigan, to Lake Numakagon in Wisconsin, a distance of about eighty miles. Its course from Lake Gogebic to the Montreal River is about west, and from the Montreal to Lake Numakagon about 20° south of west. Our more detailed investigations have extended over an average width of five miles. Of this width, the iron-bearing series, which particularly forms the subject of the present volume, occupies from a quarter of a mile to about three miles, the remainder being occupied, to the south by granites, gneisses and schists, and to the north by the interbedded eruptives and fragmentals of the Keweenaw series.

Whatever the structural relations of the schists, gneisses and granites mapped in Pl. XXI to each other and to the rocks north of them, they are sharply separated in surface distribution from the series of parallel belts to the northward. These belts, four in number, follow one another in regular succession, with the exception of a few miles at the eastern end of the area. They are separated from each other upon the principle of fragmental and nonfragmental character. This memoir treats of the rocks between the schist-gneiss-granite areas and the Keweenaw Series, and to them is applied the name Penokee Series.[1] The southernmost of the belts is called the Cherty Limestone Member. This name sufficiently indicates its character. Whether it is of direct chemical or of organic clastic origin, it now gives no evidence of having been fragmental. The next belt to the northward is called the Quartz Slate Member, because quartz is the preponderating constituent and a slaty structure the normal one. It is sharply separated from the underlying Cherty Limestone Member by the fact that it everywhere reveals, in thin section, its essential fragmental character. Next to the north is the Iron-Bearing Member, so called because all the known ore bodies occur within it. Whatever its origin, it, like the cherty limestone, never gives any evidence of a fragmental character. To the north of this belt is the Upper Slate Member. This last is in places several times as thick

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[1] The Wisconsin geologists called the iron-bearing rocks and associated slates the Penokee Series. On the Michigan side of the boundary the course of travel was largely by the Agogebic, or as it is now contracted, Gogebic Lake, and the geologists, explorers and miners gave to that part of the area the name Gogebic region. As the areas are parts of one geologic series, one or the other of these two names must be accepted for the whole series, or else a new name be coined by their combination. The latter course would be perhaps the less objectionable if the resultant name, Penokee-Gogebic, were not so awkward. The first systematic geological treatment of any part of the district is that by Irving and Wright, in the Geology of Wisconsin; hence, under the law of priority, the term Penokee Series is in this volume used to cover the whole area.

as the three lower members combined, but the whole width is included within a single belt because it is everywhere substantially alike. It is a slate or mica schist which is chiefly composed of quartz and feldspar. It, like the feldspathic Quartz Slate Member, in thin sections usually reveals its fragmental character. The area of rocks situated at the same geologic horizons as these four belts, between Gogebic Lake and the middle of T. 47 N., R. 44 W., Michigan, do not make up so plain a succession, so that this part of the region is separated from the four belts just spoken of as the Eastern Area, and is under this title given a separate treatment.

CHAPTER I.

By R. D. Irving.

GEOLOGICAL EXPLORATIONS AND LITERATURE.

As in the case of most other regions on the south side of Lake Superior, the first geological explorations made in the Penokee country date quite far back, but no attempt at detailed work was made before that done west of the Montreal River by the Wisconsin Survey, 1873–1878. East of this river, in Michigan, the only approach to a detailed study prior to that by the authors of the present volume was by Dr. C. Rominger, then State Geologist of Michigan, in 1882. Dr. Rominger's results have not yet been published; but he has been kind enough to send me a manuscript copy of that portion of his last report which covers this district. While this report is unaccompanied by maps, and while Dr. Rominger's locations of specimens are not closer than the quarter section, it yet contains much valuable material.

The list of explorers and geologists who have visited this region are: 1847, George O. Barnes; 1847, George O. Barnes and J. D. Whitney; 1848, A. Randall; 1849 and 1860, Charles Whittlesey; 1858, I. A. Lapham; 1871, T. B. Brooks and R. Pumpelly; 1873, 1876, 1877, 1885, R. D. Irving; 1875, O. W. Wight, E. T. Sweet and C. E. Wright; 1876, C. E. Wright; 1877, T. C. Chamberlin; 1877–1878, A. D. Conover; 1882, C. Rominger; 1884–1888, C. R. Van Hise. The results of the field work by these various persons have been published more or less in detail. However, the first systematic treatment of any portion of the range was that by Irving and Wright, in Vol. 4 of the Geology of Wisconsin. The chief of the State survey, President Chamberlin, gave a general account of the range in his final volume. The Wisconsin geologists adopted for this iron-bearing series the term Penokee, first used by Col. Charles Whittlesey to designate the bold range of ferruginous schists which extends for some miles both east and west of the passage through the range of Bad River. In the original memoir a detailed account of the field work of each of the persons mentioned is given, and also a full abstract of the various published reports with comments and criticisms. To attempt to go over these reports in any fashion in this abstract would take too much space. It must, however, be said that the main conclusions as to the structural relations of the Penokee series to the underlying and overlying rocks were reached by the Wisconsin geologists, and also that other points of interest contained in the present paper are due to these previous reports. In the monograph, Chapter I, full credit is given for all the work previously done upon the Penokee series, but in this shorter paper we are obliged to make the acknowledgment for previous work in this general way.

CHAPTER II.

BY C. R. VAN HISE.

THE SOUTHERN COMPLEX.

The rocks south of the Penokee Series (Pl. XXI), are exceedingly complex, both as to their lithological character and structural relations. They comprise, first, unmistakable eruptives, fresh and in various stages of alteration, including diabases, syenites, gneissoid granites, granites; and second, many different varieties of gneisses and schists. There are large areas which contain only massive rocks, and other large areas which contain only schistose ones, except for infrequent cutting basic eruptives; but between the different areas are zones in which are found mingled massive and schistose kinds and apparent gradations between the two. The rocks of the schist areas vary widely in dip and strike. More often than otherwise they are in rough conformity with the members of the overlying Penokee Series; but this is true only in a very general way, the strikes frequently being almost or quite at right angles to the strike of those rocks. Farther, the strikes vary widely within short distances, presenting a strong contrast in this particular to the rocks to the north. If this variation in strike is noticeable, the variation in dip is still more remarkable, frequently inclinations in opposite directions occurring within a short distance of each other. These abrupt changes in strike and dip clearly indicate that the series is one which has been closely crumpled.

This report is not primarily designed to cover the complex basement series, so what follows is of an incomplete and somewhat general character. It is chiefly a lithological treatment, and even as such is but an outline, the only reason for entering into the subject at all being to give a basis for comparison with the rocks of the Penokee Series.

In Sec. 20, T. 43 N., R. 7 W., Wisconsin, as discovered by Mr. Charles E. Wright, late State Geologist of Michigan, the rocks of the copper-bearing series and a gneissoid granite belonging to the complex system under consideration are found upon opposite banks of the Numakagon River. To the west of this point no rocks, aside from the above mentioned, are known for a considerable distance; so that it may be considered that here is the westernmost point at which exposures belonging to the Penokee Series proper will be found. From this point eastward to Bad River occasionally outcrops of gneissoid granite and granite are found. As within this stretch of twenty-five miles, south of the Penokee Series, no rocks other than those mentioned are known, the area is called the Western Granite. At Bad River, close to the Penokee Series, first appears a fine-grained crystalline schist. This continues adjacent to the overlying series, without a break so far as known, to the West Branch of the Montreal River, another stretch of more than twenty-five miles. For some distance east and west of the Montreal River, the boundary line between Michigan and Wisconsin, granite is again found immediately south of the Penokee Series. East of this Central Granite, running from near the middle of T. 47 N., R. 46 W., Michigan, to within a few miles of Gogebic Lake, appears, south of the Penokee Series, the Eastern Green Schist area. Between the eastern limit of these schists and Gogebic Lake are the Eastern Granites. How far the two schist areas extend to the southward is not definitely known. In both cases, for some distance, after the schists appear next to the Penokee Series, they constitute but a narrow belt, the granites being found south of them. The distribution is such as to suggest that if the exploration had been extended far enough southward the three granite areas would have been connected.

Although the easternmost exposures of granite are fully ninety miles distant from the westernmost ones, the prevailing variety of rock is throughout this distance remarkably alike. This likeness of character suggests, as well as the distribution, their continuity. It is also suggestive that a like condition of affairs prevailed for a very considerable distance at the time of the formation of these rocks.

The granites and granitoid gneisses are not separated, as they differ but little from each other in mineral composition, and their differences are probably due to secondary causes rather than to primary ones. In the predominant phase of rock of these areas (Pl. XXII, fig. 1), an alkaline feldspar is always the chief constituent, while in the majority of cases it composes three-fourths or more of the rocks. Moreover, a large proportion of this feldspar is of the species orthoclase, although microcline and acid plagioclase are always present and often plentifully. There is a very marked tendency for these feldspars to have idiomorphic forms. In some cases in which the feldspar is predominant this tendency is so strong that the rock might be described as panidiomorphic. This characteristic of the granites and syenites is shown both in hand specimen and in thin section. Quartz varies from almost entire absence to an amount about equal to that of the feldspar in rare cases. When the quartz is not plentiful it is in part so arranged with reference to the feldspar as to suggest that it might be of secondary origin. This suggestion is reenforced by the fact that occasionally the feldspars near their exteriors contain pegmatitic quartz. This mingling of the two minerals may be due, however, to the simultaneous crystallization of quartz in the final stages of the formation of the feldspar. Farther, it does not appear probable that all the quartz found in these rocks is a secondary product, for in the most acid of them the feldspar and quartz interlock in the irregular fashion characteristic of ordinary granites. In the massive granites the only other important constituents are hornblende, biotite and chlorite. The hornblende quite often occurs in well defined crystals. The chlorite frequently imitates the forms of the hornblende. The biotito is in well developed, sharply outlined blades. These minerals are ordinarily between the feldspars, but bear such relations to them as to suggest that the feldspars have adapted their forms to these minerals rather than the reverse. Not infrequently each of them, in large blades or crystals, is included in the feldspar. It follows from these relations that the hornblende and biotite were earlier than the feldspar, or else that these minerals have developed subsequently to the consolidation of the rock.

All of the minerals in the granites are more or less altered. A kaolinitic decomposition has widely affected the feldspar. Less frequently chlorite and mica have developed within it, and often the chlorite has further partly changed to epidote. But far the most interesting change shown by the feldspar in the average granite is its alteration into quartz and biotite. This change has taken place to some extent in quite a number of rocks, and has gone so far in one place as to transform the massive granite into a gneiss. Here the large individuals of feldspar have each decomposed in a great measure to the more basic mineral biotite, the excess of silica apparently separating as finely crystalline quartz, so that a single feldspar contains many score folia of biotite and grains of quartz. In certain parts of the section this decomposition has gone on until little or no feldspar remains, the result being a finely crystalline interlocking aggregate of quartz and biotite instead of a single grain of feldspar. In other words, a somewhat coarsely crystalline strongly feldspathic rock—the normal phase of granite—has changed to a finely crystalline gneissoid biotitic quartz rock. It is interesting to note in this connection that these are the identical changes which have, in the upper belt of the Penokee Series, changed a feldspathic fragmental rock to a crystalline mica-schist, pp. 429–434.

In the Central Granite, adjacent to and west of the Montreal River, the rocks are of a more basic character. Between these basic phases and those in which there is the usual amount of quartz there seems to be a gradation. The more basic phases are properly gabbros or syenites, or syenite schists, the latter having the appearance in the field of coarse gneisses. These schists (Pl. XXII, fig. 2) vary from mottled red and black to black, depending upon the quantity of the iron-bearing silicates present and the color of the feldspar. When examined in thin section they are found to be very much coarser grained than would have been suspected from the hand specimens. They contain as a background, large, closely fitting and interlocking individuals of alkaline feldspar comprising the three species, orthoclase, microcline, and plagioclase. In the centers of some of the larger individuals of nonstriated feldspar, in irregular areas, the microcline twinning is developed. The feldspar is in structure just as in the massive granites, the schistose character of the rock in no measure affecting them. In most of the syenites the abundant mineral, aside from the quartz, is hornblende accompanied with a considerable quantity of biotite and chlorite. The hornblende is in well defined blades and crystals, and the biotite in its usual broad leaflets. Sometimes transverse sections of hornblende show almost perfect crystals which exhibit the prismatic faces or these combined with the orthopinacoids. The large blades of these minerals frequently cut through the feldspar, a single biotite or hornblende often passing through several individuals. In places the hornblende and mica are massed together so as to wholly exclude other constituents. If the iron-bearing minerals are original crystallizations, they must have formed before the feldspar; more probably they are secondary and have developed within it. The strongly marked schistose structure characteristic of the rock is wholly due to the arrangement of these minerals, the larger blades of hornblende and biotite usually having their greater lengths in a common direction.

Differing from these hornblende syenites is a mica-pyroxene syenite, the pyroxene in this case replacing for the most part the hornblende. This rock is like the other syenites in all other points, and the relations of the mica and pyroxene to the feldspar are the same as those of the hornblende and biotite in the mica-hornblende syenites. All of the syenites contain very numerous, large, well formed crystals of apatite, which are included in all of the other minerals.

Not much more basic than these syenites are coarse altered gabbros which in large exposures are closely associated with them. In the field and in hand specimen they do not differ greatly in appearance from some of the syenites just described. Their feldspars have a reddish cast as in the syenites, and their structure is much the same. However, when they are examined in thin section, they are seen at once to be altered basic eruptive rocks of the ordinary type. The chief original constituents were plagioclase, magnetite and diallage, which have relations characteristic in a rock intermediate in structure between a diabase and gabbro. The plagioclase has altered very extensively to chlorite and kaolin and is in many places replaced to some extent by saturating quartz. The magnetite occurs in well defined areas and crystals, which give no evidence of alteration, it being the only mineral within the rock which is unaffected. The pyroxene has very largely decomposed, the resultant products being hornblende, biotite and chlorite, more largely the first. It is a very noticeable thing that the secondary hornblende is not paramorphic, but several or many blades have formed which are in crystallographic position independent of the original augites, and much of this hornblende in its forms is like the hornblende contained in the syenites just described. As a result of the complete decomposition of the diallage, hornblende and biotite are formed with their axes arranged quite often in a common direction. In this case these minerals, in their appearance and relations, are much like those of the same minerals in the associated syenites. It is further noticeable that these rocks also contain numerous large, well formed crystals of apatite.

Considering all of the foregoing facts, it is quite probable that the gabbros, syenites, syenite schists and possibly the granites are parts of the same continuous rock-mass.

Constituting an exception to the ordinary rocks of the granitic area is one exposure of micro-granite found in Sec. 27, T. 47 N., R. 47 W., Michigan. As it presents some interesting points in reference to the crystallization of rocks, it is described in greater detail than would otherwise be warranted. Macroscopically it has an aphanitic background which contains simple and complex areas of varying sizes, consisting of coarse individuals of feldspar, a dark colored mineral and quartz. The larger areas have a true granitic texture. More abundant than these are single porphyritic crystals. In thin section the background contains numerous roundish areas consisting of large individuals of quartz and feldspar, with quite a quantity of chlorite, each mineral occurring separately and together in complex intricately interlocking areas. In most known cases in which crystallization has thus occurred in two generations, only detached porphyritic crystals are contained in a finer grained matrix. If this difference in the character of the coarse and fine parts is taken to mean that the coarser part crystallized at depth and the latter after a change of condition and near the surface, the conclusion would be that the crystallization had proceeded much farther than usual in porphyries before the change in condition occurred. And if this is so, the specimen throws some light upon the manner of crystallization of granites. In the development of the minerals in massive igneous rocks, it is usually assumed that the crystallization of the different species is in the main successive, although to some extent simultaneous. In this rock, while this may be to a small degree true, it appears certain that before the change of condition occurred, all of the minerals found in a granite had begun to develop, and in such a fashion as to make small masses of perfect granite. These masses of granite associated with simple individuals of quartz and feldspar were separated from each other by the liquid magma in which they were contained. After the change of conditions the magma rapidly crystallized thus preserving the individuals and clusters of individuals which had before formed. If the growth had continued without a change of conditions, the simple and complex areas would probably have formed larger and larger masses of granite until the whole space was occupied. This implies that in the outward growth of each mass all of the minerals which go to make up a granite would separate from a magma in which these same minerals have before developed in such relations to each other as to have for short distances the typical structure of a deep-seated crystalline rock. This manner of growth differs radically from the first mentioned as the ordinary conception of the crystallization of igneous rocks.

The exposures in the Eastern Green Schist Area are very numerous, and the rocks have great variety within a certain narrow range. Macroscopically the schists are light gray to very dark green; they vary in coarseness from aphanitic to the texture of a gneissoid granite. In all of the rocks a schistose structure is very strongly developed. In the coarser phases the foliation is marked, both in hand specimen and in exposure, but in the finer grained varieties it is often only exhibited by readier cleavage in one direction. When these schists are examined in thin section, they are all found to be technically gneisses, as in them, with few exceptions, feldspar is a chief constituent. They are, for the most part, however, in no particular like the evenly banded, coarsely foliated rocks to which the term gneiss is ordinarily given in the field. They would there in nearly every case be called fine grained schists.

One of the most characteristic and abundant phases of schist, as seen in thin section (Pl. XXIII, fig. 1) is that which has a white granular background composed of quartz and feldspar. The proportions of these two minerals vary widely in the different specimens, running from those in which quartz is preponderant to those in which the feldspar almost entirely excludes that mineral. The individuals of each of these minerals in this background are approximately of uniform size in each section, although varying widely in different sections; in general they have roundish or oval forms. The particles of the two minerals fit each other closely, but do not intricately interlock. The feldspar is very largely of the species orthoclase, although microcline and plagioclase are often abundantly present. It has usually altered much, the resultant products being kaolin, sericite, chlorite, epidote, and at times biotite and hornblende. This alteration is sometimes certainly, and often probably, attended with the simultaneous separation of quartz. This decomposition, in the cases when it has extended far enough, results in producing in the place of a feldspar a complex, interlocking mass of finely crystalline material. In a few cases in which the gneiss was originally strongly feldspathic the alterations have caused it to closely resemble some of the feldspathic greywackes of the Upper Slate Member of the Penokee Series.

The abundant iron-bearing minerals of the gneiss are hornblende, biotite and chlorite; less frequently epidote, sericite and calcite become important. In a single section any one of these minerals may be predominant, or two or more, or all of them may occur together. There seems to be absolutely no regularity as to their occurrence either in the field or in the sections themselves. Hornblende is, however, the preponderant mineral in many sections, although chlorite and biotite are hardly less frequently so. In the more coarsely grained gneisses the hornblende often occurs in large, well defined crystals, which in transverse sections show either the planes of the prism or the planes of the prism combined with the orthopinacoids. The terminal planes are seldom well developed. The hornblende individuals, when of any considerable magnitude, always include many grains of the other minerals present, usually more quartz and feldspar than of chlorite and biotite. It apparently shows by its inclusions, combined with its idiomorphic forms, that it was the last mineral to crystallize. Its growth within these gneisses may be compared to the growth of crystals of garnet and staurolite in staurolitic and garnetiferous mica schists, which frequently include large quantities of foreign materials. In its development, if a late mineral, it took within itself such material as it could not force aside. More often in the gneisses the hornblende is in small blades free from inclusions, located between the particles of quartz and feldspar or else penetrating them. The biotite and chlorite occur in well developed folia, and in small fibers and irregular areas. Each of these minerals is in turn in quite a number of the exposures the chief constituent aside from the quartz and feldspar. Each frequently contains numerous smaller particles of what is taken to be oxide of iron, which are arranged in regular manner. A portion of the chlorite and biotite are certainly secondary to feldspar and hornblende. This is particularly true of the chlorite. However, there is no evidence that the abundant, well defined blades are secondary. The epidote, so plentifully present at times, is found alike in the feldspar, chlorite, hornblende and biotite, although most common in the two first. It occurs in numerous small granules and large, irregular areas. A large part of it is certianly derived from feldspar, chlorite often being an intermediate stage in its formation. It also has formed from hornblende. In some of the rocks the epidote is with quartz the chief constituent and the rock consequently is an epidosite. There is no evidence of the derivation of the epidote here from feldspar, hornblende and chlorite, but it may be true that the rocks in which the origin of the epidote is plain is an intermediate phase in the formation of the epidosite.

In general the hornblende, biotite and chlorite are largely in the spaces between the quartz and feldspar, but they also are extensively included within them, a single individual of one of these minerals perhaps penetrating several particles of quartz or feldspar, or both. Usually the chlorite, biotite and hornblende are arranged with their axes more or less regularly in a common direction. Sometimes this arrangement is imperfect, while in other cases the parallelism is remarkable, the fibers of the many individuals lying almost exactly parallel with each other. When this parallelism is so marked it is sometimes the case that the quartz and feldspar particles are elongated in the same direction. This elongation of all of the minerals in such a case doubtless indicates that the rocks have been subject to great dynamic forces.

Within these evenly granular gneisses are quite often larger grains of quartz and feldspar which have very distinct oval outlines. This is particularly true with reference to the quartz grains, although when examined closely they are seen to be minutely angular. As in the roundish grains of the quartzose background, no proof has been found that the quartzes are of a fragmental character.

An important phase of hornblende schist has somewhat exceptional characteristics. Macroscopically it is very fine grained, and compact, and yet finely schistose. Its schistose structure is so close, however, that in the field no proper strike or dip is obtainable. When examined in thin section (Pl. XXIII, fig. 2), it is seen to be a completely crystalline schist; its background consists in about equal quantity of finely crystalline quartz and feldspar, although each in certain cases becomes preponderant. The two minerals intricately interlock, both with each other and with themselves. In the majority of the sections in the background are larger grains of quartz and feldspar, which have a roundish appearance. This feature is particularly characteristic of the quartz, although in each case the exteriors of the grains are minutely angular. A general oval form is also very marked with some of the feldspars. The larger feldspars in the coarser phases of the rock are about 1^{mm} in greatest length. They are nearly all striated and have the appearance of this mineral in ordinary basic eruptives. Included in the feldspars are blades of hornblende and grains of quartz, the latter in some cases averaging not more than $1\text{-}50^{mm}$ in diameter. Manifestly either the feldspar has crystallized subsequently to the quartz and hornblende, or, and this is perhaps more probable, the decomposition of the feldspar has formed the hornblende and quartz. The appearance of the hornblende individuals both within and without the feldspars is such as to suggest that they are now in the process of growth. In general the feldspar is badly altered, so that it not only includes hornblende and quartz, but a gray decomposition product taken to be kaolin. When the alteration of a large feldspar has proceeded far, the area may consist of many detached particles of feldspar, included in which are large hornblendes and numerous quartzes. Unless examined closely this peculiar relation would not be noticed, and the area would be concluded to be an intricately interlocking one in which the particles of feldspar are independent, as they are only recognized as a skeleton of a single feldspar when closely examined in polarized light. The hornblende is of the pale green variety; it has normal pleochroism and extinction. The individuals do not have well defined outlines, but fray out in every direction in ragged stringers. This is especially noticeable in sections cut parallel to the vertical axes, but is also distinctly seen in transverse sections. If this mineral was the first to crystallize, as must be the case if all those individuals now present are original crystallizations, the exceedingly ragged forms are inexplicable. If, upon the other hand, the hornblende is a product which has formed subsequently to the feldspar, these are precisely the forms which would be expected. It thus seems probable that these rocks are badly altered ones which originally contained much more feldspar than at the present; perhaps those containing almost no feldspar being as feldspathic as those of the gneiss which contains a large amount of this mineral. In some of the sections biotite is as abundant as the hornblende. It is intimately associated with that mineral and bears the same relation to the feldspar that the hornblende does. Magnetite in small areas and crystals is plentiful in some of the sections. It is scattered quite uniformly throughout all the minerals as though it were the earliest present. The secondary minerals, epidote, sericite and chlorite, are at times in quantity.

These rocks might with almost equal plausibility be regarded as of eruptive or sedimentary origin. In the Eastern Schist Area they have, however, been traced step by step into those which are almost certainly eruptive. This rock in hand specimen in one case is massive and has strongly the appearance of a basic eruptive. Within the same exposure are other phases of rock which have the distinct foliation of the hornblende gneisses of the region. These rocks and others within the locality under consideration have almost no quartz, the background being composed of large areas of feldspar, which intricately interlock. Between these feldspars and in them are many hornblendes of varying sizes, individuals frequently being large. They have the same jagged outlines which are characteristic of the hornblende already alluded to. The sections also contain much comparatively fresh magnetite. There can be little doubt that this massive rock is a modified eruptive and the schistose one from the same exposure is of the same character. As there is every phase of gradation between this massive rock and those schistose ones in which there is a large amount of quartz present, it is exceedingly probable that all of this class of hornblende schist is eruptive, although I would guard myself by saying that we have no absolute proof of this.

Between these two main phases of schist there are intermediate ones which will not be described in detail. Also there are subordinate phases which can not be mentioned.

The question as to whether any of the crystalline schists and gneisses of the region are of fragmental origin can not be answered. The roundish, evenly granular appearance of the quartz and feldspar in many of them strongly suggests upon casual examination a clastic origin. However, the more closely they are examined, the more clearly it is apparent that this is no sufficient evidence of a fragmental character. It has been noted that in the gneisses of this class the individuals fit each other perfectly. The grains as fragmental ones could not possibly have been thus deposited. If fragmental, either they must have recrystallized or else have been enlarged until they interlocked. Each of these processes and both combined are now known to transform fragmental rocks into crystalline ones; but in order to prove that such a transformation has occurred it is necessary to show that the original rock in which they are found was a fragmental one. The rounded cores in a quartzite are sufficient to show this, but in the case of a recrystallization of feldspar it is necessary to actually trace the crystalline rock back to its fragmental state. The modified fragmental rocks of these kinds in the Upper Slate Member of the Penokee Series reveal themselves as such with little difficulty.

Upon succeeding pages it is remarked that whenever quartz is present as a fragmental constituent, even if associated with quartz not of this origin, it is easily discovered. Its original outlines are so strongly marked by particles of gas, iron oxide and other inclusions that all subsequent changes seem inadequate to obliterate them. While this is the case with these known fragmental rocks, the complete absence of anything which suggests that there have been cores in any case in the sections of the crystalline schists loses largely its force as negative evidence against the fragmental origin; because the fragmental rocks mentioned are nowhere foliated, while the schists are strongly foliated. Fragmental rocks in other districts which have been subject to dynamic forces, and have therefore become foliated, have rapidly lost evidence of their original fragmental character.

To conclude, if the massive, coarsely crystalline rocks are assumed to be of eruptive origin, it necessarily follows that a large number of the schistose ones are certainly derived from them; also, it has not been possible to trace any of these crystalline schists back to a rock which can be asserted to be fragmental.

The most important fact developed by the study of the Southern Complex is the apparent gradations which are found between the massive rocks and the schistose ones. These gradations have already been alluded to. It will, then, only be necessary to remember here that the lines separating the granites and the gneissoid granites from the fine grained gneisses and schists are more or less arbitrary. In the field the massive granite, gneissoid granite, granitoid gneiss, coarse gneiss and fine-grained gneiss are sometimes found in order in passing from a granite into a schist area. This change has not been found in continuous exposure, but in detached ones. More frequently a different relation is found, the fine grained crystalline schists being cut by massive granites in such a manner as to leave no doubt of the eruptive nature of the latter (Fig. 39.) In passing from a schist to a granite area, there first appears cutting the schists rare, small veins and stringers of granite; then the granite is found in dike-like forms or in masses and bosses within the schist. Next the granite becomes predominant, and finally the schists altogether disappear as we get wholly within a granite or gneissoid granite area.[1]

FIG. 39.—Schist cut by massive granite, northwest quarter of Sec. 4, T. 46 N., R. 2 E., Wisconsin.

The old interpretation placed on such apparent transitions from finely schistose to massive rocks has been that metamorphic agencies have transformed the crystalline schists into the massive granites. Extreme metamorphism of fragmental rocks is known to produce completely crystalline schists. Metamorphism in massive eruptive rocks also often produces crystalline schists. The forces of metamorphism are, then, known to produce foliated rocks, but have not been shown to form massive rocks unless actual fusion has occurred. It has been taken for granted that the strongly schistose, finely laminated phases of rocks must be of sedimentary origin. This being the case, their gradation into massive rocks was taken as proof

[1] These relations are similar to those described by Mr. Andrew C. Lawson of the Canadian Geological Survey as occurring between the Keewatin and Coutchiching Series and the associated granites. (CC of annual report of the Geological and Natural History Survey of Canada for 1885, Alfred R. C. Selwyn, director; also a paper read before the Geological Congress at London, 1888.) In the latter paper Mr. Lawson maintains that the granite which is associated with and cuts the schist has been produced by the fusion of the schists, thus changing them to true igneous rocks. In this discussion he assumes that all the schists and gneisses are of sedimentary origin. So far as I can make out, he does not verify this position.

of the derivation of the latter from the former by metamorphosing agencies; that is, moisture, heat and pressure have recrystallized the rock, giving it a coarsely crystalline granitic structure in place of the finely crystalline schistose one. This interpretation is based upon the assumption that the strongly foliated schistose rocks are of sedimentary origin. If this is unproved the conclusion is valueless, and even if proved it would not follow. At the present time this derivation of massive syenites and granites from schistose rocks by metamorphosing agencies is greatly discredited. It is almost universally believed that massive granites, syenites, and gabbros are of eruptive origin. If this is assumed, there seems to be no escape from the conclusion that a large proportion of the crystalline schist and gneisses of the area were originally eruptives.

CHAPTER III.

BY R. D. IRVING AND C. R. VAN HISE.

THE CHERTY LIMESTONE MEMBER.

The lowest member of the iron-bearing series in the Penokee region is a cherty limestone. In places the limestone and chert are sharply separated from each other and each concentrated into a single belt, so that in making a cross-section it would be considered to consist of two formations rather than a single one. However, the white quartz, or chert, and limestone occur as a rule interstratified or thinly interlaminated. Taken together, these two classes of rock constitute a well marked belt, which is sharply separated, not only from the granites and schists to the south of it, but also from the fragmental slates immediately above. It has a considerable longitudinal extent, as shown by Pl. XXI, but certainly is not continuous, as in quite a number of localities the next overlying member is found directly in contact with the Southern Complex. Upon account of this lack of constancy in the belt it is mapped as occurring only in those places where exposures demonstrate its existence. The occurrence of cherty fragments in the lower portion of the next overlying member of the Penokee series, in some places where the cherty limestone is altogether wanting, is strongly suggestive of a greater former continuity for the member than it now possesses, for it is possible that the same forces which were at work in the accumulation of the overlying fragmental slate may have in places completely swept away the underlying limestone and chert. From the foregoing it is plain that the thickness of the cherty limestone varies from its maximum amount, 300 feet, to nothing.

Externally the limestone of this belt varies in appearance, the variation being due mainly to a difference in coarseness of grain. Usually it is so fine grained as to be not far different in appearance from a compact, earthy limestone of the fossiliferous series; while, on the other hand, it often presents a somewhat coarsely crystalline aspect. Its color generally ranges from white to gray. Occasionally thin blades of white tremolite may be seen on the surface of a specimen. Analyses of the soluble portions of these limestones indicate that they are always strongly magnesian; the analyses by Mr. W. F. Hillebrand, of the U. S. Geological Survey, showing that in these cases they are sufficiently so to justify the application to them of the name dolomite.

Under the microscope (Pl. XXIV, fig. 1) the dolomite individuals constitute the larger part of each section, presenting the usual appearance met with in crystalline limestones, the particles being irregular and fitting together closely. In addition to the carbonate most of the sections show more or less tremolite, which, however, varies greatly in quantity. Occasionally only a few minute flakes are discoverable, while in other cases broad single blades or radiating clusters make up a large portion of the thin section. The tremolite blades often penetrate the carbonate in every direction; and in the case of the larger blades the dolomite is included within the tremolite. In yet other cases the tremolite, in aggregated blades, appears to make up the whole of certain narrow belts in the thin section.

Many of the sections of these limestones show more or less of a siliceous ingredient, which is found in varying quantities up to an amount which very largely predominates over that of the carbonate. In fact, these siliceous varieties furnish us with a complete gradation into the chert rock, which, as already indicated, at times excludes the limestone completely. Now and then there are apparent in the thin sections of these siliceous limestones a few grains of quartz whose fragmental nature is demonstrated by their rounded contours and by the secondary enlargements they have occasionally received. But these fragmental particles are relatively sparse and unimportant, the most of the silica having plainly solidified in situ. Of the latter silica there may be distinguished two varieties, which, however, grade into one another. The first of these presents itself in the shape of an interlocking mass of quartz individuals of finer or coarser grain. As these become finer and finer there is found intermingled with them more or less of a fine spotty and chalcedonic silica with the characteristic aggregate polarization and radiating structure, and finally these pass into kinds containing a good deal of a completely amorphous opaline material.

As already indicated, the cherty material (Pl. XXIV, fig. 2) of this limestone belt is often in layers of considerable thickness, at times apparently making up the greater part of the whole belt. At Penokee Gap, for instance, it has a thickness of some forty-five feet. In other cases it is scattered through or is interstratified with the limestone in narrow seams. As in the case of the siliceous material just described as occurring at times closely intermingled with the dolomite, so also in the case of this chert rock the silica presents itself in completely crystalline, half crystalline, and amorphous conditions, these several phases occurring at times intermingled with one another. In some cases, however, as for instance in the rock at

Penokee Gap, all of the silica is completely individualized and the individuals furnished more or less thoroughly with crystal outlines. As seen macroscopically, this peculiar rock is perfectly white, studded with minute crystalline facets, and of a saccharoidal texture, being often so crumbly as to be readily mistaken for a fine grained sandstone. This impression is confirmed by the crystal facets which one takes at once to be in the nature of the enlargements of quartz fragments commonly met with in sandstones, but the examination of the thin section fails to substantiate the impression, since the outlines of the original grains are not perceptible. This fact, taken in connection with the gradation varieties between this peculiar rock and those phases in which there is more or less chalcedonic and amorphous silica, leads to the conclusion that here also the whole of the silica has separated out in situ.

The accessory constituents in the chert are few and unimportant in quantity. They include sericite, brown iron oxide, and occasionally magnetite and dolomite. The usual snow white color of the rock is due to the general absence or sparseness of the iron oxide ingredient. Only rarely is the iron oxide present in sufficient quantity to thoroughly redden the rock. In these rare cases, however, the chert resembles a jasper.

One of the most notable peculiarities of this cherty rock is its tendency to assume a brecciated form, in which angular pieces of the chert, ranging from microscopic sizes to fragments two or three inches across, are buried in a chert of a character wholly similar to that of the fragments, or differing from them only in carrying a small quantity of other ingredients, such as magnetite and chlorite. These brecciated phases occur at times wholly within the horizon of the cherty limestone member itself, and in other cases are very near to its junction to the overlying slate, when it is not always easy to draw the line between the two members, as is further indicated in the next paragraph.

As already noted, and subsequently further explained, the limestone or basal member of the iron-bearing series is directly overlain by a very considerable thickness of completely fragmental rocks, whose main constituent is quartz, which mineral is, however, accompanied by a large proportion of feldspar fragments and by various alteration derivatives from the feldspars. The transition from the limestone member to this quartz slate is usually a very sharp one, the fragmental rock carrying often at its base pieces from the cherty material belonging directly beneath it. In some places, however, there is a narrow transition belt, in which fragmental quartzes are buried in a matrix of finely crystalline silica (Pl. XXV, fig. 1), an occurrence which seems to demonstrate the simultaneous action of the two processes of nonfragmental and fragmental sedimentation.

These peculiar breccias or conglomerates occur also interstratified with the slate member in its lower horizons.

From the statement already made it is apparent that no facts have been obtained going to show that the limestone and the major portion of the chert of this belt are other than original water-deposited sediments. Whether the carbonates are of chemical or organic origin we have no definite proof. Early in the study of these rocks it was thought that they were chemical sediments, as we had then little or no evidence of life independent of the nature of the rocks themselves and the iron carbonates at higher horizons. Later, as other proofs of life accumulated, the assumed chemical deposition of these carbonates became more and more doubtful. Many geologists hold that such carbonates are evidence of and could have been produced only by life agencies.

The deposition of similar cherty carbonates of great thickness is definitely known to occur in the Carboniferous and Permian periods.[1] The chert is here probably all of organic origin. Then, whether the chert in the limestones under discussion is an organic or a chemical substance it may be impossible to say; but it is certain that in later geologic times we have the exact analogue of the deposits described which are definitely known to be organic deposits. Subsequently the origin of similar cherty deposits in the iron-bearing formation is discussed, pp. 393–397. What is said there with reference to the "original rock" applies with equal force here.

There is even stronger evidence that the chert was present at a very early date in these limestones than in the cherty iron carbonates. It appears that the chert of the limestone belt, whether original or secondary, had in the main reached its present condition before the accumulation of the immediately overlying quartz slate; since, as already stated, very numerous fragments of this chert are found included within the slate at its base (Pl. XXV, fig. 2), and even in its middle and upper parts. Also considerable belts of conglomeratic chert, having both well rounded and angular fragments of chert in a matrix of the same material, are found within the body of the limestone-chert belt itself. It thus appears that chert existed in its present condition at the time of the formation of the cherty limestone member; that an interruption came, in which these layers were more or less broken by mechanical agencies, forming the pebbles and angular fragments for the conglomerate, which were later cemented by a subsequent chert. There is, then, no escape

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[1] Geol. Mag., London, New Series. Decade III, vol. 4, pp. 435–446, George Jennings Hinde. On the Organic Origin of the Chert in the Carboniferous Limestone Series of Ireland, and its Similarity to that in the Corresponding Strata in North Wales and Yorkshire. Ibid., vol. 5, pp. 241–251, Dr. Hinde, On the Chert and Silicious Schists of the Permo-Carboniferous Strata of Spitzbergen, and on the Characters of the Sponges therefrom, which have been described by Dr. R. von Dunikowski.

from the conclusion that a large part of the chert of this belt was formed simultaneously with or shortly after the carbonates with which it is interstratified, except upon the supposition that the breccias and conglomerates were originally wholly of calcite or dolomite, and that a substitution of this carbonate by silica has taken place in such a manner as to make the chert breccias and conglomerates pseudomorphous masses of rock. For this somewhat violent assumption we have, however, no evidence. That the chert has been rearranged to a greater or less extent since its deposition, and that in the cracks infiltrating solutions have brought additional silica, is more than probable, as is shown by the vein-like character which the chert not infrequently takes.

At the time of this subsequent rearrangement and introduction of silica, doubtless the tremolite was formed, although even this mineral may have developed very early. In the formation of the tremolite, the silica in solution had but to unite with a portion of the bases present, calcium and magnesium. The origin of actinolite from an analogous rock, except that it bore iron, is discussed in a later chapter, pp. 400–402. What is there said applies equally well to the tremolite in the cherty limestone.

CHAPTER IV.

BY R. D. IRVING AND C. R. VAN HISE.

THE QUARTZ SLATE MEMBER.

Resting directly upon the limestone or white chert of the formation described in the last chapter, or, in the absence of that formation, directly upon the gneiss, schist, or granite of the Southern Complex, follows a set of slaty layers, which, though for the most part less than five hundred feet in total thickness, constitute a singularly well marked horizon, traceable throughout the entire extent of the area occupied by the iron-bearing series of the region. The principal ingredients of these layers are quartz and feldspar, which fact has led to our selection of the name "quartz slate" for the entire member; although, as shown subsequently, very many varieties deserving of distinct lithological names occur within it. The possession of a fragmental texture, as its most pronounced characteristic, puts the formation in strong contrast with the chert and limestone of the member immediately underlying it, and with the various ferruginous and cherty rocks of the immediately overlying Iron-Bearing Member, all of which rocks are entirely without the fragmental texture, and, whatever their mode of deposition, are certainly not in the nature of mechanical sediments.

From the west end of the Penokee Range, a short distance east of Bladder Lake, to some distance in T. 47 N., R. 44 W., Michigan, a distance of more than fifty miles, the outcropping edge of the quartz-slate formation forms a practically continuous belt. In T. 44 N., R. 3 W., Wisconsin, this member reappears and may be traced for a distance of about three miles. Whether this horizon is recognizable in Michigan farther to the east than the point mentioned is a matter of some doubt and is considered in a subsequent chapter. From the western end of the Penokee Range, east to the vicinity of Sunday Lake, the width of the outcrop of these slates, which dip always at a high angle to the northward, presents only slight variations. East of Sunday Lake there is a somewhat rapid expansion, and the maximum width here is about one thousand feet, although the average width west of this lake is a little more than five hundred feet. The dip of the belt varies from 40° as a minimum to 75° as a maximum, the usual amount being between 55° and 65°. The thickness of the formation, then, is upon an average in the neighborhood of four hundred and fifty feet, although east of Sunday Lake it is at least eight hundred feet thick.

At the western end of the Penokee Range the layers of the Quartz Slate Member form the base of the southern slope. From here eastward, however, the slate rises higher and higher on this slope, forming frequent bold, and even precipitous, south-facing exposures. At Bad River the slate reaches nearly, and at Mt. Whittlesey, Sec. 16, T. 44 N., R. 2 W., Wisconsin, quite, to the top of the ridge. Still farther east it forms more and more of the bulk of the range, while to the east of Tyler's Fork the whole width of the outcrop lies on the northern slope of the range, the summit here being within the Southern Complex. The same is very noticeably true in the Gogebic country east of the State boundary, the Slate and Iron-bearing Members, as far as the vicinity of the west branch of Black River, forming the northern slope of a bold ridge whose summit lies within the granite. To the east of the West Branch of Black River another change in this respect takes place, the ridge itself lying within the jaspery iron belt north of the quartz slate, which now lies in the lower ground to the southward, while beyond Sunday Lake, and as far east as the East Branch of Black River, the quartz slate again appears in bold exposures, and now forms the principal ridge, with low ground to the north and south of it. This varying position of the crest of the ridge with regard to the different rock belts is plainly a result of the varying relations between the several belts as to power of resisting erosion. At the west the Quartz Slate Member contains an unusually large amount of soft chloritic slates and relatively little of highly quartzose portions, while at the same time the iron belt immediately to the north of it is exceedingly quartzose and resistant. Farther east the quartz slate becomes more and more highly quartzose, and hence resistant, and now goes along with the iron belt itself to make up the bulk of the ridge. After Tyler's Fork is passed, however, the iron belt begins to undergo a change whereby its resisting power becomes less and less, and, as the Montreal River is neared, the granite to the south becomes the most resistant rock, and the crest of the ridge is on it. In the same way a connection between the different degrees of resisting power of the various rocks, and the position of the crest of the range may be shown to hold for that portion of the distance east of the West Branch of Black River.

The rocks of the quartz slate formation have in common, with the exception of its uppermost horizon, a strong slaty tendency and light colored weathering; the slaty structure lying parallel to the bedding, and not being in the nature of the ordinary slaty cleavage.

These two characters serve to mark this formation so strongly that after once having become familiar with them, one is never at a loss to refer its exposures to their true horizon; but while there is this general similarity of appearance, there are at the same time a great many subordinate phases presented. Macroscopically the most prominent phases are: A thinly laminated, rather soft, usually very fine-grained dark-colored rock, having often a distinct tendency towards a greenish tint; a rock shading into the last, but differing from it in being harder and in tending to a paler or even light gray color, often showing mica flakes on the slaty surface, but as often being fine grained or nearly aphanitic, and a genuine vitreous quartzite. Between these three varieties there are all gradations; also there are other subordinate phases, among which are a little indurated sandstone, a red clay shale, or slate, breccias and conglomerates, sometimes magnetitic, in which the fragments are at times white chert and at times from the underlying schists.

A microscopic study shows that the difference between these several phases, so far as they are not the result of unusual conditions, are almost entirely dependent upon the original proportions and degrees of fineness of the two main fragmental constituents, quartz and feldspar. A portion of the larger flakes of mica are taken to be of fragmental origin, but in the main this mineral and kaolin have resulted from the decomposition of the feldspathic particles, accompanied by the separation of a secondary silica. Disregarding the special, or rare phases, the important kinds may be microscopically listed under the following heads: Feldspathic quartz slates, chloritic and biotitic quartz slates, vitreous quartzites, sandstones, novaculites and argillaceous slates. These are variously interstratified with one another, except the vitreous quartzite which is always a persistent element in the stratigraphy, composing everywhere the uppermost horizon of the formation. While no further definite subordinate arrangement is observable, a change in character is noted in the belt in following it from west to east, the biotitic phases predominating in the western portion. In passing eastward the amount of biotite steadily lessens, and east of Tyler's Fork is subordinate in quantity.

The *feldspathic quartz slates* (Pl. XXVI, figs. 1 and 2) are the prevailing varieties of rock east of Tyler's Fork. When examined in thin section a single glance generally suffices to show that they are composed of two parts, a coarser plainly fragmental, and a finer interstitial material. The relative proportions of these materials vary greatly, the coarser parts at times sinking to quite a subordinate position, and again nearly excluding the matrix. Between the finer and coarser portions there is often a material of intermediate fineness. In large measure the two portions are but finer and coarser particles of the same minerals. The coarser part of the sections has always fragments of both quartz and feldspar. With these is often a rather coarse grained mica, which is taken to be fragmental also.

The fragments of quartz are for the most part portions of single individuals, but not unfrequently they are minutely complex, having been derived from some cherty or flinty rock. These particles vary greatly as to the degree of rounding which they have received. In general the amount of rounding appears to be in a direct relation to the size of the particles, the more minute pieces having remained quite angular. In speaking of these pieces as rounded we refer always to the original fragments, whose outlines for the most part still remain distinct; but as they now stand a large proportion of them are built out by secondary enlargement; the added portions varying greatly in width, but often extending beyond the original fragment a distance equal to a fifth or sixth of its diameter. These enlargements are, as usual, optically continuous with the original fragments and have frequently interlocked with one another in such a fashion as to produce very irregular outlines. It is noticed that these secondary enlargements are most narrow in those sections which have a considerable quantity of brown iron oxide among the interstitial materials. The outlines of the original quartz fragments where they have received enlargements are emphasized as is usual in such cases, partly by particles of brown iron oxide and partly by the presence of minute cavities. In a few cases, mingled with this brown iron oxide, and at times almost excluding it, are films of a greenish chlorite.

The feldspar fragments include three distinct kinds. The most abundant is unstriated and its appearance is in every respect that of the ordinary orthoclase of the granitic rocks, and there can be no reasonable doubt that it is of this nature. A second variety is the ordinary cross-twinned microcline and a third is a striated plagioclase. On making many measurements of the extinction angles by Pumpelly's method of the last named variety we fail to find any angles which would suggest the presence of plagioclase more basic than one belonging in the oligoclase series. We may therefore with some confidence say that the feldspar particles of these rocks include pieces of orthoclase, microcline, and albite, or oligoclase, or both, an association which is that of the ordinary granites. Often these feldspar fragments are very fresh, but in other cases many of them are much altered or decomposed, a gradation in this respect being found to obtain between those kinds in which the particles are still very fresh into the chloritic slates above mentioned, or into the argillaceous shales; the most plentiful products of the decomposition of the feldspars being chlorite and kaolinite. In the decomposition of the feldspars to chlorite, the particles of the latter mineral are found to form in the first place in the neighborhood of the edge of the feldspar fragments, the alteration having progressed regularly from the outsides of the grains; in the case of the kaolinitic alteration, the kaolinite particles appear as usual in numerous minute flakes throughout the entire feldspar grains.

The fine interstitial material in these rocks (aside from the minute grains of quartz and feldspar) which, as already said, varies from a predominating almost to a vanishing quantity, is a mixture of a minutely divided silica, flakes of kaolinite, chlorite, and a fine mica, which is taken to be sericite and muscovite in proportions which vary between wide limits, although in nearly every case all of these minerals appear to be present in the matrix, except, perhaps, the sericite. All of these interstitial minerals are ones which, as is known, result from the alteration of feldspars and micas, and it is supposed that they are the result of metasomatic changes carried out particularly in the finer detrital material subsequently to the original deposition of the rock.

The *biotitic and chloritic quartz slates* (Pl. XXVII, fig. 1) are the predominant variety of rock west of Tyler's Fork. In thin section they are as a whole much finer grained than the slates just described, and do not usually show the same separation into a coarser fragmental and a finer interstitial portion. In them the background is composed mainly of quartz, but also usually contains more or less of feldspar, while in some sections this mineral is quite abundant. Scattered through this background in varying quantity are green flakes of chlorite and brown ones of biotite, each mineral predominating at different times. The particles of quartz are now minutely angular. However, many of the large sized ones have plainly marked fragmental cores, whose outlines are emphasized by films composed of minute flakes of chlorite and biotite. It is impossible to say how much of the finer grained quartz is of a fragmental character. The flakes of chlorite and biotite are usually small but well defined, although occasionally larger flakes are seen. Much, and probably all, of these two minerals, and also the nonfragmental silica, have resulted from the decomposition of detrital feldspar. In some sections all three of these minerals occur within the outlines of a single original fragment of feldspar in such a manner as to render their derivation from that mineral certain. This is the process of alteration which, as shown on a subsequent page, has, in certain portions of the Upper Slate Member of this region, changed a fragmental feldspathic rock into a crystalline mica schist. As a result of this method of decomposition, we would expect feldspar fragments, as such, to be abundant in inverse ratio of the amount of chlorite and biotite. This is actually the case. In the most highly chloritic and biotitic varieties there is found little or no feldspar. That all of these rocks are of a fragmental origin is further rendered evident by the gradation of those kinds in which the fragmental texture is lost, into those in which it still remains distinct. These gradations occur constantly within short distances, and those portions in which no distinct trace of fragmental origin is now perceptible are relatively of small extent. It is a noticeable coincidence that the most completely changed varieties in this slate belt are in the western portions, the same being also true of the upper member of the series. On pages 434–435 an explanation of this fact is suggested.

The *vitreous quartzites*[1] (Pl. XXVII, fig. 2) prove, as one would expect from their macroscopic appearance, to be composed almost entirely of relatively large sized quartz fragments, each one of which has received a characteristic enlargement, the several secondary enlargements interlocking with one another in a more or less intricate manner. Feldspathic quartzites are interstratified in thin seams at various horizons in the quartz-slate formations, particularly so in the more eastern portion, but the only occurrence of pure quartzite in this formation, as already noted, is that persistent belt which forms throughout the entire extent of the formation its uppermost horizon. The specimens brought from this particular layer furnish some of the handsomest illustrations which we have ever met with of a transformation of a sandstone to a vitreous quartzite by the enlargement process.[2] The outlines of the original fragments of these rocks are in many cases emphasized by a brown iron oxide, in which case the rock has usually a more or less distinct brownish tinge, but in many cases the emphasizing mineral is chlorite in minute flakes. In the latter case the rock is either of a light gray color, or, if the chlorite is somewhat plentiful, of a distinct greenish tinge. The entire, or nearly entire, absence of particles of any other minerals than quartz in these rocks is taken to indicate a greater amount of sorting than has been received by materials which have composed the other phases of this formation. This conclusion is borne out by the uniform size of the quartz fragments, the sorting having been carried so far as to remove not only the other mineral particles, but the smaller particles of quartz.

The *sandstones* are relatively of small importance and are known only in Michigan at a few points. An examination of the hand specimens, without reference to their source, would suggest that they came from some modern formation rather than from so ancient a terrane as that in which they occur. A microscopic examination shows that they are merely less consolidated phases of the quartzites

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[1] As used in this paper, the word "quartzite" is restricted to rocks which have been derived from fragmentals. The fundamental difference which exists between rocks of this kind and those in which the quartz is an original crystallization we believe is here for the first time fully recognized. However quartzite-like the non-fragmental quartose rocks of the iron-bearing cherty limestone members are, they are always designated by some other name than quartzite.

[2] For a more complete explanation of this enlargement process, with illustrations drawn from very many localities and from different geological horizons. see Bull. U. S. Geological Survey, No. 8, by R. D. Irving and C. R. Van Hise.

and feldspathic quartz slates just described, the latter rocks being in fact no whit less fragmental in texture than the sandstones themselves.

The *novaculite*, or whetstone-like phase (Pl. XXVI, fig. 2) of the quartz slate member, occurs here and there in thin seams in the eastern half of the belt. It is nothing more than a very fine and even grained variety of the feldspathic quartz slates.

The *argillaceous slates* occur in a number of places, but nearly always in thin seams interstratified with the coarser varieties into which they grade. These rocks differ from the feldspathic quartz slates in having the coarser fragmental portion almost or quite wanting; that is to say, they are of the same nature as the matrix of those rocks.

As a rule the contact of the quartz slate formation with the more southerly rocks is concealed. At several points, however, it may be

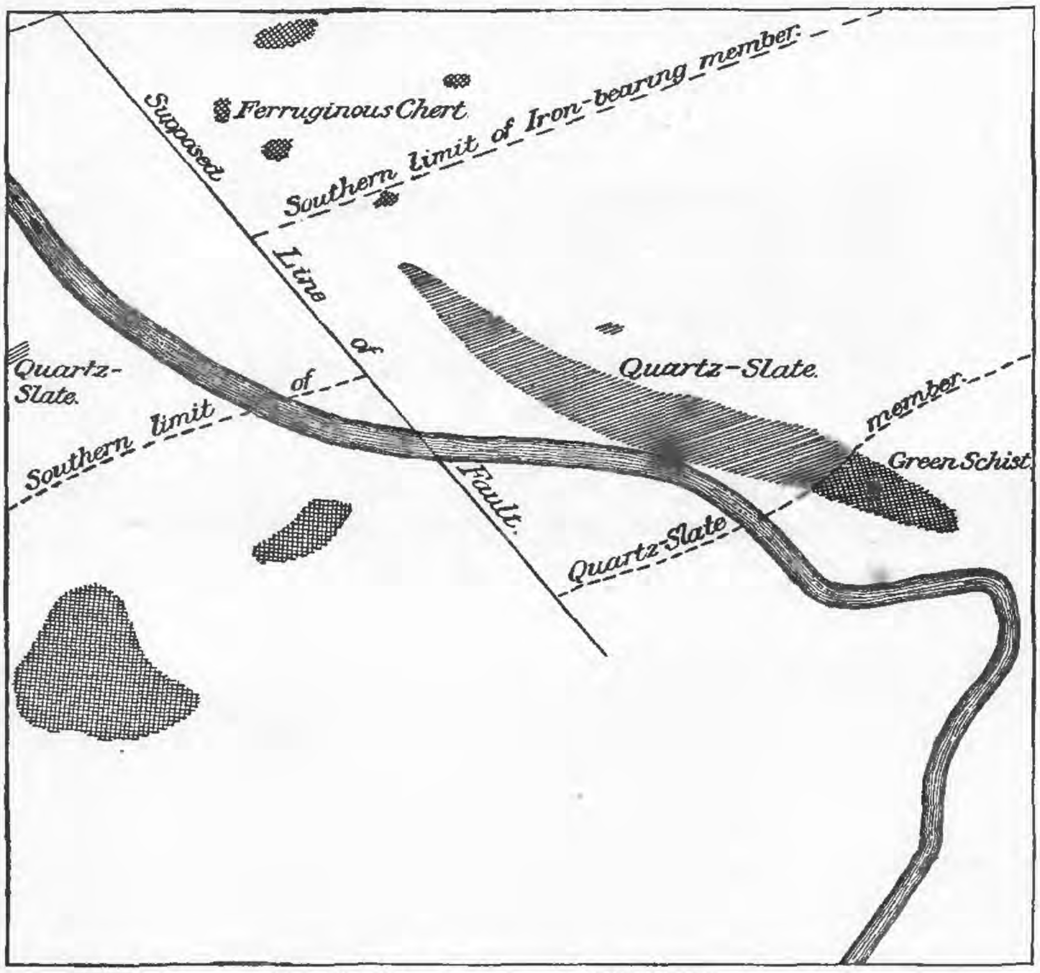

FIG. 40.—Map of exposures at Potato River.

seen either in contact with or very close to exposures of the white chert or limestone of the underlying formation, and in other places again with the granite, gneiss, or schists of the Southern Complex. At the contacts with the white chert, it has already been intimated that in the lower layers of the quartz slate formation are found numerous fragments of the chert which immediately underlies it;

while at the same time the chert layers themselves begin to have mingled in them as they approach the overlying rocks a small proportion of fragmental material (Pl. XXV, figs. 1 and 2). These occurrences are taken to indicate an intermingling of the two processes of deposition. The chert fragments generally occur in thin bands interstratified with nonconglomeratic slate, or in the form of a conglomerate at the base of the member. In passing from the contact toward the north, the chert fragments become very soon of smaller size, although pieces of the chert are occasionally microscopically recognizable even in the higher horizons of the formation. In the southwest quarter, Sec. 17, T. 47 N., R. 44 W., Michigan, the passage from the cherty limestone to the quartz slate member is of a peculiar character. A thickness of several feet of limestone is interleaved with the slate—an occurrence which must indicate an alternation of the two methods of deposition at the transition horizon.

At the Potato and West Branch of the Montreal Rivers the Quartz Slate Member is seen in contact with greenish schists on the south.

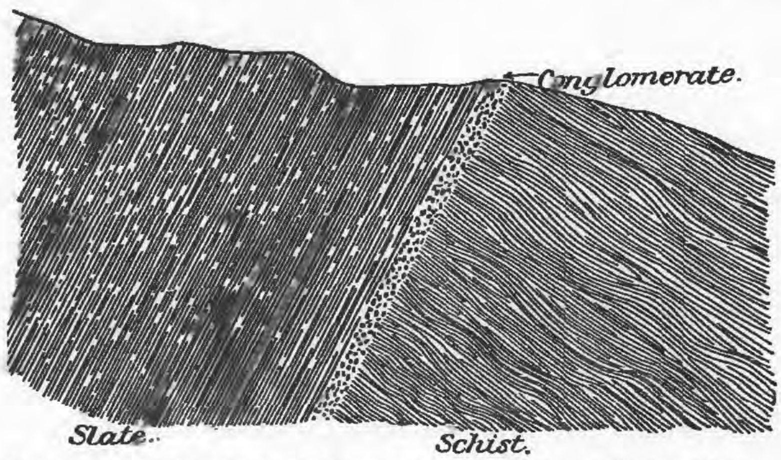

FIG. 41.—Junction of quartz slate and green schists at Potato River.

The Potato River junction is illustrated by Fig. 40, which shows the position of the various exposures. The river here has a bold bank some seventy-five feet in height, along the face of which the contact between the slate and the underlying schists is finely exposed. The best view of the contact is that obtained at the foot of the bank where there is a perpendicular cliff of bare rock. The details of the junction shown on this cliff are represented in Figs. 41 and 42. The more southerly rock is a greenish chloritic schist, with a fibrous or parallel structure in a direction almost exactly at right angles to the junction line. The thin sections show that this rock was probably once some sort of a porphyritic eruptive. Whatever its original nature, however, it has certainly been most intensely altered, the minerals having been rearranged into new combinations and a parallel structure superinduced. Moreover, this alteration was all carried out previously to the deposition against it of the quartz slate, the lowest layers of which are crowded with fragments from the schist of all sizes from a fine detritus to blocks several feet in diameter. This exposure then shows one of the handsomest instances of unconformity that we have ever met with, the worn upper surface of the schist being traceable, and having fitted into it a finer detrital material belonging to the overlying fragmental slate. The accompanying sketches of this contact were drawn on the ground, and represent actual occurrences, the sizes of all of the larger fragments of the conglomerate band being drawn in Fig. 42 to scale, while the

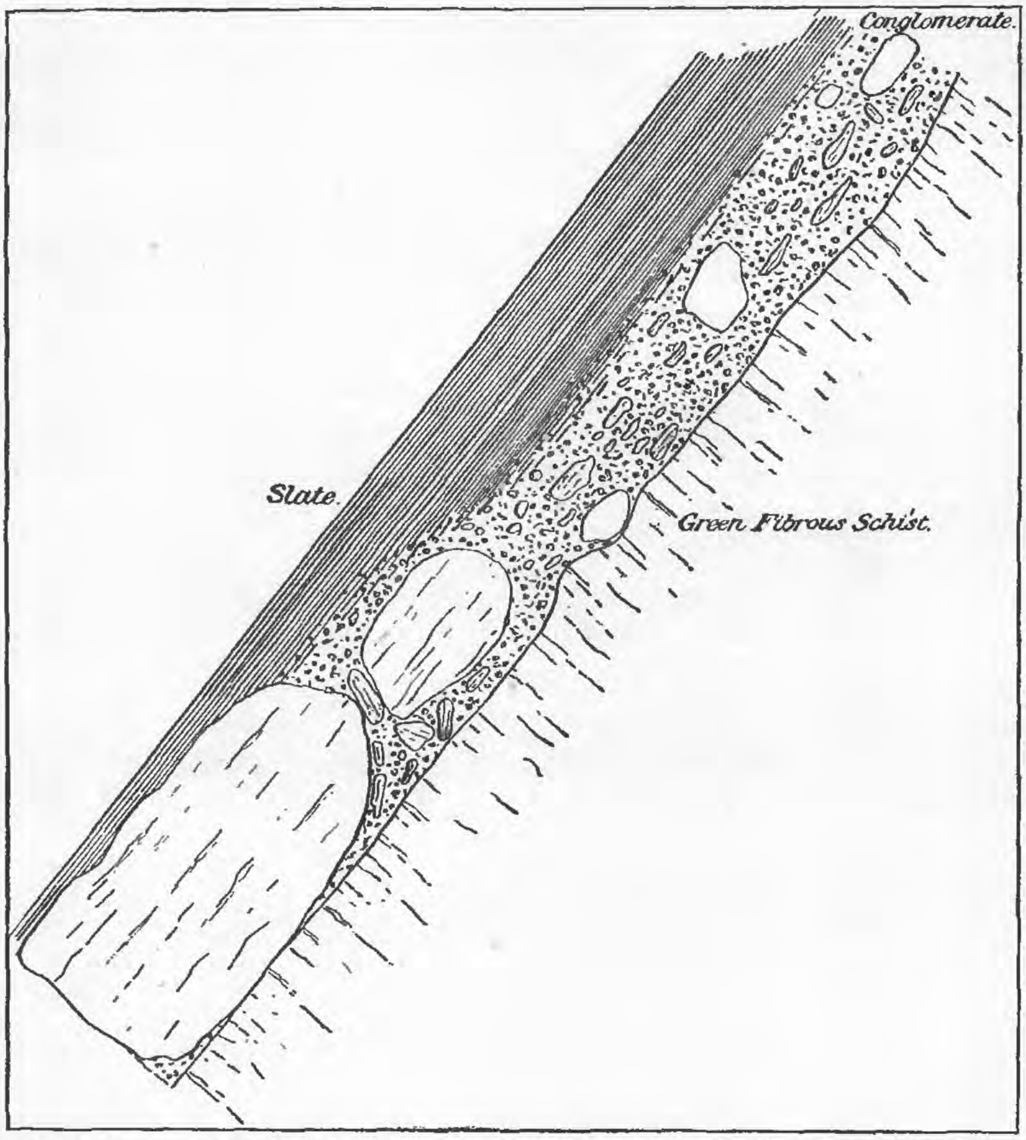

FIG. 42.—Large scale drawing of junction of quartz slate and green schists at Potato River.

structures of the underlying schists and overlying slates are exactly as represented. The junction at the West Branch of the Montreal is in all respects similar to that on the Potato, except that the exposure of the contact is much smaller and therefore less satisfactory. The similarity of the rocks at the two places is such as to render it extremely probable that the same contact extends for all the distance between the two streams.

The contact between the quartz slate and the iron formation which immediately overlies it, as a result of mining operations, is exposed in scores of places. Nowhere where it has been seen, however, does this contact suggest anything but the most abrupt change from one formation to the other. In places the upper part of the quartzite appears to be no more than a coarse sand, and occasionally blocks of it are contained in the basement layers of the iron formation. This would seem to indicate that here and there the quartzite was somewhat broken before the beginning of the deposition of the overlying member. Also the upper part of the quartzite is often heavily stained with iron oxide which has been carried down along the cracks by leaching action. Nevertheless the change from one formation to the other is astonishingly abrupt—it often being possible to locate to a fraction of an inch the plane between the two formations. Upon one side of this plane is the coarse fragmental quartzite, upon the other the nonfragmental varied rocks of the Iron-Bearing Member.

It has already been made evident that the various rock phases of which the Quartz Slate Member is composed are of a detrital nature. Even the finest grained phases and the finer interstitial material of the coarser phases, although at times not now plainly showing their fragmental character, are taken, notwithstanding this, to be wholly of detrital origin, being composed of the same materials as the coarser phases, whether in the original unaltered condition, or, as is more generally the case, somewhat changed by metasomatosis, the chlorite, kaolinite, micas, and finely crystalline quartz being in the main secondary derivatives from feldspathic detrital material.

The nature of the detritus of which this formation is mainly composed is such as to suggest very strongly the derivation of its material from some sort of granitic or gneissic rock. The pieces of quartz, orthoclase, microcline, plagioclase (probably albite and oligoclase), and mica are in their association and in their peculiarities just what we would expect in a granite detritus. And more than this, it is entirely similar to the particles of these same minerals as they appear in the granite and gneiss, which is so largely exposed immediately to the south. One of most noteworthy things about the formation (excepting the upper horizon) is the relatively small degree of assortment that the detrital material of which it is composed has received. The detritus, which, while quartz predominates, is still largely composed of feldspar and mica particles, can not have been carried to any great distance from its source. The quartzite, however, which forms the uppermost horizon of the formations, represents of course a more thoroughly assorted detritus, and it is very interesting in this connection to note the extraordinary persistency of this horizon.

CHAPTER V.

BY R. D. IRVING AND C. R. VAN HISE.

THE IRON-BEARING MEMBER.

SECTION I.—DETAILS.

The name given to this member is justified by its large content of iron. Certain phases of the belt contain little or no iron, being wholly made up of silica in one form or another, but such phases have no very great extent, there being nearly always present at least a little iron oxide, while throughout the greater portion of the belt the content of metallic iron certainly exceeds 10 per cent. Very considerable thicknesses are met with in which the amount of iron reaches 20, 30, 40, and even 50 per cent.

As indicated already in Chapter II, the main distinction between the Quartz Slate and Iron-Bearing Members lies in the fact that the former is wholly of clastic origin, being still made up mainly of fragmental material readily recognizable as such, while the latter not only contains no fragmental material whatever, but presents us with no evidence at all of ever having accumulated as a mechanical detritus. Upon the other hand, the slaty rocks which overlie the Iron-Bearing Member, though occasionally so much changed by metasomatic processes as to have lost the fragmental character, have in the main preserved it thoroughly. The transition then from the Quartz Slate Member to the Iron-Bearing Member is one from a mechanical detritus to a formation of chemical or organic origin. The contact between these two formations is to be seen at numerous points, and at all of them the change is abrupt. This conclusion has been reached, not merely by an examination in the field, but as the result of a careful study of thin sections of specimens collected on each side of the contact with the very object of obtaining light upon this point. In the more eastern portion of the district and so far west as the vicinity of the passage of Tyler's Fork, in T. 45 N., R. 1 W., Wisconsin, this contact has been brought to view by mining operations at many points, the rule being, as further explained hereafter, that the principal deposits of ore lie at the base of the

Iron-Bearing Member and immediately upon the vitreous quartzite which forms the uppermost layer of the Quartz Slate Member. In these mines the contact is between this quartzite on the one side and either the ore or a hematitic cherty material of an entirely non-fragmental character. The contact between the two formations is also visible at a number of natural exposures.

Longitudinally the Iron-Bearing Member is coextensive in distribution with the underlying Quartz Slate. To the west of the western end of the Penokee Range, as indicated heretofore, the entire succession of the iron-bearing series is lost for a distance of six miles, in which exposures of the underlying granitic and gneissic rocks on the one hand, and of gabbros on the other, come in close proximity with one another and make it a question whether the entire iron-bearing series is not here cut out. In the north half of Sec. 23, T. 44 N., R. 5 W., Wisconsin, as already stated, outcrops of the Penokee series reappear, and from here for a distance westward of four miles exposures of the iron-bearing and quartz slate members are sufficiently frequent to indicate their continuity through this distance. Beyond this point no exposures have yet been found until those met with in the southeast quarter, Sec. 26, T. 44 N., R. 6 W., Wisconsin, where the characteristic rocks of the iron belt are seen at their westernmost point. To the east of the easternmost point indicated as reached by the continuous iron-belt of the Penokee Range, exposures of ferruginous rocks allied to those of the iron-bearing member are met with for a distance of six or seven miles, and to within three or four miles of Gogebic Lake; but these occur in a peculiarly disturbed and difficult area, whose geology, whatever be the true interpretation of it, is unlike that of the Penokee belt proper. The iron-bearing rocks of this area receive special attention in Chapter VIII.

The width of the belt of country occupied by the Iron-Bearing Member is surprisingly uniform from the westernmost exposures as far east as the central portion of T. 47 N., R. 46 W., Michigan. Throughout this very considerable distance the width of the belt rarely falls below 800 feet, and as rarely exceeds 1,000 feet; the variations in width being frequently explicable by changes in amount of northward inclination, though apparently some part of it may be due to actual variations in thickness. Still, through most of this distance the thickness must be taken as more nearly constant than the width. When R. 46 W., Michigan, is reached a distinct widening of the belt becomes perceptible, and in the eastern part of that township this becomes so rapid that at Black River it is 2,400 feet. From Black River eastward there is a still more rapid increase, the width on the west side of T. 47 N., R. 45 W., Michigan, being fully 4,700 feet. Immediately east of this point the overlying Keweenaw rocks, whose southern boundary has been for some time rapidly approached by the northern edge of the iron-bearing belt, are reached by it. Continuing to the east the iron belt is in part cut off by the Keweenaw series, so that at one place its surface width is not much more than 500 feet. Not far east of Sunday Lake a widening comes in again. This is evidently due to a change in the course of the iron belt, which now trends southward and thus diverges from the Keweenawan beds, the divergence, however, not being so great as to allow the reappearance of the slates belonging above the iron-bearing member to as far east as the middle of T. 47 N., R. 44 W., Michigan.

Throughout the greater part of the distance the actual average thickness of the formation can not differ much from 850 feet. How far the great increase in width in the eastern portion of the belt is due to an increase in thickness is exceedingly difficult to determine. Some of it is plainly the result of an unusually low northern dip. Much of it is also due to layers of basic eruptives, exposures of which, and bodies shown by underground workings, are found with sufficient frequency to indicate the existence of such intercalations. But, after these two causes of widening have been allowed for, the thickness of the iron-bearing part of the formation must be materially greater than the average.

The Penokee iron range, save for several transverse cuts made through it by the northward flowing streams, is a continuous ridge from the east side of T. 44 N., R. 4 W., Wisconsin, eastward to beyond Sunday Lake, in Michigan. To the west of the western termination of this range, as indicated before are again other detached ranges, which, being made up of the same kind of strata dipping in the same northerly direction, may be looked upon as forming portions of the same general line of elevation. The same is true east of the eastern termination indicated, as far as the vicinity of the Little Presqu' Isle River. The ridge rises from one to three hundred feet above the elevated swampy region to the south of it, and from one to six hundred feet above the lower region to the north. In its more western portions this range is broad, and has a rather narrow serrated crest, while eastward from Tyler's Fork it becomes more and more of a gentle swell until west of Sunday Lake, where there is again a broader range. In much of this distance the ridge forms the most prominent feature of the topography of the country, being visible from the waters of Lake Superior in the vicinity of the Apostle Islands as a blue line against the horizon. On a preceding page the relations of the Quartz Slate Member to this ridge has been indicated, and incidentally that of the Iron-Bearing Member also, and therefore need not be here repeated.

Three main types of rock make up this member of the series. Between these three types there are various gradation phases, while each main type presents itself in a number of forms between which there are minor differences. In certain rare instances a little clastic material has been introduced during the original deposition of these rocks, but ordinarily this is completely lacking. The three types referred to may be briefly characterized as (1) *slaty and often cherty iron carbonate;* (2) *ferruginous slates and cherts, and* (3) *actinolitic and magnetitic slates.*

The first type is a very well marked one, and is present in very considerable thicknesses. It is characterized by the invariable presence of iron carbonate as a chief constituent. In many cases the iron carbonate constitutes the only important mineral in the rock, but usually it is mingled with more or less of cherty silica, which ranges in character from minutely crystalline to amorphous. Other minor ingredients, one or more of which may be present, are hematite, limonite, or other brown iron oxide, magnetite, carbonaceous or graphitic matter, iron pyrites, a chloritic and viriditic ingredient, an excessively fine, clayey substance, and—only very rarely—pieces of a fragmental quartz. In texture these rocks are commonly earthy and aphanitic, but in some cases the iron carbonate is sufficiently coarsely crystalline for the cleavage surface of the minute crystals of siderite to be perceptible to the naked eye. There is ordinarily a regular and thin lamination produced by an alternation of lighter and darker gray shades of the carbonate. Frequently, however, the gray carbonate is interlaminated with seams of black graphitic matter, red jasper, red hematite, black flint, greenish black, or viriditic carbonate, or with seams of carbonate in which magnetite particles are particularly abundant. While the platy or thinly stratiform habit is very characteristic of these rocks, these laminæ often become irregular, presenting the appearance of having been broken apart and recemented, in which case there is usually a considerable quantity of the cherty silica present. The observations thus far made have applied particularly to fresh surfaces. On exposed surfaces there is prevalent a brownish or reddish iron stain from peroxidation of the iron of the carbonate. In specific gravity these rocks range generally between the two other types. The specific gravity of pure iron carbonate is given in the mineralogies as between 3.7 and 3.9. The rocks now considered fall below this figure because of the presence of other lighter substances, particularly the silicious and clayey ingredients, and range from 2.97 to 3.50. A number of analyses of the fresher of the iron carbonates have been made in the chemical laboratory of the U. S. Geological Survey, which show that aside from the silica the major portion of the material is ferrous carbonate. The silica, however, runs in some cases nearly to 50 per cent, and siliceous bands could be taken which, without doubt, would contain above 90 per cent of silica. The rocks also contain variable amounts of calcium, magnesium, and manganese carbonates, as well as alumina and iron sesquioxide. In one case the manganous oxide is more than 5 per cent.

In thin section the siderite varies in its character from earthy to well crystallized. The silica, making up the greater part of the remainder of the rock, is in part amorphous. It is that variety of silica or quartz which has in the polarized light a minute spotty appearance, due to exceedingly small individuals of quartz, mingled with more or less of silica, which is apparently amorphous. Hornstone, or flint, gives in thin section the same appearance, and the chert of the iron carbonates and hornstone have a very close macroscopic resemblance. That a portion of the silica is really amorphous, as indicated by the appearance of the section under the microscope, is further shown by its ready solubility in caustic alkalies. Nowhere does this chert present a concretionary or brecciated appearance.

The iron carbonate and chert occur sometimes in solid bands alternating with each other, and interstratified with these are other bands composed in greater or less proportion of the chert and siderite. Sometimes the bands of siderite contain a little chert, and the nearly pure bands of chert frequently contain more or less of siderite, the individuals of this mineral generally being in a regular rhombohedral form. In the unaltered rocks the chert can no more be said to be a background in which the siderite has crystallized than the reverse. Apparently as a result of changing conditions, regular alternations of siderite and chert and various mixtures of the two have been deposited. Sometimes the layers of solid siderite are of considerable thickness; the same is true to a less degree of the cherty layers. These rocks appear to be in essentially their original condition. If there has been any change since they were formed there is no evidence of it, and for our present purposes they must be regarded as original rocks. It is not impossible that they have undergone great changes, but if so we are unable to find any clew as to their nature.

From these apparently unaltered rocks of the first type there are gradations to those of the first phase of the second type. The first alteration to which these rocks are subject is an oxidation of the carbonate producing brown hydrated hematite, red hematite, or magnetite. Very frequently the decomposition of the iron carbonate has not changed the forms of the original crystals, and thus leave the various oxides as perfect pseudomorphs after the iron carbonate (Pl. XXVIII, fig. 1; Pl. XXXII, fig. 2). All phases of this change to each of the iron oxides is exhibited by the various sections. Frequently upon one side of the same section is unaltered iron carbonate, and upon the other side, iron oxides alone, pseudomorphous after the iron carbonate. Between the two are all phases of the change. The formation of magnetite pseudomorphs after the carbonate is much less common than that of the brown hydrated hematite and the red hematite. In the siderites which were more nearly pure, this alteration, completely carried out, produces the lean ferruginous slates which are one of the characteristic rocks of the second type below described. Accompanying this oxidation of the siderite is generally a rearrangement, and apparently often an introduction of silica from extraneous sources. The silica in these altered rocks, instead of being the spotty chert characteristic of the unaltered rock, is frequently more coarsely crystalline, and often in combination with the iron oxides has a concretionary and brecciated appearance. When this rearrangement and introduction of silica is carried to the extreme, with accompanying changes in the iron oxide, the cherty iron carbonate passes into a second phase of the second type of rocks—the ferruginous cherts.

A very characteristic feature of the iron carbonates is the appearance of numerous veins and fissures which cut through the rock. These veins are of greatly varying width, one of them frequently breaking into several smaller veins, and in some cases the sections are cut by a system of ramifying veins. They are generally composed of the same minerals which make up the section in which they are contained; that is, chert, siderite, and sometimes chlorite. Upon the whole, silica is much the more abundant filling. This silica is frequently easily separated from the remainder of the silica in the section by being more coarsely crystallized, or having the radial fibrous arrangement of chalcedony, and by including little iron oxide. Not infrequently, however, the veins contain a large amount of siderite. This siderite, like the silica, is usually purer and more coarsely crystallized than the original siderite.

The rocks of the second type (Pl. XXVIII, fig. 2 and Pl. XXIX, fig. 1) which we have collected under the general designation of *ferruginous slates and ferruginous cherts*, have in common a prominent siliceous constituent, which is always of a nonfragmental nature, and ranges in crystallization from a wholly though minutely crystalline condition, through partly crystalline and chalcedonic phases to an entirely amorphous phase, the several phases being frequently associated in the same thin section. Compared with the siliceous ingredient of the rocks of the third type, the silica of the rocks of the second type is in general very much finer in grain. Indeed those phases in which the silica is either in so minute individuals that they can only with extreme difficulty be separated under the microscope, or in which it is mingled with more or less chalcedonic or even amorphous forms, greatly predominate. In addition to this siliceous groundmass, the principal ingredients of these rocks are the several iron oxides; that is magnetite, hematite, and a brown hydrated oxide. These are generally greatly subordinate in quantity to the silica. In other cases they are present in considerable quantity, and frequently occur so plentifully as to furnish intermediate phases between the cherts and the iron ores of the region. The principal one of these oxides is hematite. When magnetite is present in any considerable quantity, it is generally accompanied by more or less actinolite in minute needles, and phases of gradation between the cherts and the actinolitic rocks of the third type, subsequently described, are thus produced. On the other hand, more or less iron carbonate is found in remnants in the many sections of these cherts, and by its increasing quantity leads us through phases of gradation into the rocks of the first type above described. In color these rocks vary greatly, presenting red, brown, gray, and white colors, depending upon the amount of iron oxide present. Perfectly white nonferruginous phases are occasionally met with; also light to dark gray kinds; and grayish kinds mottled irregularly with black, in which phase the iron oxide is mainly magnetite. When hematite is present in large quantity the rock may have a uniform red color. Occasionally the red iron oxide is present in just such quantity and condition as to make of the chert a genuine jasper. A rather unusual kind is quite black, apparently from the presence of carbonaceous matter.

In structure these rocks vary from the regular lamination of the first type to those that are much less regular, being either without any uniform banding, or if the banding is present, the laminæ present the appearance of having been disrupted and the broken fragments recemented. Both the regularly and irregularly laminated phases are found in large areas. The specific gravity of the second type of rock varies from 2.65 to 3.39, depending upon the amount of iron oxide contained.

In thin section, the *ferruginous slates* have the iron oxide and silica quite uniformly mingled. The manner of formation of the first phase from the cherty iron carbonates has already been sufficiently indicated. In them there has sometimes been a concentration of the iron oxide to a small extent into layers. At times these layers are very regular, between which alternate others of chert containing comparatively little oxide of iron. From these perfectly laminated phases, which are as regular as any of the slaty iron carbonates of the first type of rock, the specimens vary into those which in thin section show no proper lamination, although in hand specimens there is always evidence of rough stratification.

In one direction the ferruginous slates may then be traced into rocks of the first type. In the reverse direction, by concentration of the iron oxide and by the development of a concretionary and brecciated character, this phase passes into the *ferruginous cherts*. The latter are best described as cherts containing bands and shots of ore. These shots occur in cavities in the chert, and ofttimes they do not entirely fill them. In such cases the iron oxide is apt to be coated with crystals of quartz. The structure is upon a small scale that of a geode, the cavity of which has a layer of iron oxide, and within this quartz crystals. Even when the cavities are completely filled with iron oxide the same similarity to a geodic structure is apparent. It would seem that the cavities formed at some stage in the development of the rock (probably by a solution of a part of the iron carbonate at the time another part was oxidized), were subsequently partly or completely filled with iron oxide, after which, if space remained, followed silica.

In this phase of rock the arrangement of the constituent particles are often closely similar to that which has been described on a preceding page as characterizing the chert of the limestone member at the base of the series; that is, it often presents a more or less perfect concretionary arrangement, but in the limestones and cherts these are at times exceedingly vague. However, the concretions are so numerous as to be one of the most important characteristics of the ferruginous cherts. In the concretions (Pl. XXVIII, fig. 2, and Pl. XXIX, fig. 1), the iron oxide is arranged in concentric oval or spherical bands, and this is equally true whether it is limonite, hematite, or magnetite. The bands pay not the slightest attention to the individuals of quartz, cutting through them in the most indiscriminate manner. The concretionary structure also affects the silica, both in concentric arrangment and coarseness of individuals, they quite often being larger in the concretions than in the cherty matrix. Rarely the concretions have nuclei from extraneous sources, as for instance, small particles of fragmental quartz, but ordinarily they have none, or else nuclei of iron oxide or of a comparatively large individual or a cluster of individuals of nonfragmental quartz, and these would seem rather to be a part of the concretions than nuclei for them. Sometimes the concretions are so closely clustered that in their growth they interfere, and in such cases two or more are used as a nucleus about which the bands of iron oxide arrange themselves concentrically, thus forming compound concretions.

A characteristic of these rocks less prevalent than the concretions, consists in the extraordinary brecciated appearance which they present. A similar appearance has already been noted as characterizing the chert of the limestone. The outlines of the fragmental areas are very commonly more or less sharply angular while frequently projections in the outline of fragments correspond to recessions in other fragments in such a manner as to demonstrate of them a former continuity. The concretionary areas occur alone and with the fragment like areas, while between the two there is found such a complete series of gradations that it is impossible to resist the conclusion that in many cases both are of the same origin.

The great variety of forms presented by the different sections fortunately relate the history of these concretionary areas (Pl. XXXII, fig. 2). In the first place, entirely unaltered areas of iron carbonate are found associated with them. Other iron carbonate areas, lying within the usual siliceous groundmass, may be cut by ramifying veinlets of silica. Again, areas are seen in which have been developed at or near their edges curving lines of iron oxide. These lines may or may not complete a loop. If the outline of the original carbonate area is more or less irregular and angular, the iron oxide curve cuts off the irregularities. In other cases again several such complete or partial iron oxide lines, concentric with one another, have been developed. Subsequent, alternate, or simultaneous with this process silica appears within the concretion, filling the spaces between the rings of iron oxide, the iron carbonate being previously removed. At other times the space occupied by the iron carbonate is left vacant, or else only partly filled, whence arise the frequent geodic and other cavities found in this phase of rock. Finally no iron carbonate remains, its place being taken by the concentric rings of iron oxide and the minutely crystalline to amorphous silica. Between the unaltered iron carbonate areas and the perfectly formed concretions there are at times, often in a single section, every possible gradation. If the iron oxide developed from the carbonate was very plentiful, but little room was left for the entering silica, and these areas appear now nearly or quite opaque with oxide, but generally the iron oxide has been developed in the partial or complete curves referred to, and the substitution of silica for the remaining carbonate left them as if lying within a siliceous background.

Quite similar has evidently been the process by which the pseudofragmental areas, such as shown in Pl. XXIX, fig. 1, have been produced. In such cases the silica of the background has plainly also been rearranged so that it resembles and merges into the silica of the concretionary areas, thus giving the vague, irregular outlines which make these forms so closely resemble fragments. More rarely the fragmental areas are tabular in form or else show a subordinate parallel lamination which appear to be lines of original deposition. The laminæ of these areas frequently abruptly terminate at the exteriors of the apparent fragments. A number of such areas sometimes occur in a single section now lying within the siliceous groundmass in such position as to have the laminæ of the different areas make all sorts of angles with each other. In such cases the area must be believed to be real fragments which have formed, either in situ by an actual local brecciation of the rock caused by chemical or mechanical action, or they may be considered as having been derived from the immediately underlying layer of nonfragmental rock by a temporary mingling of fragmental and nonfragmental deposition.

It is exceedingly difficult to convey in any general description a good idea of the multitudinous phases presented by this second type of rock, but some further and more accurate conception may be obtained by an examination of the accompanying plates.

In connection with the second type of rock, it is necessary to allude to some peculiar phases which resemble on the one hand the brecciated rocks described above, and upon the other the true fragmental rocks of the underlying Quartz Slate Member.

In them there has evidently been a mingling of clastic and nonclastic sedimentation. They contain simple grains of quartz which have been enlarged, the fragmental character of which can not be doubted. These same sections also contain rounded chert areas, which include sometimes little iron oxide; sometimes abundant red hematite, making them jasper; and sometimes both hematite and magnetite. Often the areas containing little or no iron oxide and those containing it abundantly are in juxtaposition. The simple fragmental grains of quartz and the chert areas are generally arranged with their longer axes in a common direction. The fragmental character of the simple quartzes, the likeness to them in form of chert areas, and their arrangement with longer axes in a common direction, are almost conclusive proof that these parts of the rocks are genuine mechanical sediments. The fragments are cemented by a matrix, which is a ferruginous chert in every respect similar to those just described.

These semifragmental rocks are interstratified with others which are typical of the iron-bearing member. The meaning of this interlamination of the two classes of sediments will be considered later.

The rocks belonging to the third type the *actinolitic and magnetitic slates* (Pl. XXIX, fig. 2; Pl. XXXIII, fig. 2; Pl. XXXIV, fig. 1, and Pl. XXXV, fig. 2) are in the main very dark colored, being often nearly black. Occasionally, however, in bands the color is lighter, in which case the light and dark colored bands present a very striking striped appearance in natural exposure. The grain is usually very fine, being at times quite aphanitic. Occasionally each of the main individual constituents may be detected with the naked eye. These main constitutents are shown by the miscroscope to be in most instances quartz, actinolite, hematite and magnetite. The first of these is occasionally lacking, but such phases are unusual. The four minerals vary greatly as to relative proportion, each in turn predominating over the others; the lighter colored phases being of course the most highly quartzose ones, while the darker kinds are richer in iron oxide, which mineral is often present in sufficient quantities to give the rock a more or less distinct metallic luster. Except in certain thin seams, however, which are at times even pure hematite and magnetite, the content is not so great but that the powder of the rock is of a light color. In one unusual phase garnet is a prominent constituent, and chlorite and biotite occur frequently as somewhat important alteration products. The lamination of these rocks is usually more or less strongly marked by variations in shade; the individual laminae more commonly running from very narrow to about one-fourth or one-half inch, only occasionally exceeding the latter figure. Parallel to the lamination there is generally a distinct tendency to cleavage. The large amount of magnetite and hematite which nearly all phases of this rock contain render it very noticeably heavy, the specific gravities running from about three to five. Those having the highest specific gravities are nearly pure oxide of iron and occur in relatively narrow seams. Numerous analyses of the richer seams, made by the Wisconsin Geological Survey, show that magnetite is more often the predominant iron oxide, although not infrequently the hematite is equally or even more abundant. The large amount of magnetite contained in these rocks produces extraordinary attractions upon the magnetic needle.

In thin section any one of the main constituents may be found to the almost complete exclusion of the others, although in large exposures all of the minerals are invariably found. The order quartz, iron oxide and actinolite expresses their usual relative abundance, taking the exposures as a whole. In order of time of crystallization the iron oxide is always the earliest of the constituents, next the actinolite, and finally the quartz. Yet, while this is true as a general statement, it is not meant to imply that the crystallization of any one mineral is finished before that of the second one begins, for they are to a certain extent simultaneous. The areas of iron oxide are the freest from inclusion of the other two chief constituents. The actinolite contains large quantities of iron oxide, but everywhere penetrates the quartz, a single needle of actinolite commonly cutting two or more individuals, and finally the quartz includes much magnetite and actinolite. However, each one of the minerals is, in certain cases, found to include both of the other two. In addition to these three main constituents, chlorite and biotite are found as extensive alteration products of the actinolite. The magnetite and hematite are directly associated and probably were formed at the same time. Occasionally the hematitic ingredient is macroscopically detected by the peculiar steely luster characteristic of specular iron, or by a purplish tint to the powder of very highly ferruginous varieties.

Of the three principal constituents named, the quartz, or silica, presents itself in a general way as a minutely crystalline ground mass or background in which the other minerals are contained. Only rarely is the crystallization of this quartz so coarse as indicated in Pl. XXXV, fig. 2, in which, however, the individuals are still small, being greatly magnified. On the other hand, it only rarely sinks to that excessive degree of fineness which is characteristic of the chalcedonic form of silica. Still, a few sections have been found in which it does reach this excessively fine condition, and even becomes partly amorphous ; but these conditions are, as seen, far more characteristic of the cherty rocks of the types previously described. Since these types, however, grade into one another, it is evident enough that all of the silica of the three types is of the same origin; that is to say, is all water-deposited. Even where least minutely crystalline, as in some of the actinolitic slates, the individuals of silica interlock with one another in such a fashion as to place their deposition in situ quite beyond question. Nowhere is there any indication of a fragmental origin for any of the siliceous ground mass. Cases have been noted of the occurrence of genuine fragments of quartz within the nonfragmental mass of the rocks of the first and second types, but these fragments are always sharply defined and wholly distinct in character from the prevalent nonfragmental silica.

The magnetite and hematite occur partly in the form of an excessively fine dust contained within the quartz and actinolite individuals; partly in the shape of single crystals or groups of crystals of moderately good size, and partly in the irregularly oval, opaque bunches of crystals above mentioned (Pl. XXXV, fig. 2). The outlines of the single crystals are usually very sharply defined, square, hexagonal and rhombic outlines presenting themselves constantly. On the whole the rhombic outline is the most common. In the most regularly slaty phases of the actinolitic schists, the iron oxides are found to be aggregated much more plentifully in certain bands than in others, the individual laminæ of these slaty rocks presenting in turn each of the three main constituents as the predominant one (Pl. XXXIV, fig. 1). The rocks of the second or ferruginous chert phase have been described as presenting very commonly a most singular occurrence of the oxides of iron; the particles of these oxides being distributed upon the quartz background in rude circles or ovals, or in two or more concentric circles or ovals. While this occurrence is far more common among the cherty rocks, it is also met with among some of the highly actinolitic slates, in which case the actinolite is usually associated with the curving lines of iron oxide. In some cases actinolite and magnetite are associated in a bunchy fashion, and are at times dissevered from one another by the intrusion of silica; this silica, however, presenting the appearance of passing about the several detached areas where these are sufficiently translucent to allow such a relation to be seen. The existence of this peculiar structure in the highly actinolitic rocks is of very considerable interest, since it furnishes one more link between them and the ferruginous cherts of the last type, and is, then, one more indication that all are derived from essentially the same original material.

The actinolitic ingredient of these rocks presents itself usually in bunches of minute, radiating blades of a pale greenish tint. Occasionally the individual blades are large enough, as indicated previously, for them to be seen with the naked eye or with the magnifying glass, but more usually they are microscopic. The radiating bunches of actinolite are often aggregated into certain laminæ to the approximate exclusion of the other mineral ingredients. They occur also in single blades, scattered over the thin section, many minute blades being not unfrequently inclosed in a single grain of quartz, while other blades or bunches of blades often traverse a number of such individuals.

In all that portion of the iron belt which lies to the west of Tyler's Fork the rocks of the third type, actinolitic and magnetitic slates, prevail. At this river the actinolite has sunk, however, to a subordinate place, while the siliceous constituent is the most prominent one. At the same time the hematite and brown iron oxides begin to prevail over the magnetite. East of Tyler's Fork the first and second types greatly predominate, though phases carrying minute quantities of actinolite continue to occur as far east as the Potato River. For some 30 miles now to the eastward—that is, near the east side of T. 47 N., R. 45 W., Michigan, the ferruginous cherts and cherty iron carbonates, with iron ore bodies at or near the base of the formation, continue nearly to the exclusion of the actinolitic rocks. In this distance is included, with few exceptions, all of the working mines of the Gogebic district. A rude, subordinate stratigraphic arrangement in the iron belt appears to hold for this distance; that is, the pure carbonates are characteristic of the upper, the ferruginous slates of the middle, and the ferruginous cherts of the lower horizons, while the ore bodies lie within the latter. It is later explained that this arrangement has a connection with the origin of the ore bodies, and is much more definitely made out through the ore-bearing part of the range than elsewhere. Even here, however, there is no sharp division between these phases in cross-section. East of T. 47 N., R. 45 W., Michigan, another change in the nature of the belt is met with, the actinolitic and magnetitic rocks of the third type coming in plentifully. At first these occur along with both the ferruginous cherts and carbonates, but as one passes farther to the eastward no carbonates are found, the actinolitic schists and ferruginous cherts only being known, and in turn, the latter, lessen in amount, and near the Little Presqu' Isle River the actinolitic slates are alone.

To one visiting the iron belt only at two or three points distantly removed from one another, without examining the intervening portions—say, for instance, at Penokee Gap and in the vicinity of the mines at Bessemer, Mich.—the difference between the rocks which compose it might be so striking as to give rise to a doubt of the actual continuity of the belt between the two places; but for one who follows the belt throughout its whole length no such question for a moment can be entertained. Mining developments and natural exposures make the belt practically continuous, and one finds a gradual transition between the three types of rock, which takes place only in the most gradual manner. Farther, he always finds immediately beneath the iron belt the quartz slate, and immediately above it the upper slates.[1]

SECTION II.—ORIGIN OF THE ROCKS OF THE IRON-BEARING MEMBER.[2]

Knowing the exact facts as to the nature and method of occurrence of the iron-bearing rocks, we are now prepared to present some consistent account of their origin. In the general account of their macroscopic and microscopic characters it has been necessary to anticipate, to some extent, the origin of certain phases. To the degree that their genesis has thus been anticipated it is not in the nature of theory, but fact; because the stages of their development to this degree have actually been observed.

The facts developed in the foregoing part of this chapter all unmistakably point in the same direction, that is, that all these rocks at one time were cherty iron carbonates. There may be differences of opinion as to whether at some earlier stage they did not have another form; there may be differences of opinion as to the manner in which, from the cherty carbonates, some of the multitudinous phases have been produced; but the conclusion can not be escaped that these rocks, which still make up so large a proportion of the belt, were the original rocks of the member. It is extremely improbable that in a narrow belt of regularly stratified rocks, interstratified with other belts of sedimentary rocks, there should be deposited in patches here and there, large and small, at nearly all horizons, cherty iron carbonate, and a short distance east or west ferruginous cherts and actinolitic slates.

The question arises, whether the *cherty iron carbonates*, the least altered rocks now observable, have been derived from an earlier and different rock. They are apparently unaltered, and that they were originally deposited in the condition now found is probable enough from analogies presented by later geological times. The cherty iron stones from the Carboniferous, which occur so plentifully in our own country in Ohio and Pennsylvania, and so extensively in other countries, are like these thinly bedded carbonates, except that they are generally more argillaceous. Certain Ohio ores are so remarkably like

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[1] At the time the Wisconsin Geological Survey of this region was made, there had been no prospecting along the east end of the Wisconsin part of the range, and the exposures between the Potato and Montreal Rivers are very sparse; yet with these few exposures, with feeble magnetic attraction and with the assistance of topography, the Survey was able to locate so accurately the iron-bearing belt. that within it or very close to it are all the iron mines yet discovered on the Wisconsin side. (See Pl. XXVI, Atlas Geology of Wisconsin.)

[2] Section I of the original memoir was essentially complete when Professor Irving's sudden death occurred. From this point the junior author alone is responsible, although much of the substance of Section II is Professor Irving's work.

some of the iron carbonates of the Penokee-Gogebic Series that they can hardly be distinguished in hand specimen or thin section from one another. (Pl. XXXII, fig. 1.)

Another analogy presented by the formations of more recent times is seen in the cherty limestones which are so widely found at all horizons. It may be a question as to these limestones whether the chert was originally in nodules and layers, or scattered through the limestone as disseminated particles of silica; but it appears certain that in some cases the chert was originally deposited in the position where it is now found. As has been seen, such cherty limestones also occur in deposits of considerable thickness at the base of the Penokee series itself. In the cherty iron carbonates of the Penokee series calcium and magnesia are present as in the limestones, and we need only to replace a portion of these elements by iron to have rocks which are the exact analogue of the cherty limestones of contemporaneous and later times.

It is certain that a large portion of the silica now present in these rocks was there very early in their history. That part of the overlying slate belt just above the iron-bearing member, or more properly the transition belt between the two formations, in places contain numerous rounded fragments of a complex cherty quartz, or silica, which, in all probability, came from the immediately underlying belt. Again, there are several localities in which the rocks of the iron belt for short distances are semi-fragmental; that is, they are largely composed of rounded ferruginous cherty areas, which give every indication of a fragmental character. It is among the possibilities that these fragments when deposited were of another material, but this seems hardly probable. An extensive pseudomorphism implied by such a replacement by silica and iron oxide would almost certainly betray itself.

Further, in other regions in the Lake Superior country, notably at Gunflint Lake, in the Animikie series, a similar cherty carbonate is found in extensive beds. That the chert was here present at a very early day can not be doubted. The cherty bands, where there is no folding, are evenly interlaminated with the carbonates, but in folded areas the brittle cherts have been fractured in every direction, so that the rock, instead of being a regularly laminated one, is a breccia, which contains angular fragments of chert of greatly varying sizes. Such a brecciated rock frequently runs into the regularly laminated kinds in the space of a few inches. It is then certain that the chert of these beds was present before the folding of the rocks. Further, there is no evidence that most of this chert was not deposited simultaneously or alternately with the iron carbonate. The relations of a portion of the chert and the iron carbonate are, however, such as to show either that some of the chert has entered by subsequent solution, or that the silica originally deposited with the carbonate was subsequently, to a greater or less extent, rearranged. This is indicated by the facts that the silica is quite completely crystallized, and that the silica belts, instead of being laminated with the carbonate, at times break across it in the most irregular manner. This fissuring must have been subsequent to the deposition of the carbonate, and may imply the entrance of silica from an extraneous source, but also may mean no more than silica originally present has been taken into solution and recrystallized. In either case there is no proof that the greater part of the silica was not an original deposition.

It is assumed that such a cherty carbonate is water-deposited, as a direct eruptive origin has never been maintained for a rock of this character. Taking it for granted, then, that this cherty carbonate is a water-deposited sediment, the questions arise, in what manner the iron carbonate and silica got in solution, and how they were precipitated. In these ancient times we may, without varying too far from the law of uniformity, believe that the atmosphere was more highly charged with carbon dioxide than at present. We may also believe that the rocks composing the crust of the earth were at a somewhat higher temperature. An increase in heat of but a few degrees would be a powerful assistant in the process of solution of the iron, and this would be especially true if the atmosphere at this time was still richly charged with carbon dioxide. The atmospheric waters would absorb this acid, carry it into the rocks which bordered this ancient sea, would decompose them and take in solution ferrous carbonate. Such waters escaping into the shallow ocean at hand would bear the material for these irony deposits. While it is believed that these conditions may probably have been present, their assumption is not necessary to account for the solution of the iron; for it is well known that thick beds of iron ore have formed in recent times by virtue of the solubility of iron as a carbonate under ordinary conditions. It is also not impossible that its solution was greatly assisted by means of terrestrial life. That there was marine life at this time, as will be seen, we have strong evidence. Of terrestrial life we have no such proof, but it is highly probable that life existed on the land, and if so the organic acids would be a powful assistant in decomposing the rocks and taking iron carbonates into solution. The iron is a carbonate rather than a hydroxide, for the same reasons that the bedded carbonates of Carboniferous time are thus. It is usually taken for granted that in the Carboniferous deposits the presence of a large amount of organic matter explains the combination in which the iron occurs. Analyses of the carbonates of the Penokee series show conclusively that there still remains in these rocks quite a large percentage of organic matter. Also in the thinly bedded argillaceous slates above them the percentages of hydrocarbons are at times quite large. Some of the black slaty carbonates and black slates of the other iron-bearing series in the Northwest[1] remarkably resemble the black carbonaceous slates of the Carboniferous. That carbon in the form of graphite could be produced in other ways than by life may be conceded; but it will hardly be urged that the finely disseminated carbon and hydrocarbons in these slates is other than of organic origin.

Text books commonly regard chert contained in limestones as organic. More recently it has been maintained by a number of writers that this chert is a chemical sediment, which has entered the carbonates as a pseudomorph shortly after its deposition. The evidence that any of the chert is not of an organic origin is of a negative character; but, as has been said, at the time of the formation of these rocks it is not at all impossible that the crust of the earth had a higher temperature than at present. If so, we need not necessarily go to life to account for this silica. What a powerful assistance an increase of temperature is, in the solution of silica, is shown by the geyserite deposits so well described by Hague.[2] While it may thus be possible that a part of the silica is a direct chemical precipitate, it is certain that life alone is sufficient to collect from sea waters silica in solution. Dr. G. J. Hinde[3] has shown that extensive deposits of chert in Ireland, England, Wales, and Spitzenberg are largely, and possibly wholly, accumulations of sponge spicules. At Spitzbergen, Axel's Island, Yorkshire, and North Wales there are alternations of chert and limestone, the pure cherty layers of which are often quite a number of feet in thickness. The most remarkable occurrence is that of Spitzbergen and Axel's Island. The beds of cherty material here aggregate 870 feet in thickness. That the cherty layers of Wales and England are almost wholly, if not wholly, of organic origin seems to be conclusively shown. These cherts in Great Britain are carboniferous;

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[1] Whether the iron was originally precipitated as a carbonate, or was decomposed and precipitated as a hydrated sesquioxide, just as limonite now forms from iron carbonate in places where bog ore is depositing, is uncertain. If the latter is taken to be the case—and it is perhaps the more probable supposition—it is necessary to believe that the organic matter with which the limonite was associated reduced the latter to the protoxide, and by decomposition furnished the carbon dioxide to unite with this protoxide and thus reproduce iron carbonate.

[2] Trans. Am. Inst. Min. Eng., vol. 16, pp. 783–803, Arnold Hague. Geological History of the Yellowstone National Park.

[3] Annals Nat. Hist. 1880, pp. 384–395, 437–461. Prof. W. J. Sollas on the Flint Nodules of the Trimmingham Chalks. Geol. Mag., London. New series, decade III, vol. 4, pp. 435–446, George Jennings Hinde. On the Organic Origin of the Chert in the Carboniferous Limestone Series of Ireland, and its similarity to that in the corresponding strata in North Wales and Yorkshire. Ibid, vol. 5, pp. 241–251, Dr. Hinde, on the Chert and Silicious Schists of the Permo-Carboniferous Strata of Spitzbergen, and on the characters of the sponges therefrom, which have been described by Dr. E. von Dunikowski.

those of Spitzbergen and Axel's Island are Permian. It is of interest to note that these are the terranes in which the most extensive beds of iron carbonate in Paleozoic time are found. Further, the sponge remains pass into a "pure translucent chert." If, as Dr. Hinde maintains, all this silica is derived from sponge spicules, it must now in some cases be extensively rearranged; for a large part of the chert appears from the descriptions to be cherty or chalcedonic silica, in forms independent of organic remains. In the Penokee cherts, no evidence of organic origin for any of them has been found. This fact does not seem, however, to be any proof that the chert was not originally deposited in the form of sponge spicules. For if the silica in deposits so late as the Cretaceous have been so extensively rearranged as has that in the Trimmingham Chalks it would not be strange if similar deposits, so far back in geologic times as the Penokee series, have lost the evidence of organic origin. The thickness of chert in the iron-bearing belt, supposing it to be as rich in silica as are the upper horizons, could not have been beyond three or four hundred feet. It appears clear that there are original formations of chert which have more than twice this thickness. Our conclusion is then: First, that the chert was mainly deposited simultaneously with the iron carbonate with which it was so closely associated; and, second, that it is probable that the chert is of organic origin, although we have no positive proof that it is not an original chemical sediment, while it may in part be from both sources.

The descriptions of the first phase of the second type of rock—*the ferruginous slates*—have so fully indicated their origin that but little more need be said. Into the genesis of this phase little or no theory enters, as all the stages of its growth have been seen. The only conclusion which goes beyond the observed facts is the comparatively safe one as to the nature of those exposures which can not be directly traced into the cherty carbonates. The stratification of these slates is precisely like that of the original rock. The mineral composition of the two rocks is the same, except that iron oxide in the ferruginous slate takes the place of siderite. The change from siderite to the various iron oxides of the slate has been repeatedly noted in all its phases in thin section, and is everywhere found in the slides when in the field the change from the cherty carbonate to the ferruginous slate could be traced. The background of the slates is at times more coarsely crystalline than in the cherty carbonates; also, the rocks are cut by veinlets of silica to a greater extent. The quantity contained is not materially greater than in the unaltered cherty carbonates, and it seems a sufficient explanation of its variation in character to suppose that it is mostly due to a rearrangement; that is, the silica has been taken into solution, to some extent, and subsequently crystallized (other silica perhaps at the same time *being added), thus becoming more perfectly quartzose, and forming* the veins which cut across the laminæ of the rocks. The chemical change implied in the above transformation are stated below.

In explaining the genesis of the second phase of the second type of rocks, *the ferruginous cherts,* it is necessary to account for their concretionary and brecciated character; for the production of brown hydrated hematite, red hematite and magnetite; for the concentration of the iron oxide in shots and bands; for the large quantity of silica which they contain; for the somewhat coarsely crystalline character of the chert as compared with that of the original carbonates; and for the presence of numerous ramifying veins of finely crystalline quartz.

In the microscopic description of this phase of rocks, pp. 385-389, the concretionary and brecciated character has already been accounted for. These peculiar areas have been actually observed in all stages of their formation, so that their history is not theory, but definitely observed fact, and will not be repeated here. The oxides of iron have been produced from the iron carbonate, just as are the oxides of the first phase of rock, the only difference being that here occasionally magnetite is formed. This mineral, however, is readily accounted for by the decomposition of iron carbonate under conditions not favorable to complete oxidation. It is not to be supposed that these rocks were highly heated, but it may be remarked that a low degree of heat is sufficient to change iron carbonate into magnetic oxide of iron, with the liberation of carbon monoxide and dioxide. Percolating waters, bearing oxygen in solution, have decomposed a part of the iron carbonate, the carbon dioxide passing into the water, and oxygen passing from the water into the rock, thus simultaneously forming sesquioxide of iron and solutions capable of taking up other iron carbonate. Such iron-bearing waters would, after a time, reach some crack or channel in the rock. This opening in many cases would serve as a passage for other waters more directly from the surface bearing oxygen in solution, and, as a result of this mingling, the iron in solution would be precipitated, and thus concentrations of the iron oxide in bands and shots would occur. This explanation is not a wholly suppositive one, but accords with the facts of observation as seen in numerous exposures.

The concentration of silica in these cherts is partly explained by the abstraction of iron carbonate taken into solution. This chert is rarely pure, and frequently contains a large amount of iron oxide; and this is what would be expected from the character of the processes above indicated, yet the silica is much more abundant in the ferruginous cherts than in the unaltered carbonates. It is to be remembered that most of these cherts are at low horizons, and it is probable that they have, to a considerable extent, been silicified. The proof of this silicification lies both in the abundance of the silica itself and in the manner of its occurrence. The greater part of it is relatively perfectly crystalline as compared with the chert of the carbonates. The cavities which the rock frequently contains are lined with quartz crystals. Numerous veins of quartz cut through the rock in every direction. The concretions which, as explained pp. 386–388, are areas which were originally carbonate of iron, but are now largely composed of silica. Many of them have been severed by veinlets of silica. All these facts imply an extensive rearrangement of the silica originally present, and the introduction of additional silica.

In a subsequent consideration of the origin of the ore deposits it will be seen that it is probable that the silica for this silicification was derived from original cherty carbonates which have been swept away by erosion. If this is the case, a portion of the silica within the ferruginous cherts must have been carried some distance. The ferruginous cherts are cut, as shown by mining operations, by numerous dikes, which are much decomposed and are certainly more basic than they were originally. This alteration of the dikes may also have furnished a portion of the silica. The nature of the solutions which dissolve silica in rocks and deposit it in other places is more or less a matter of conjecture; but that silica is largely thus carried is conclusively shown by the quartzites of this and numerous other regions.[1] The quantity of silica required to fill the interspaces of a thick bed of loose sandstone is very considerable; yet it is absolutely certain that such cementation has occurred again and again. Silica in silicates, in the amorphous form and even in a quartzose condition is soluble in alkalies, although with great difficulty in the latter case. Prof. Sollas, in a paper already alluded to,[2] has drawn a sharp distinction between organic and mineral silica, the first being easily soluble, while the latter is relatively insoluble. Probably most of the silica, even in the cherty carbonates, would fall in his class of mineral silica, but a part of it is amorphous, and a portion of it certainly is quite readily soluble, as shown by actual laboratory tests with caustic alkalies. In accounting for this increase in the quantity of silica, we have explained its relatively coarsely crystalline character and the presence of the veinlets; for in the silicification of the rock as explained, these are the phenomena which we would expect to find.

It is probable that the peroxidation of a portion, the removal of another portion of iron carbonate, and the deposition of silica have, to some extent, been simultaneous, but it seems to be the case that they have in general been in part successive, that is, the first two

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[1] Bull. U. S. Geol. Survey, No. 8, R. D. Irving and C. R. Van Hise, On Secondary Enlargement of Mineral Fragments in Certain Rocks.

[2] Annals Nat. Hist., 1880, pp. 384–395, 437–461. Prof. W. J. Sollas, On the Flint Nodules of the Trimmingham Chalks.

processes began before the third and were completed before it ended. The arrangements of the iron oxide and quartz in rough layers in the rock and in concentric belts in the cavities go to show this. The cavities generally have as an exterior lining an iron oxide. This is formed at the stage in which the iron carbonate was partly decomposed and partly removed. Later the solutions passing through the rocks have begun to carry silica, and finally the silicification has been the chief reaction; as a result of which the layers of quartz crystals within the cavities and veins in the cracks have formed, oftentimes entirely filling them. In producing the many peculiar phases and mixtures of chert and iron oxides the conditions must have varied in different places. With the stages of growth of one particular form, the concretions, we are familiar. In them the series of operation seem to have been exactly as described above.

The field relations of the *actinolitic slates* are such as to show that they, like the ferruginous cherts, are almost certainly derived from iron carbonates. There is not here the intimate association between these two types of rock that there is between the cherty carbonates and ferruginous cherts. The latter are for many miles directly overlain by the carbonates. Within their mass they contain large exposures of this rock, so that between the two, both in exposure and in thin section, we have transitions showing all the intermediate phases. The ferruginous cherts and iron carbonates, which occupy the central portion of the iron formation, grade into the actinolitic slates to the east and west. This transition is slow, occupying in each case several miles of distance; but above the actinolitic slates no carbonate is found, also within the belt itself there are no bodies of this material. So that the only proof of the derivation of this rock from the cherts and carbonates lies in the facts that the two classes of rock occupy the same horizon, and in the passage from one to the other there are transition phases.

The actinolitic slates are not so different from the ferruginous cherts in their essential properties as might at first be thought. In mineral constitution the two types of rock are the same, except that in the actinolitic slates the additional mineral actinolite is present and magnetite more plentiful. In the peculiar arrangement of the iron oxide and silica the ferruginous cherts and actinolite slates are often identical, the regular laminæ of iron ore and silica, the concretions, and the breaking of these concretions and laminæ by veinlets of silica, all occurring in both classes of rocks (Pl. XXXIII, fig. 2; Pl. XXXIV, fig. 1). The two types of rock are also alike, in that they both contain at times residual iron carbonate. It is true that the amount of siderite is not so great in the actinolitic slates as in the ferruginous cherts. A further likeness between the two rocks lies in the occasional pseudomorphous aggregates of actinolite and magnetite after iron carbonate. The only essential difference then between the two classes of rocks is the introduction of actinolite; the subordinate differences are the more completely crystalline character of the quartz and the abundance of magnetite. To account for the actinolite is comparatively easy. We have only to suppose that the silica-bearing waters, at the time of the rearrangement and silicification of these rocks, united with a portion of the protoxides of calcium, magnesium and iron, thus producing actinolite. As has been seen by the descriptions, the order of crystallization of the minerals in these slates are magnetite, actinolite and quartz. The condition which explains the large amount of magnetite also explains the production of the actinolite. In the ferruginous cherts it has been seen that the oxidation of the carbonate was mainly prior to the rearrangement and introduction of silica; so in the actinolitic slates, the first step in the process of alteration from the cherty carbonates was the production of magnetite by the decomposition of siderite. That this resultant oxide is largely magnetite is proof of an insufficient amount of oxidizing agent. When the rearrangement and subsequent introduction of silica occurred, a portion of it simply united with the protoxide bases present and thus formed actinolite. An abundance of protoxide of iron was here, perhaps as carbonate, and certainly in the magnetite.

In this connection the relations of the actinolite and magnetite are of great significance. The actinolite frequently surrounds the magnetite areas, less often penetrates them, and is usually, although not always, associated with them. In the final stage in the process of the formation of this rock the most of the silica separated as a quartz, but apparently actinolite continued to form to the very last, as it is almost everywhere included within the quartz. To explain the difference between these rocks and the ferruginous cherts we need then only to suppose one different condition—the absence of a sufficient amount of oxygen at the time of their alteration to change all of the iron to the peroxide. The details by which the particular phases of the actinolitic slates have been produced can not be satisfactorily given, for in so few of them is there any remaining iron carbonate. However, taken in connection with their position and intermediate links, there can be little question of their derivation from a cherty iron carbonate. If there is any doubt upon this point, it is set at rest by considering the occurrences in the Animikie series in northeastern Minnesota. That these two iron-bearing series are stratigraphically equivalent can hardly be doubted. It will be seen that in the Animikie series all the transition phases between cherty iron carbonates and the most crystalline actinolitic slates are as perfectly illustrated as are the intermediate phases between the cherty iron carbonates and the ferruginous cherts in the Penokee series.

The origin of these actinolitic slates is analogous to that of the tremolitic limestones so widely present in the iron-bearing series of the Northwest and in later geologic times. Tremolite is calcium-magnesium silicate; *actinolite is calcium-magesium-iron silicate.* The tremolitic limestones are, aside from the tremolite, mostly composed of cacium-magnesium carbonate. The original material from which the actinolitic slates were derived is a silicious iron carbonate bearing calcium and magnesium. In this case the silica had but to unite with these bases to produce the actinolite; like solutions in the limestones had only to unite with the bases there present to produce tremolite.

SECTION III.—THE ANIMIKIE IRON-BEARING SERIES.

Before leaving this part of the subject, it is necessary to make some allusion to like formations in other parts of the Lake Superior country. The Animikie and Vermilion Lake series of northeastern Minnesota and Canada, the Marquette and Felch Mountain series of Michigan, and the Menominee series of Michigan and Wisconsin, all contain large developments of rocks which, in their characters are almost exact reproductions of the iron-formation rocks in the Penokee series. In each of the regions mentioned all the types and most of the varieties described in the latter series are quite widely found. Cherty iron carbonate is not extensively known in some of them, but in one is more largely developed than in the Penokee series itself, while in the most folded and altered series of the number this rock typically occurs (Pl. XXX, fig. 1). A general condensed account[1] of the iron formations of these various regions, including the iron-bearing rocks of the Penokee series, has been published by the senior author. While a continued study has made some modifications of detail necessary, the main conclusion of the paper has been but rendered more certain; i. e., that the many phases of peculiar rocks associated with the iron ores in these various regions have been derived from a clayey or cherty iron carbonate. In the paper referred to, an exception was taken in the case of some of the coarser grained actinolitic slates which are found in the Marquette country, "as to whose relations to the other ferruginous materials we feel now unwilling to speak." Later investigations make it not improbable that some of these rocks have been derived from eruptives; but the origin of this class of rocks has not yet been certainly determined. Nothing will be here added to what was said as to the character of the ferruginous rocks of the Marquette, Menominee, and Vermilion Lake regions. While some additional work has been done upon them, it has not gone far enough to warrant a more detailed account. However, the Animikie series, in the rocks of the iron formation and its simple, unfolded condition, is so remarkably

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[1] Am. Jour. Sci., 3d series, vol. 32, pp. 255-272. On the Origin of the Ferruginous Schists and Iron Ores of the Lake Superior Region; R. D. Irving.

like the iron-bearing belt of the Penokee series, that additional material has been obtained and a careful study made of them in order to compare their character and origin with those of the latter series.

The following general description of that part of the of Animikie series, which contains in its best development the iron formation, is by Prof. Irving[1]:

> The Animikie rocks are exposed in four distinct areas, one of which is separated from the others by an overlap of the great gabbro, which forms the base of the Keweenaw series. The others are separated from one another, so far as known, by drift covering only. The first of these areas is that which, with its principal development in Canada, along the shores of Thunder Bay, crosses into the United States in northeastern Minnesota, the national boundary line being within this formation from the outlet of Gunflint Lake eastward to the eastern extremity of Pigeon Point. Around Thunder Bay the rocks of this series, which are chiefly black slates, greywackes, argillaceous quartzites, interstratified diabase, and gabbro layers, which are many in number and individually often have a considerable thickness, are exposed on a large scale. Immense dikes of gabbro and diabase also penetrate these layers, the gabbro dikes, which are at times several hundred feet in thickness, being noticeably much closer in character to the great gabbro at the base of the Keweenaw series than to those gabbros which are interleaved with the Animikie slates.
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> In the vicinity of Thunder Bay the Animikie rocks are often nearly horizontal, but show a general tendency toward a southeastward inclination. As the formation crosses into United States territory it shows more marked inclinations, which average probably about 10 degrees, though at times less than this, and sometimes reaches as much as 20 degrees. The national boundary line is situated within this formation from the mouth of Pigeon River to Gunflint Lake (see Pl. XLII), but on the north side of the latter lake, and again to the north of the next lake to the east, called North Lake, the unconformable abutment of the Animikie series against an older formation of granite and schists is very handsomely shown. The actual contact of the two formations is not seen, but the exposures approach to within a few feet of each other, and the relative attitudes of the two formations are such as to leave no question whatever with regard to the unconformity. Not only is this shown by the vertical position of the schists as contrasted with the flat inclinations of the slaty series, but also by the way in which the latter beds, to the north of the two lakes mentioned, fit into the sinuosities of outline of the older formations. The entire contrast as to lithological characters between the two set of rocks furnishes further proof. So far as it is developed along the national boundary line the lowest layers of the Animikie series in sight are those on Gunflint Lake. The highest layers are those in the vicinity of Grand Portage Bay, the whole succession between these points being some thousands of feet in thickness. The iron-bearing horizon at the base of this succession is lithologically identical with that of the Penokee series of northern Wisconsin and Michigan, while the black slates, greywackes, etc., which succeed the iron-bearing horizon, are in turn the counterparts of those which form the middle and upper portions of the Penokee series. The interstratified gabbros of the Animikie are wanting, however, or are relatively rare in the Penokee region.

The iron formation of the above described area of the Animikie series contains all the phases found in the Penokee region, with the exception that no extensive ore-deposits have been developed.

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[1] U. S. Geol. Survey, 7th Annual Report, pp. 420, 422. On the Classification of the early Cambrian and pre-Cambrian Formations; by R. D. Irving.

There is further a much more intimate association of the less altered and most crystalline forms than in the Penokee series. The relations of the original cherty carbonate with the various phases of the actinolitic slates are as intimate as are the relations of the unaltered rocks with the ferruginous cherts in the Penokee series.

The *cherty iron carbonates* (Pl. XXX, fig. 2 and Pl. XXXI, fig. 1) are extensively exposed in various localities. They are known as far east as Lake Superior, on the ridge which is just back of Port Arthur. They are also largely found at the Kaministiquia River; but the largest and most characteristic exposures are at Gunflint Lake, T. 65 N., R. 2 and 3 W., Minnesota. At times these rocks are very nearly pure carbonate, which contain from 35 to 45 per cent of metallic iron. These beds are, however, not usually of any considerable thickness. They alternate with layers which contain a large percentage of calcium and magnesium carbonates, and with belts of chert of greater or less purity. Sometimes the transition from the thick bands of carbonate to those of chert is abrupt; at other times the carbonate layers contain thin seams of chert finely interlaminated with them. Not unfrequently the chert is in nodular forms, or a layer of chert which has been continuous for some distance has a somewhat abrupt oval termination (Pl. XXXI, fig. 2). The carbonate areas may contain here and there minute particles of cherty material, just as the cherty areas contain rhombohedra of siderite (Pl. XXXI, fig. 1). In fact, there is every possible gradation between bands of almost pure carbonate and others of almost pure chert. Upon the weathered surface these rocks show, in a marked degree, the peculiar weathering shown by cherty limestones. Because of the resistant character of the chert the carbonates are more rapidly dissolved, and thus leave the silicious bands in ridges protruding from the face of the rock, varying in width from those not more than a hair's breadth to those several inches across.

That this material is of the same origin as the rock which has been regarded as an orignal one in the Penokee series is manifest. The rocks of the two regions are so remarkably alike that if the specimens from them were mingled many of them could not be separated by difference in appearance. Upon the whole, some phases approach more nearly to certain of the Ohio carbonates (Pl. XXXII, fig. 1) and those near Old Livingston Manor House, Hudson River, New York, than do most of the Penokee carbonates. That the silica now present in these rocks was there at a very early date is shown by the remarkable brecciation which they exhibit where folded. In general the series is a quite uniformly flat-lying one, but the exposures upon the north side of the main body of Gunflint Lake exhibit in places somewhat sharp bowing. The layers, where cherty, have not uniformly yielded to this bowing, but have been shattered as would a rigid, brittle, inelastic body, and thus conform themselves by a succession of fractures to the general bowing taken by the strata. As a result of this peculiar feature, the chert and carbonate are in places as finely and uniformly laminated as can be found in any sedimentary formations, and in other places they suddenly change to a rough breccia along a line of fracture. These breccias alone might be taken to be water-deposited fragmental rocks, but, as examined in exposure, their positions at the point of abrupt variation in the bedding of the rock shows that they resulted from the folding. The contained fragments are exceedingly angular, as would be expected, and give no indication of having undergone any considerable change since the folding, except that their inter-spaces are cemented with chert and iron carbonate which must have subsequently infiltrated.

When these rocks are examined in thin section the relations of the chert and carbonate are seen to be exactly like those described in the Penokee series. As a general rule there is a regularity of interlamination of the two, but quite frequently also the cherty layers break across the belts of carbonate in such a manner as to imply an introduction of silica subsequent to the carbonate layers. This introduction may imply merely a rearrangement of the silica which was orignally deposited in the rocks, as explained with reference to the Penokee series; but it may also imply an actual introduction of silica from an extraneous source, that is, a secondary silicification. The siderite is often well crystallized in perfect rhombohedra or oval forms (Pl. XXX, fig. 2 and Pl. XXXI, fig. 1.) These rhombohedra often average larger than in the corresponding rocks of the Penokee region, and, as in them, they are occasionally argillaceous. The chert also varies greatly in the coarseness of its grains, running from almost completely amorphous to almost completely crystallized. The wholly amorphous condition is, however, unusual.

The *ferruginous slates* are always found associated with the unaltered cherty carbonates. They are not known to be so extensively developed as in the Penokee region. In microscopic character they differ from them only in that magnetite is relatively more abundant. Their derivation from the iron carbonates is seen in all its phases. A description of these stages of gradation would but be a repetition of what has been said as to similar rocks in the Penokee series and so will not here be given.

The *ferruginous cherts* are abundant (Pl. XXXIII, fig. 1). They comprise all the phases described in the Penokee series, and exhibit as finely their origin and also the character of the brecciation which sometimes accompanies these concretionary forms. The chief difference between the Animikie ferruginous cherts and those of the Penokee region, is the relatively greater abundance of magnetite. To describe the ordinary concretionary and brecciated forms would be a repetition of what has already been given as applying to rocks in the Penokee series, so that here all that will be said is in reference to the occurrence of the magnetite. It has been noted that magnetite is occasionally pseudomorphous after siderite in the Penokee series. This is often the case in the Animikie series. This formation of magnetite from iron carbonate, as exhibited in many sections in all its phases, is illustrated in Pl. XXXI, fig. 1, which shows on one side of the figure oval and rhombohedral areas of nearly pure siderite, and in the middle of the section similar areas which have completely altered to magnetite. In the intermediate parts of the figure is a transition zone. In this section the magnetite has taken its forms from the siderite, but it is more often the case that its crystal forms are independent of the original areas of carbonate. In sections in which both siderite and magnetite are abundantly found, the magnetite is ordinarily scattered through the section, disconnected with, adjacent to, and included in the exterior parts, or even quite to the centers of the siderite areas. The relations are such as to show that the magnetite is in the process of formation from the siderite, but the crystals of the oxide thus included generally have their own octahedral form, and their outlines consequently bear no relations to those of the carbonate from which they are derived. Magnetite and hematite in these sections are most closely associated. Generally areas are made up of an intimate mingling of the two. In very thin sections, in transmitted light, the blood red hematite can be seen as spots here and there through the magnetite areas (Pl. XXXIII, fig. 1), or, if the hematite predominates, the reverse is the case. In some cases, however, the relation between these two minerals is somewhat peculiar. The magnetite is found as cores in the hematite areas. In this case it is possible either that magnetite was originally formed from the iron carbonate, and that it has subsequently peroxidized upon its exterior and thus formed hematite; or, that at first the conditions were favorable for the production of magnetite, and subsequently changed so as to produce hematite.

The most important addition to our knowledge of the origin of iron-formation rocks given by the Animikie series is from the *actinolitic slates* (Pl. XXXI, fig. 2; Pl. XXXIV, fig. 2 and Pl. XXXV, fig. 1). It has been seen that in the Penokee series the transition phases were somewhat sparingly present. This is not the case in the Animikie. The many phases of unaltered carbonate, ferruginous slate, and ferruginous chert contain actinolite and magnetite. Different sections exhibit these two minerals in quantity from accessory to chief constituents. There are kinds which are mainly composed of actinolite and siderite, others which are mainly composed of actinolite and iron oxide, including magnetite, and still others which are composed of actinolite, iron oxides and chert; the latter including the most concretionary and brecciated forms.

The evidence that the actinolite slates have been formed from cherty iron carbonates is like that which proves the ferruginous cherts and the ferruginous slates are of this origin.

It has already been shown that the magnetite is largely a secondary product of siderite, being very frequently pseudomorphous after it. Also, when not thus pseudomorphous, its relations are often such to the siderite as to show that it is secondary to it. The relations of magnetite and the other oxides of iron in the concretions have already been given. The growth of these concretions has been traced out step by step precisely as in those in the Penokee series; so that there is no doubt that the magnetite in them is secondary to the siderite. It then follows that the proportion of this mineral which is derived from siderite is so great that it is exceedingly probable that it is of secondary origin, even in those cases in which this can not be demonstrated.

The secondary character of the actinolite can not always be clearly shown, but the cases in which its origin can be made out are so numerous, that the conclusion is reached that all of it is of the same nature. That the silica in the actinolite slates has been extensively rearranged and more coarsely crystallized, with the probable addition of silica to that which the original rock contained, can not be doubted. The way in which the silica cuts the other minerals is nicely illustrated by Pl. XXXV, fig. 1. The actinolite constantly cuts the quartz. The association of the actinolite with the magnetite and siderite, that is, with minerals which contain protoxide of iron, is characteristic. The actinolite began to form at the time of the entrance and rearrangement of the silica, the magnetite and siderite furnishing the necessary bases and the silica furnishing the acid for its formation. The reactionary nature of this actinolite is illustrated by Pl. XXXI, fig. 2, where the actinolite constitutes an almost solid band between a cherty nodule composed mostly of silica and the finely laminated slate which largely contains siderite and magnetite. Also actinolite and magnetite occur together in well formed concretions. Frequently in the concretions a ring of magnetite is surrounded upon both sides by a border of actinolite. Again, in other places, when a magnetite ring is not quite complete, the actinolite border which follows the magnetite throughout the part of the concretion where it is present, completes the ring.

It has been suggested of the actinolitic slates in the Penokee series, that the conditions which explain the presence of the magnetite also explains the appearance of the actinolite. Yet it is not always true that actinolite is accompanied by magnetite; also magnetite may appear without the presence of actinolite. In some few of the sections actinolite and a calcium-magnesium-bearing siderite are the only two important constituents, silica, however, always being present, and the rock then becomes an actinolitic carbonate. It is here to be noted that this rock is an exact analogue of the tremolitic limestones. Silica entering in the case of the limestones, has united with the bases present to form tremolite; in a similar way the actinolite has formed in the ferriferous carbonate by the entrance of silica and its union with the bases.

It need hardly be said that the rocks of this formation are mainly nonfragmental. It is, however, the case that fragmental material is more widely mingled with the iron formation of the Animikie than of the Penokee series. Quite a good many thin sections contain a considerable amount of fragmental quartz, which exhibits itself in its true character, as usual at a glance, showing its rounded outlines and frequent enlargements. This occurrence then furnishes another illustration of the fundamental difference in the nature and ease of separation of fragmental and nonfragmental quartz when the rock has not suffered dynamic action.

The relations and order of crystallization of the minerals contained in the actinolitic slates and ferruginous cherts are then precisely the same as in the Penokee series. A cherty ferriferous carbonate was the original rock. From this the iron oxides have been in the main the first to form. Before their formation was complete, when actinolite is present, it has begun to develop and is included in the oxides and particularly in the magnetite to a small extent. Its growth is most pronounced at the beginning of the rearrangement and introduction of silica, as would be expected from its requiring this material to produce it. The average amount of silica is much greater than in the original cherty carbonates, and also more largely in the form of quartz. The final stage in the development of these rocks has been then a rearrangement of silica already present, and an addition of silica to a greater or less degree, at which time the most of the quartz crystallized. Cherty carbonate located elsewhere may have been the source whence the most of this silica was derived, as will be more apparent after the origin of the ores in the Penokee series is considered. Interbedded with the Animikie rocks are also heavy beds of diabase and gabbro, alteration of which may also have furnished silica for the silicification. The likeness of the Animikie and Penokee iron formations is further exhibited in a striking manner by the fact that in the most typical exposures of the Animikie series upon Gunflint Lake, are, in upper horizons, almost pure cherty carbonate; in intermediate horizons, ferruginous cherts and carbonates; and in the lower horizons, actinolite slates, jaspers and ferruginous and concretionary cherts, which, however, often contain siderite; i. e., the most altered kinds.

SECTION IV.—THE IRON ORES.[1]

The iron ores are all located, as far as known at present, in that part of the iron-bearing formation between Sec. 33, T. 45 N., R. 1 W., Wisconsin, and the east line of T. 47 N., R. 45 W., Michigan, a distance of about thirty miles. The greater number of the larger deposits are found in the central half of this area. Also most of the known deposits lie at the base, or very near the base of the Iron-Bearing Member; that is, they rest upon or close to the coarse grained fragmental quartzite, which constitutes the uppermost horizon of the quartz slates. The number of important mines is about twenty-three, and of these all have deposits upon the fragmental quartzite except five, and three of these, situated east of Sunday Lake, at the eastern extremity of the belt of mines, have exceptional characteristics which exclude them from the present discussion. It is true that three other mines have also deposits which are north of the fragmental quartzite; but in one case, that of the Colby mine (Pl. XXXVI, fig. 3), the two ore-bodies have been shown by developments to have such connections as to show that they are essentially a single deposit. It is not meant to imply that the numerous deposits resting upon the foot-wall quartzite have clean ore always in contact with it. Quite often there is a layer of what the miners denominate "paint rock," or a layer of sand rock between the quartzite and the ore. This latter material is sometimes as much as twenty feet in thickness, although it is usually not more than a few inches, or at most a few feet. Sometimes also there is, between the ore and the quartzite, a mass of greater or less thickness of the ferruginous chert or mixed ore of the miners; rarely a thin layer of nearly pure white chert is found between the ore and quartzite. Notwithstanding these exceptions, the south side of the ore never penetrates the quartzite and in a general way follows it, so that it may be spoken of as resting upon it. This quartzite, although subject to local variations, has an average dip to the north of sixty to seventy degrees, and thus furnishes an approximately regular wall, north of which the ore lies, and is consequently called the foot-wall by the miners. The few deposits north of the foot-wall quartzite are described by Mr. J. Parke Channing as also having tolerably regular south walls which dip with the formation and are known as foot-walls. Whether the ore deposits rest upon the fragmental quartzite or are north of it, they have usually as their southern boundaries a plane dipping to the north at an angle of sixty to seventy degrees.

Mining developments have shown that the Iron-Bearing Member is cut by numerous eruptives, the presence of which would not

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[1] The remainder of this chapter is nearly as published in advance in the Am. Jour. Sci., 3d series, vol. 37, pp. 32–48, by the junior author. For this section Professor Irving is in no way responsible.

have been suspected from natural exposures. These eruptives are described, pp. 436–438. They are much altered; many of them are so decomposed as to be soft, friable matter which can be picked to pieces with the fingers, and which now contain none of the original minerals which compose ordinary basic eruptives. They retain, however, distinctly their diabasic structure, and occasionally can be traced into comparatively unaltered phases which are true diorites. These altered greenstones are known to the miners either as soapstones or as diorite dikes. That they are dikes is manifest from their shape, and the way in which they cut across the layers of the Iron-Bearing Member, being traced at times into the foot wall quartzite. This dike-like character is well shown by Pl. XXXVI, figs. 3, 4, 5; Pl. XXXVII, figs. 3, 4, 5. The association of the ores and these soapstones was found to be so constant that Mr. J. Parke Channing, inspector of mines for Gogebic County, Michigan, was secured to work out the relation of the ore bodies and dike rocks. What follows as to the position of the dikes themselves, and as to the position of the ore bodies with reference to them, is wholly the result of data furnished by his investigations.

The position of the dikes is given with reference to the iron formation in which they occur. This formation has a northern dip and a general east and west strike. As used in reference to the dikes, an east and west direction means parallel with the iron formation, a north and south direction transverse to it. The important thing for the present purpose is not the absolute direction in which the dikes run, but their relations to the containing formations. The dikes vary a good deal in their dip and strike in different mines, and the same dike at times in the same mine also varies in dip and strike. However, certain of their elements are quite constant. The dikes always dip to the south, and generally the southern dip, or its component transverse to the formation, is from twenty to thirty degrees. The northern dip of the iron formation has been said to be from sixty to seventy degrees. *It follows from this, that if the stratified rocks were placed again in a horizontal position, the dikes would be vertical.* The true dip of the dikes is usually, however, not exactly transverse to the formation, but east of it; so that a component along the dikes, parallel to the strike of the rocks, has usually an eastern pitch (Pl. XXXVI, figs. 2, 4; Pl. XXXVII, fig. 1). This pitch may be as high as thirty-five degrees. From this amount it varies to horizontality, or even to a western pitch of ten degrees. The position of these dikes with reference to the foot wall quartzite will be better understood by Pls. XXXVI and XXXVII.

The thickness of the dikes varies greatly, running from those of but a few inches in thickness, to those nearly ninety feet thick (Pl. XXXVI, fig. 3). In most of the mines in which the ore deposits are of any magnitude the dikes are six feet or more in thickness;

while it is noticeable that the three largest mines have dikes of considerable thickness. At least one dike has been found in connection with every deposit west of Sunday Lake, with the single exception of the Ironton-Puritan ore body, and it is possible that when the workings of these mines penetrate deeper they will come in contact with a dike—one is known to come to the surface three or four hundred feet west. As to the three mines east of Sunday Lake, it has already been noted that their character is exceptional. From the eastern pitch of the dikes, it is evident that they must, if they continue in their observed directions, reach the surface to the west of the present workings of each of the mines. As these workings are but a few hundred feet deep, it follows that when these dips are high the dikes would reach the surface but a short distance from the ore deposits. It thus becomes probable that there are as many dikes in the lower horizon of the Iron-Bearing Member as are seen in all of the different mines, while doubtless there are many more. In some mines there are as many as three or four parallel dikes (Pl. XXXVI, figs. 4, 5). In some cases in which there are several dikes in a single mine, one is known as the main dike. The smaller ones are in certain instances clearly offshoots from the larger, the actual connections between them being traced.[1]

The ore has been spoken of as resting upon the fragmental quartzite as a foot wall, and in exceptional cases as resting upon a nonfragmental quartz-rock, which belongs in the Iron-Bearing Member, but which nevertheless forms a foot wall for the ore deposits, dipping north with the formation. From the description of the position of the dikes and the quartzites, it is evident that the two rocks form V-shaped troughs, which have at the apices right angles, and the south arms of which are nearer vertical than the north arms; the first being upon an average twenty to thirty degrees from a vertical, while the second is from twenty to thirty degrees from a horizontal position. The relation is that of a right angled trough tilted toward the north until it lacks twenty to thirty degrees from having its arms in horizontal and vertical positions. In one or two mines, for a short distance, these troughs do not incline either east or west, but at most of them, from what has gone before, it is evident they incline to the east. *The ore bodies lie in the apices of these troughs* (Pl. XXXVI, figs. 3, 5; Pl. XXXVII, figs. 3, 5). Each deposit of ore in following a trough will evidently be at different depths at different places east and west, depending upon the nearness of the dikes to the surface. All ore deposits in the position described would reach the surface if the underlying dikes dip to the east or to the west. As a matter of fact, many of them were found at

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[1] The foregoing illustrations represent the development of the mines mentioned at the time this section was written, and no facts have subsequently been developed which contradict the principles of occurrence as above explained.

the rock surface, but others were found after cutting an overlying rock. However, at present (October, 1888) mining developments have traced all deposits which are large enough to warrant working, with two exceptions, to the surface, and these exceptions are newly discovered deposits, which in all probability will be traced to the surface in the future. As would be expected, it is also true that the development of the deposits which were originally found at the surface have carried them, in every case in which they are of any magnitude, below the surface of the country rock. Both of these facts, the tracing of the ore deposits discovered at depth to the surface, and those discovered at surface beneath rock, are inevitable deductions from what has preceded.

The rocks which are found above the ore deposits are the ferruginous cherts—the rocks which have been spoken of as the characteristic ones near the base of the Iron-Bearing Member throughout the area in which the ores occur. The upper boundary of the deposits differs from the quartzite and dike boundaries, in that the change from ore to the cherty rock is a transition instead of an abrupt one. In passing upward through an ore deposit, as its border is reached, the ore becomes mixed with chert until so poor in iron as to become unsalable. In passing still farther upward, the amount of chert becomes greater, until a fractured chert and iron ore, known to the miners as "mixed ore," is found. In passing up still farther this mixed ore grades into the ordinary ferruginous chert of the lower horizons.

To summarize, then, the boundaries of the ore deposits are to the south, either fragmental quartzite or ferruginous quartz rock in the ore formation—generally the former; under the ore, the dike rocks; and above the ore, the typical ferruginous cherts of the region.[1]

The horizon above the ferruginous cherts is in most cases the red ferruginous slate. Above this slate, constituting the upper horizon of the ore formation, are often found cherty iron carbonates. While this section is known to occur at several of the more important mines, it can not certainly be said to be common to all of them. Also the respective thicknesses of the ill defined belts are very different at different mines. A general statement may be made, that at most of the mines a cross-section of the iron formation shows the proportion of unaltered iron carbonate to increase in passing from lower to higher horizons. It is true that almost solid carbonate occurs at three places at relatively low horizons, although none of them are known to be at the base of the member, while one is certainly underlain by a ferruginous chert. Also at several localities a typical chert is found at very high horizons.

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[1] Evident practical deductions for carrying on prospecting and mining follow from the foregoing, but in this paper the space is too limited to give them.

The iron ore is a soft, red, somewhat hydrated hematite. By chemical analyses it is shown to be more or less manganiferous, the manganese occasionally running to a high percentage. Much of it is so friable that it can be broken down with a pick, although as taken from the mines it is compact enough to hold together in tolerably large lumps. These lumps are porous, often more or less nodular, and also often roughly stratiform. The strata conform in a general way to the strike and dip of the formation. Adjacent to the dike rocks in a few mines, is a small quantity of aphanitic steel-blue hematite. The south deposits carry upon an average more manganese than the north deposits, the average in the South Iron King being above 10 per cent, while from the South Colby ore has been taken which contained as much as 30 per cent metallic manganese.

We have before us the character of the iron ores, the shape of the deposits, their relations to the rocks surrounding them, the nature of the rocks of the iron formation above the ore horizon, and the character of the formations above and below that bearing iron. An attempt will now be made to suggest an explanation of the genesis of the ore bodies.

The shape of the deposits and their relations to the strata of the iron formation are such as to exclude the idea of original sedimentation in place; neither can they be considered as the result of oxidation of iron carbonate in place alone. All of the unaltered iron carbonate now found contains a much larger quantity of silica than the ores, so much as to make them entirely valueless. Also the red banded slates found at the middle horizons give every evidence of being a material which has resulted from the oxidation of the bedded carbonate in place. Further, the large amount of manganese which the ores, especially the south deposits, contain is greater than that found in any carbonate from which analyses have been made; and the average content of manganese in the ore is much greater than the average of the carbonates. While it is thus true that the ores are not carbonates of iron which have altered in place, it is almost as certainly true that the iron carbonates of the belt have been the source whence the iron oxides for these ores have been derived.

Since, then, the iron ores can not be explained by oxidation of carbonate alone in place, and since the carbonate was the source whence they were derived, they are necessarily concentrations of iron oxide, combined perhaps with iron oxide furnished by oxidation of carbonate in place. If this explanation is adopted, however, it is not only necessary to explain the presence of the iron oxide in its peculiar position, but the nature of the whole lower part of the formation. The explanation must account for the great increase in the amount of silica in the lower horizon of the ore formation as compared with the original cherty carbonate; for its almost total absence in the ore;

for the concentration of the iron oxide; for the almost complete absence of carbonate of iron at the lower horizons; for the red banded slates and carbonates in the middle horizons; and for the relatively much more abundant unaltered carbonate in the upper horizons.

Before attempting to give a general explanation of these facts, it will first be well to refer to one of several occurrences of narrow belts of iron ore in natural exposure. At Sunday Lake outlet, in Sec. 13, T. 47 N., R. 46 W., Michigan, the actual transformation from cherty iron carbonate to iron ore is seen in all its phases. In clefts, joints and partings along the bedding of the exposure are narrow seams of hematite. In passing from the seams the hematite becomes mingled with some chert; going still farther, the chert increases in quantity until a background of silica contains many rhombohedra of iron oxide. The iron oxide then gradually passes into siderite. This siderite is in perfect rhombohedra, and it is evident, in thin section, that the iron oxide adjacent is pseudomorphous after it. (Pl. XXVIII, fig. 1.) The rock has now passed from an ore into a sideritic chert, which is of a light gray color, aphanitic texture, and breaks with conchoidal fracture. The latter rock is manifestly in its original condition. The processes by which the seams of iron oxide occupied the space once taken by sideritic chert are plain. The iron carbonate has decomposed in place to iron oxide, the rock becoming a hematitic chert. Along the seams, waters bearing iron in solution have passed. These waters have particle by particle dissolved out the chert and replaced it with iron oxide, and where once was lean sideritic chert is rich ore. A part of the iron oxide is due to the oxidation in place of iron carbonate, but the larger part has come from a greater or less distance there to be deposited. The seams of iron oxide at this point are but a few inches in thickness, but it is probable that the series of changes which have here taken place upon a small scale will upon a large scale explain the concentration of workable ore deposits.

It has been stated that the iron belt rocks are much less altered as a whole in the upper horizons, being there composed largely of unaltered cherty carbonate, while the lower horizons contain very little carbonate and are mostly composed of ferruginous chert and iron ore. It follows as a deduction from this succession that the series of changes which have so completely altered the lower horizons of the formation have occurred subsequently to the uplifting of the series. The alterations can be explained only by the action of percolating waters bearing oxygen, and which therefore came from above. If the layers were horizontal when the changes occurred, the waters passing downward would have altered most that part of the formation nearest the surface. The reverse would be the case if the alteration was subsequent to the tilting, for the upper layers of the member would partially escape the action of percolating waters, as will readily be seen by glancing at Pl. XXI, and taking into consideration the nature of the belt of the rock above the ore formation. It is a member composed of black and gray clay slates, greywacke and greywacke slates, all of which contain a large amount of clay, rocks particularly impervious to water. A rock underlying any great thickness of such a formation in a horizontal position could not be greatly affected by waters from above. However, when the series had been uplifted and eroded, this upper impervious member would have been removed, and the waters would come directly in contact with the lower horizons of the ore formation, while the upper horizons of the belt would still be somewhat protected.

Before going farther, it is necessary to consider the porosity of the rocks which underlie the ore formation. They have been said to be composed of quarzites and feldspathic quartz slates. Included in the latter are clay slates; consequently the rocks of this member are also almost impenetrable to percolating waters. The uppermost layer of the member, the quartzite, is not itself a perfect barrier to the passage of water, on account of the joints which are always found in such a brittle rock. These joints do not affect the underlying slates, for these thinly laminated, clayey rocks are so flexible that under the slight bowing which they have received they are scarcely fractured at all.

An attempt will now be made to trace the passage of percolating waters through the inclined layers of the iron formation. Plate XXXVII, fig. 6, is a section showing the condition of this member at the present time at the surface, and illustrating how this state of affairs was reached. The strata of the formation are now exposed by their dipping at a high angle, sixty-five degrees to the north. The whole Penokee series more than 13,000 feet thick in some places, of which the iron formation is a part, is exposed in the same fashion. Therefore thousands of feet of the iron member have certainly been carried away by erosion. The figure assumes that about 2,000 feet have been eroded from this member since it has been upturned. It would, however, make no difference with the argument if this erosion occurred during the time of the upturning. The upper part of the figure represents the surface of the iron formation and a part of the underlying and overlying rocks at some past time. Near the bottom of the figure is the present land surface, showing the succession of rocks from north to south which are now actually found. A transition from unaltered cherty carbonate to completely decomposed carbonate is noted. At the time when the upper supposed land surface was an actual one, the present surface would be but little exposed to the action of the percolating water. It could not pass through the slates which overlie the iron formation; neither could it get in through the underlying feldspathic quartz slates. Therefore most of the water which at that time was able to reach the present land surface must have done so by passing down, along and through the layers of the iron formation itself. The dotted broken line represents a perpendicular course which the water would follow were its passages not deflected by the laminated character of the rocks; but there would be a tendency for this water to follow the bedding, so that, entering the iron formation at its uppermost horizon, it would follow an irregular course marked by a broken line and would reach the foot-wall quartzite at the line of the present surface of the country. It is immaterial to the argument whether this line ought to vary farther from the perpendicular than marked or not; for, in any case, nearly the whole of the present surface of the iron formation would escape the percolating waters, or if not this surface, some other yet lower down. It is, however, probable that the lowest horizon would not thus escape until a great depth was reached; for the waters entering the formation would steadily work their way to a greater and greater depth along the foot wall, until such depth was reached as to prevent its further penetration.

Now, suppose erosion gradually to sweep away the rocks which are between the old surface of the country and the present surface. Beginning at the base of the formation, the rocks at the present surface would be more and more exposed to the action of percolating waters, which would in turn affect the middle, and finally the higher layers, until its whole width was subject to the agencies of alteration. There is, then, a gradual increase in the time that percolating waters have acted upon the various layers of the formation in passing from south to north. The difference in time to which the highest and lowest layers have been subjected to such action is at least the length of time that it has taken erosion to remove the thickness of rock between the old surface of the country and the present surface; therefore the slower the erosion is taken to have been, the greater the difference in time.

Next suppose that erosion had continued until the surface of the land is at some intermediate point. In tracing the percolating waters it is necessary to take into account the deflection to which they would be subjected by its layers and the impenetrable character of the underlying slates and intersecting dikes. The relative position of the ore bodies, quartzites and dikes has already been given. The water which fell upon the layers of the iron formation near its base would readily pass through the rock, it being here already much altered and broken by the long action of water. Passing through these ferruginous cherts, the water would quickly reach a dike or the fragmental quartzite, and would follow along this barrier, deflected to the north if upon the quartzite, and to the south if upon a dike, until it reached a trough made by the dike and quartzite, along which it would follow, traveling toward the east as it penetrated deeper. Such water would be likely to contain oxygen in solution, and would be capable, if it contained alkalies, which might be readily obtained from the alteration of the basic dikes, of taking up a small amount of silica. Other water falling upon higher layers would make its way slowly and with difficulty through these less altered parts, and would oxidize iron carbonate until all oxygen had been extracted from it. This oxidation of a part of the iron carbonate would liberate carbon dioxide, which would be taken into solution and added to the carbon dioxide which the water already contained.[1] Such water would take into solution unaltered iron carbonate. It would also in its upper course take up what silica it was able to carry. As it penetrated farther and took more carbon dioxide in solution, and consequently also more iron carbonate, it would be less able to carry silica, and would deposit that material as chert in the lower horizons. The water thus traveling on with an increasing amount of iron carbonate would finally reach a dike and be deflected toward the foot wall quartzite. It would follow this dike until the apex of the trough was reached; here it would mingle with a larger amount of water more directly from the surface bearing oxygen, and therefore capable of oxidizing the iron carbonate. The iron would then be precipitated in the apex of the trough as more or less hydrated sesquioxide of iron.

Upon the other hand, the silica would here be dissolved; for the carbon dioxide solution containing iron carbonate would be greatly diluted by the large amount of water which bore the precipitating agent for the iron, and the resultant abundant dilute solution of carbon dioxide, bearing perhaps alkalies with it, would be capable of taking up silica which was either originally present or had been subsequently deposited in the apex of the trough. Such solutions may have furnished the silica which has enlarged the particles of quartz in the foot wall and thus indurated it. The result of this leaching would be to steadily add iron oxide to and remove the silica from the apices of the trough formed by the quartzite and dike, and thus to form ore bodies. At the same time the other parts of the formation would be steadily impoverished in iron content. Much of that which remained disseminated through the formation would have been changed from carbonate to oxide. In its lower part, the silica which was taken into solution in the upper part of the water's course would be precipitated.[1]

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[1] In this discussion carbonated water is taken as the agent of solution. It is likely enough that organic acids have helped to take the iron carbonate in solution and bear it to the points of precipitation.

[1] The chemistry of the processes thus outlined assumes the following: That the oxygen of percolating waters is sufficient to oxidize iron carbonate not in solution and set carbon dioxide free; that the resultant carbonated waters are sufficient to take iron carbonate in solution; that if such waters bearing dissolved carbonates are mingled with other waters bearing oxygen, the iron carbonate or a portion of it

The processes thus outlined would penetrate to deeper parts of the formation as erosion steadily advanced until the present surface of the country is reached, and the ore bodies thus formed at depth are now found at surface. It follows that a large amount of iron found in the ore bodies was originally in rock which has been removed by erosion. So far as the deposits are at the surface, all of the iron oxide, except that which came from the oxidation of carbonate in place, must have come from such a source, while it is probable that a large part of the deposits located at considerable depths have been stored from rock which has been broken down and scattered far and wide. These are not so much concentrations of iron oxide which were originally deposited as a carbonate above them as from the layers which stretched to the southward, but which were subsequently by upturning placed over the ore bodies. Also the large proportion of silica now found near the surface, and particularly in the southern half of the belt, is probably much greater than was here originally present. The silica of these highly cherty rocks associated with the ores may represent a concentration from many hundreds, or even thousands, of feet of rock which have been swept away, just as the ore bodies are concentrations from the iron carbonates which these same rocks contained. A portion of the silica may have come from the alteration of the dike rocks contained in this removed material, but doubtless most of it came from the original cherty carbonate.

The exceptions to the facts assumed in the above discussion are as follows: At three places iron carbonate is found near the base of the formation. At the first of these localities the rock contains a considerable quantity of clayey material. At the second and third the rocks are exceedingly dense, finely laminated, and bear contortions, as shown in the exposures, without breaking the stratification. In all of these places, then, the original cherty iron carbonate had exceptional characteristics, which prevented ready penetration by water. The presence of an unaltered carbonate at these low horizons is, however, interesting upon two accounts. In the first place it greatly increases the probability that the whole base of the formation, which now contains so little carbonate, was once a cherty iron carbonate; secondly, one of these exposures shows how completely the presence of a little clay in a rock may prevent the action of percolating waters, even when the remainder of the belt is completely altered by such agencies.

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will be precipitated; that silica may be carried in percolating waters; that carbon dioxide is sufficient to precipitate silica from such solutions, and that a carbon dioxide solution strong enough to precipitate silica by dilution may be made so weak in carbon dioxide that it would be capable of taking silica into solution. All of these facts and principles of chemistry are so well known, that no discussion of them or reference to authorities is needed.

The only other exceptions of moment are the occurrence of iron ore at a higher horizon than the foot-wall quartzite, and the ore bodies east of Sunday Lake, which, so far as present developments go, are not known to be associated with dike rocks. It has been said that those ore bodies in the main part of the range which are north of the fragmental quartzite have a well defined cherty quartz foot wall of a regular character. In these cases, this quartz-rock has served as the plane which checked the waters in their downward passage before reaching the fragmental quartzite. Here the relation of the ore to the dikes, and its other characters, are the same as when the ore is found upon the fragmental quartzite. It is of interest to note that in one of the largest mines of the region, the Colby, as shown by Pl. XXXVI, fig. 3, the north and south deposits have as their basement the same great dike, the two ore bodies being separated merely by a gigantic horse of rock which served as the impervious layer to form the foot wall of the north deposit. The explanation given of the origin of the ore found upon the fragmental quartzite applies perfectly to these north deposits with the modifications above indicated. That there are layers of the iron-bearing formation which are not readily pervious, and therefore become basements along which the down-flowing waters passed, is not at all strange. It would be stranger if, in a thickness of water-deposited sediments of 800 feet, there were no layers which, at least for a short distance, were effectual barriers to the passage of percolating waters. The chemistry of the process of concentration of the ore deposits east of Sunday Lake, in all probability, is like that of the typical deposits of the range. Their concentration is apparently, however, more nearly analogous to the narrow seams of ore described in the early part of this section than to the typical deposits. The formation here apparently being cut by no impervious dikes, the waters have not been carried over to the quartzite, thus forming main channels of percolation, but the comparatively small ore bodies have developed here and there as favorable conditions for concentration occurred.[1]

The above explantion of the origin of the ore deposits accords well with the facts of their occurrence, and also with the idea that the iron formation deposits were originally an impure cherty carbonate of iron. It explains perfectly the peculiar position of the ore bodies with reference to the dikes and the foot wall quartzite; it explains their presence in a similar position in the few instances in which the deposits are north of the fragmental quartzite; it explains the flat, wedge shaped character of the ore deposit; it explains the nature of the ore, a soft somewhat hydrated hematite, bearing more or less of manganese; it explains the excess of manganese which the ore car-

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[1] As bearing upon the truthfulness of the above theory as a whole, it is an interesting fact that the practical miners, in prospecting, eagerly follow underground water channels, hoping that they will lead to ore deposits.

ries beyond the amount found in the unaltered carbonates, and its relatively greater abundance in the south deposit; it explains the presence of large quantities of unaltered carbonates in the upper horizons of the iron formation, the gradual lessening of this carbonate in passing to lower horizons, and its absence at the base of the formation; it explains the large percentage of silica contained in the greater part of the lower horizons and the low percentage at the apices of the troughs.

This explanation of the origin of the ores may throw some light upon the depth to which the ore bodies extend. The fact that all of them have been traced to the erosion surface is favorable, rather than otherwise, to their extending to a considerable depth. The ore bodies, at the depth now penetrated, must have formed almost wholly before the sweeping away of the rocks of the iron formation above them. They could, then, have received but little of the iron they contained since the end of the Glacial Epoch, for erosion was then terminated by the mantle of drift dropped over the region. The deposits, with some degree of probability, may be said to continue to a depth at which the agencies of concentration could effectively work. Whether this distance will be found to be measured in hunreds or thousands of feet, the data at present are too scant to indicate. While they may extend in unimpaired richness and magnitude to a depth as great as can be penetrated by workings, it is certain that they do not continue to an indefinite distance. There is also a possibility that the deposits may become poorer than at the surface at comparatively small depth; for it may be that percolating waters, since the termination of the Glacial Epoch, have been able to remove from the upper parts of the deposits a small percentage of silica. Such a removal, even to the extent of five per cent or less, would have an important influence upon the value of the deposits.

It is of interest to compare the conclusions reached to those of Emmons[1] as to the origin of the silver-lead deposits of Leadville, Colo. He finds that the ore did not form in preexisting cavities, but by a gradual replacement of the rock materials by substances brought in solutions; and also that these solutions did not come up from below, but have reached their "immediate locus" by passing downward through the rocks above. In his discussion upon ore deposits in general, he maintains that a like origin is much more common than has been believed. It will be seen that my conclusions as to the origin of the iron ore of the Penokee series, arrived at independently of Mr. Emmons's work, are in exact harmony with his general conclusions.

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[1] U. S. Geol. Survey; Monograph XII; Geology and Mining Industry of Leadville; Samuel Franklin Emmons, pp. 375-379. Trans. Am. Inst. Min. Eng., vol, 16, pp. 804-839. Structural Relations of Ore Deposits, S. F. Emmons.

Before closing this part of the subject some allusions must be made to the nature and origin of the iron ores which are found in other regions in the Lake Superior country. Large deposits of ore are found in rocks remarkably like those of the Penokee-Gogebic series, in the Vermilion Lake, Marquette and Menomonee regions. These ores are associated in almost every mine with a somewhat varying peculiar rock, universally known as soapstone. The connection between the ore and these soapstones is so constant that the appearance of this peculiar, greasy, altered material is considered as a very favorable indication in prospecting. It is true that the rock which miners denominate soapstone, in different localities has quite different appearances, and frequently schists are called soapstones, which have no essential likeness to the material with which the ore is found associated. These so-called soapstones, in the regions referred to, are at times peculiar green banded schists, at other times are compact strongly foliated sericite schists, and only occasionally do they retain the structure of an eruptive rock; but in the few cases of which we have definite knowledge, the manner in which the soapstones cut the adjacent rocks is that of dikes. This is particularly well shown at the large, open pits at the Jackson Mine, Negaunee, Mich., and at the Champion Mine, Champion, Mich. This same dike-like character of the peculiar schistose rock at one mine in the Vermilion Lake series is described and figured by Prof. Alexander Winchell.[1] Mr. James R. Thompson, mining engineer for the Iron Cliffs Mining Company, of Negaunee, Mich., also finds in quite a number of mines in the Marquette region that the soapstones have a dike-like character. With most of the soapstones of these regions the only evidence that they are of eruptive origin is their relations to the rocks which they intersect. They have not been shown in many cases, as in the Penokee-Gogebic region, to have the typical structure of eruptive diabases; but the transition phases between these much altered rocks and the comparatively unaltered massive eruptives have in some instances been found, and it is probable that many of them are altered eruptives. At any rate, the close association between the soapstones and the ores can hardly be accidental, and, taken in connection with what has been given in reference to the Penokee-Gogebic ores, it is very suggestive that they, in some way, and perhaps in a way similar to that in the Penokee-Gogebic region, have influenced the concentration of the iron in the ore bodies at the places found. To certainly determine the origin of all these "soapstones," and their stratigraphical and other relations to the ore bodies will require a detailed investigation. It would, however, be an interesting illustration of the uniformity of nature's processes if such future investigation should show that

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[1] Geol. and Nat. Hist. of Minn.; 15th Annual Report, pp. 24–25.

the iron ores in the other regions of the Lake Superior country have an origin like those of the Penokee-Gogebic series.

Summary of more important conclusions.—The Iron-Bearing Member is separated from the Quartz Slate Member below it and the Upper Slate Member above it because it is a nonfragmental, while they are fragmental sediments.

It consists of three main types of rock, (1) cherty iron carbonate, (2) ferruginous slates and cherts and (3) actinolitic and magnetitic slates.

The cherty iron carbonates represent the original co dition of the whole member, the other types having reached their present condition by a series of subsequent alterations.

In the change of cherty iron carbonate to ferruginous slates and cherts the siderite has been oxidized, and to some extent been taken into solution and been redeposited in other places. The silica originally present has been rearranged, and in many places additional silica has entered.

In the alteration of the cherty iron carbonate to actinolitic slates the oxidation of the protoxide of iron in the carbonate has not been complete, and thus magnetite has been formed. At the time of the rearrangement and introduction of silica a portion of it has united with the bases present and has formed actinolite.

The iron ores are found in the lower horizons of the Iron-Bearing Member, most of the deposits resting upon the upper quartzites of the quartz slate formation. Those deposits which are not at the base of the member have also somewhat regular foot walls, which dip to the north like the quartzite at an angle of sixty or seventy degrees, consisting of the ferruginous chert of the iron member itself. These foot walls form the southern boundary of the ore bodies.

The formations are cut at right angles by a series of dikes, which are in such a position that the same dike is generally at a greater depth as it is followed eastward, i. e., pitches to the east.

The ore bodies rest in the right angled troughs formed by the junction of the dike rocks and foot walls.

The iron carbonate is the source of the ore deposits.

The ores have not been chiefly produced by the oxidation of the carbonate in place, but by concentration from the lean carbonates of the formation.

The concentration has taken place during or subsequent to the uplifting of the series.

Percolating water was the active agent of concentration. It has taken the carbonate into solution, and in its passage downward has been deflected into the troughs by the impervious quartz slate formation and the dikes.

In the apices of these troughs other waters more directly from the surface, bearing oxygen, have precipitated the iron as an oxide.

CHAPTER VI.

BY C. R. VAN HISE.

THE UPPER SLATE MEMBER.

SECTION I.—DETAILS.

All the rocks of the Penokee series above the Iron-Bearing Member are placed together, although their thickness is for a distance of many miles several times as great as the three lower members of the series combined. Lithologically the great mass of the rocks are slates. Frequently the slate becomes somewhat massive and occasionally gets to be a quartzite. Also in certain localities it becomes quite schistose, but all these phases may be said to be exceptional. It is not meant to imply by the term "slate" that any of the rocks have a slaty cleavage. The direction of easiest parting and bedding always correspond, and none of the rocks possess the uniformity of composition and parting requisite for roofing slates. The formation is given the name "Upper Slate Member," which at once shows its stratigraphic position and lithological character, as well as distinguishes it from the Quartz Slate Member which is below the Iron-Bearing Member.

This Upper Slate is a belt of fragmental rocks, or rocks which were originally fragmental. It has the same basis for separation from the sediments of the Iron-Bearing Member that the fragmental Quartz Slate below it have. In general, the fragmental character of the thin sections of these rocks is recognizable at a glance, although, as will be later seen, certain portions of the belt have by subsequent alterations taken a crystalline character. These rocks both in hand specimen and thin section are separated with certainty and ease from those of the underlying Iron-Bearing Member; for they are fundamentally unlike them in texture and mineral content.

The change from the quartz slate to the Iron-Bearing Member has been shown to be abrupt, taking place usually without any transition belt. In a few localities in which the transition from the Iron-Bearing to the Upper Slate Member is exposed, the change is quite gradual. On the west side of the fault at Penokee Gap, at the foot of a northern slope of the large bluff belonging to the iron formation, is found a rock which is intermediate between the fragmental black slates and the nonfragmental actinolitic slates. Its location in either formation is somewhat arbitrary, but the line separating the two members is so placed as to put it in the upper slate formation. At several localities the basement rocks of the Upper Slate contain a considerable quantity of iron oxide, which at times is largely in the form of magnetite. At Black River, in T. 47 N., R. 45 W., Michigan, there is a continuous exposure 200 feet wide at the horizon in which the change from the Iron-Bearing to the Upper Slate Member occurs. At the southernmost point of this exposure, although it is essentially nonfragmental, a considerable quantity of fragmental material is contained. Also at the north side of the exposure nonfragmental is mingled with the preponderating fragmental material. It thus appears that the passage from one member to the other is not complete in a surface width of 200 feet, which here corresponds to a thickness of about 170 feet.

The westernmost exposure found in the Upper Slate is near the center of Sec. 18, T. 44 N., R. 3 W., Wisconsin, while the easternmost exposure is at Black River, Michigan, Sec. 12, T. 47 N., R. 46 W. Probably the rocks of the member extend somewhat beyond these points before being cut off by the Keweenaw rocks. While it is not certain just where the Upper Slate emerges from the Keweenaw eruptives at the west, it is certain that after appearing the belt rapidly widens until it attains a great breadth and thickness. A short distance east of Penokee Gap the surface width of the belt is about one and three-quarters miles, or nearly 9,240 feet. The dip is here about seventy degrees. This surface width therefore represents a thickness of 8,630 feet. At Tyler's Fork the width reaches its maximum, being almost two and one-half miles, more accurately about 12,800 feet. The dip at this locality is from seventy to eighty degrees—upon an average it may be taken as seventy-five degrees—and the surface width then represents an actual thickness of rock of 12,360 feet. From this point of maximum thickness the belt again steadily narrows, and at the West Branch of Black River the last exposure is found. A short distance east of here the belt has certainly disappeared, the Iron-Bearing Member coming in contact with the Keweenawan eruptives.

As the rocks of the Upper Slate, Iron-Bearing, Quartz Slate, and Cherty Limestone Members are entirely conformable, there is exposed throughout the whole extent of the rocks of the upper member the full thickness of all the lower members of the series. However, a very considerable portion of the area which should be occupied by the slates of the upper formation is taken by the Keweenaw series. It is not certain, even at Tyler's Fork where the maximum thickness of the formation is exposed, that its total thickness is really shown. If we have here the full thickness of this member, the surface extent of the upper formation rocks is about one-half of the area which they would cover had they not been removed by erosion before the beginning of Keweenaw time, for at Tyler's Fork the member gradually narrows both east and west until it disappears. The surface extent of this member may be roughly compared to a triangle, the area of which is one-half that of a rectangle of the same base and altitude which these rocks would extend over were they not cut off by the Keweenaw series. When it is considered that in all probability this upper member of the series once extended east and west as far as the lower members, the proportion of this formation that is removed must be concluded to be much greater than one-half.

If a topographic map of the Penokee region were available, it would show in a general way the boundaries of the Upper Slate Member. The ridge known as the Penokee Range has been described. It is always found within the Quartz Slate or Iron-Bearing Formations, or in the granite just to the southward. North of the iron formation the ground slopes rapidly in most places to a nearly level plain which ordinarly has a gentle slope to the northward, as is shown by the direction of the flow of the streams. The northern boundary of the Upper Slate is for much of the distance defined by the trap range, which constitutes the base of the Keweenaw series, and oftentimes in the form of a series of bold bluffs, which are a prominent topographic feature of the region. In general, then, the Upper Slate Member lies in a valley, bounded by the Penokee Range on the south and the trap range on the north. At many points on both of these ranges the valley may be seen. The tree tops are seen stretching as an almost level mass of forest for miles both east and west.

Within the belt the exposures are usually low and small. This results from the soft character of the slate. It is to be presumed that the judgment made up from the known exposures convey a somewhat erroneous impression with reference to the character of the member as a whole; that is, the rocks which have a certain amount of the more resistant massive greywacke or quartzite are more apt to be exposed than the softer slates. In the vicinity and a short distance west of Bad River the exposures are quite numerous; also a little way west of this locality, east of English Lake, there are again frequent exposures. This unusual number is probably due to the fact that the rock in large measure becomes a somewhat resistant mica-schist which is interstratified with quartzites and massive greywackes. East of this locality the exposures are not numerous until Tyler's Fork is reached. Here, while they are large, they are in a good measure due to the cutting action of the river. No bluffs and hills of slate are found such as occur west of Bad River. Numerous large exposures are in the south part of Sec. 12, T. 45 N., R. 1 E., Wisconsin, just south of a small lake. The slates and greywackes constitute the north slope of a steep bluff which rises rapidly from the water of the lake. The only remaining prominent exposure in the belt is that along the railroads in the west part of Sec. 28, T. 46 N., R. 2 E., Wisconsin. This is a prominent landmark, rising in a bluff of some size in the valley between the iron and the trap ranges.

It has already been said that the rocks of the member under consideration are distinctly clastic, or at least rocks which can be shown to have been once fragmental. While they are alike in this fundamental point, there is great variety in minor characteristics. The varieties may be grouped under the heads: (1) *Mica schists and mica slates;* (2) *Greywackes and greywacke slates;* (3) *Clay slates or phyllites;* (4) *Quartzites and conglomerates.* Each of these main types have various phases.

The distribution corresponds in a loose way to the classification given. At the west end of the member, the mica schist and mica slates are the only rocks found. At Bad River and vicinity, these rocks greatly predominate. In passing eastward micaceous greywackes and greywacke slates, chloritic greywackes and greywacke slates, and clay slates are each in turn the preponderating rocks. In the transition from one type of rock to the next one there are cross-sections in which two or more of these kinds may be found.

The only exposure of quartzite and conglomerate of any magnitude is in Sec. 11, T. 45 N., R. 1 W., Wisconsin. At this place the rocks of the copper series lie immediately to the northward, there being between the quartzites and greenstones an interval of but a few feet. The rocks are strongly feldspathic, and are notable only in showing nicely the alteration of fragmental feldspar to both muscovite and biotite, with a simultaneous development of quartz, which is thus inclosed in the feldspar and mingled with the other secondary products. The rather unusual alteration of feldspar to actinolite is also illustrated. This actinolite occurs in the enlargements of the quartz grains, but not in their cores, thus showing that it has formed subsequently to the deposition of the fragments of the rock.

The clay slates, or phyllites, are not numerous, being found in but a few localities in the eastern part of the Upper Slate Member. It is probable that these rocks make up a greater part of the upper member than would be inferred from the few exposures, for they are so soft that they would rarely outcrop even if widespread. Only those rocks are placed among the clay slates which are excessively fine grained, the particles that compose them being so minute as to make the determination of their mineral composition in part uncertain. A portion of most thin sections is sufficiently coarse grained to certainly show that they contain small fragmental particles of quartz and feldspar. It can also be seen that they contain much chlorite, kaolin, or sericite, finely crystalline quartz, and iron oxides. As the minerals thus known to be present are the same which ordinarily constitute clays, and as they are those which compose the greywackes and greywacke slates with which the clay slates are closely associated, there is little doubt that the greater number of these rocks are thus made up. In order to reenforce the microscopic determination of the minerals in these obscure slates, analyses of two of the magnetitic ones were made in the U. S. Geological Survey laboratory, by Mr. L. G. Eakins, with the result of confirming the microscopic observations.

The greywackes and greywacke slates (Pls. XXXVIII and XXXIX) cover much the largest territory of any class in the Upper Slate Member. The greywackes[1] have always as chief constituents fragmental quartz and feldspar. The strength of the rock is usually given by "silicious paste," although much of the cement is frequently in the form of quartz added to the rounded fragmental grains. There is frequently "argillaceous and calcareous," occasionally carbonaceous, material present as accessories. There is also found in all of these greywackes abundant chlorite or mica, or both. The mica is chiefly biotite, although muscovite or sericite, or both, are plentiful. In importance these minerals are secondary only to quartz and feldspar. The class of rocks, greywackes, and greywacke slates in this region has been divided into three phases: micaceous, micaceous and chloritic, and chloritic. These divisions have a geographical significance as well as a lithological one. All of the greywackes and greywacke slates in Michigan and Wisconsin west to the Potato River are chloritic; the Potato River rocks are mostly micaceous and chloritic, these two minerals being in about equal quantity; about half of the rocks in the vicinity of Tyler's Fork are both chloritic and micaceous; the remaining half, micaceous only; west of Tylers' Fork and vicinity the greywackes and greywacke slates are micaceous only. We have thus a series of greywackes which at the east end are wholly chloritic; in passing to the west, mica appears with the chlorite, becomes more and more plentiful, and ultimately entirely replaces the chlorite. The greywackes and greywacke slates are closely associated, both stratigraphically and lithologically, with the mica schists and mica slates.

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[1] The term "greywacke" is here used in a lithological sense, in accordance with the definition of the term given by Geikie, Text Book of Geology, 2d ed., p. 162: "A compact aggregate of rounded or subangular grains of quartz, feldspar, slate, or other minerals, or rocks, cemented by a paste which is usually silicious, but may be argillaceous, feldspathic, calcareous, or anthracitic. Gray, as its name denotes, is its prevailing color; but it passes into brown, brownish purple, and sometimes, where anthracite predominates, into black. The rock is distinguished from ordinary sandstone by its darker hue, its hardness, the variety of its component grains, and above all by the compact cement in which the grains are embedded."

The mica schists[1] and mica slates (Pl. XL) of the region have always as a chief constituent quartz, and usually this mineral is the most abundant of any. Feldspar, as in the greywackes, is almost always present, but its quantity is much less and in the typical slates and schists is almost wholly absent. Biotite, muscovite, sericite, and rarely chlorite, or two or more of these minerals are always plentifully found, the individuals generally being in well defined folia. The accessories present are the same as in the greywackes, ferrite, pyrite, some carbonate, and rarely carbonaceous matter. As biotite is usually the prevalent mica, the slates and schists have as a whole a darker color than the greywackes, ranging from very dark gray to black. The fundamental differences, however, which separate them from the greywackes is their crystalline appearance and absence of feldspar. Very many of them, when viewed under the microscope, unless closely examined, taken by themselves show no trace of a clastic origin; although the greater number upon closer examination are seen to have something of a fragmental character. The distinction made between mica schists and mica slates is based upon structure and coarseness of grain. Most of the coarser grained upper member, micaceous rocks, have a well developed schistose structure parallel to the bedding of the rock, a structure which could fairly be called foliated in some places. They never became very thinly foliated or contorted with a brilliant sheen upon the foliation surface, as do some of the most crystalline mica schists. A few exposures have a dark and light banded appearance, suggestive of a fine-grained gneiss, which in fact they are when feldspar is a chief constituent. The rocks called mica slates are generally finer grained than the schists; they cleave with a very smooth, slate-like parting parallel to the bedding. Many of them are of a black color, due to abundant dark biotite, particles of ferrite, and in some places to carbonaceous material. Like the greywackes and greywacke slates, the mica schists and mica-slates have been divided into three divisions: Those in which chlorite is the chief constituent, aside from the quartz and feldspar; those in which mica takes this place; and those in which both chlorite and mica are found. The first division is represented by but a single exposure. The chloritic and micaceous schists and slates are quite plentiful, but by far the greater number of the slates and schists are micaceous only. As with the greywackes and greywacke slates, their classification corresponds to a geographical distribution, and the distribution is of the same sort as that of the greywackes and greywacke slates. The two classes of rocks are also interlaminated with each other.

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[1] Although in one place chlorite is aside from the feldspar, the chief constituent, they will all be called mica schists and mica slates, to distinguish them from the greywackes and greywacke slates.

SECTION II.—ORIGIN OF THE UPPER SLATE ROCKS.[1]

From what has preceded it is evident that the association of the schists and slates with the greywackes and greywacke slates is of a most intimate nature, both as to composition and occurrence. It becomes, then, probable that the original condition of the greywackes and greywacke slates, and the mica schists and mica slates must, in the main, have been the same. As some of the greywackes are completely fragmental, others somewhat crystalline, others still more crystalline, thus grading into the crystalline mica schists and mica slates, we will begin with those which are nearest their original condition, and trace the processes step by step by which the original rock has been changed into a fully crystalline mica schist.

Before following out the series of changes which explains the metamorphosis of fragmental sediments to mica schists and mica slates, it is important to recall the chemical changes which occur in the alteration of orthoclase, microcline, and oligoclase to chlorite, muscovite and biotite. Lehmann, in his work "Entstehung der altkrystallinischen Schiefergesteine," demonstrates the formation of abundant secondary biotite and other minerals as accompanying metamorphosis by folding. His work does not state, however, exactly how the biotite developed. The average content of silica of the following minerals is taken from Dana's system of Mineralogy: Orthoclase and microcline, 65 per cent; oligoclase, 62 per cent; muscovite, 45 per cent; biotite, 40 per cent; chlorite, 25 to 30 per cent. Evidently where the alterations of orthoclase, microcline and oligoclase to muscovite, biotite and chlorite have taken place so extensively as in the rocks under discussion, it is not difficult to explain the presence of the silica which has enlarged the fragments of quartz, replaced those of feldspar, and separated as independent interstitial quartz. One of these alterations is stated by Tschermak[2] to occur as follows:

> Wenn man die dreifache Formel des Feldspathes $3(K_2O.Al_2O_3.6SiO_2)$ mit jener des daraus entstandenen Glimmers $K_2O.Al_2O_3.2SiO_2+2(H_2O.Al_2O_3.2SiO_2)$ vergleicht, so ergibt sich, dass von der ursprünglichen Menge $6SiO_2$ nur $2SiO_2$ in die neue Verbindung übergehen und $4SiO_2$ übrig bleiben.

In further speaking of the alteration of orthoclase to muscovite, Tschermak also observes:

> Der neu enstandene Muscovit ist öfters auch von Biotit (Magnesiaglimmer) begleitet.

For the iron of the biotite and chlorite in the rocks under consideration it is not difficult to account. Pyrite, marcasite and ferrite are quite widely present in these rocks as accessory constituents. Often the relations of the pyrite or marcasite and biotite (folia of

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[1] I insert here freely, without quotations, such part as can be used of an article by me on this subject, already published, 3d series Am. Jour. Sci. vol. 31, pp. 453–459.

[2] Lehrbuch der Mineralogie, Zweite Auflage, p. 462.

the latter surrounding particles of the former) are such as to lead to the supposition that the former minerals have furnished the iron necessary for the transformation from feldspar to biotite. At all events, they indicate a quite sufficient supply of iron.

For a part at least of the magnesium of the biotite and chlorite, it seems that we must look to some source extraneous to the feldspar fragments; i. e., we must regard it as having been supplied by some other mineral or by percolating waters. That calcium-bearing and magnesium-bearing waters have been present in these rocks is evident from the occasional presence of secondary calcite and dolomite. Partial analyses of three of the biotite schists gave an average content of MgO of 2.22 per cent, which if entirely contained in the biotite would correspond to a probable proportion of that mineral of from 10 to 20 per cent.

In the freshest of *the quartzose greywackes* (Pl. XXXVIII, fig. 2), many of the particles of feldspar are as unaltered as in ordinary granite, but generally they have decomposed to a greater or less extent. This decomposition has ordinarily taken place to a greater degree near the exteriors of the feldspar particles than in their centers. In the particles in which the decomposition has been somewhat extended the alteration has affected the regularity of the original fragmental oval outlines. Upon the other hand, at times, even when alteration has progressed quite to the centers of the feldspars, the original outlines may be quite sharp. The minerals which have resulted from the partial alteration, and which therefore are included by or closely encircle the feldspar, are chlorite, sericite or muscovite, or both, biotite, probably kaolin and quartz. In the grains which have decomposed to the greatest extent, the original feldspar remaining, the mica and quartz most intricately interlock; so that an examination with a moderately high power, which covers only one original individual of feldspar or a part of one, gives the appearance of a completely crystalline rock in which the interlocking is of the most intricate sort; yet when the same grain is examined with a low power, its rounded character is evident, and that the area is but an altered feldspar is manifest; while the completely fragmental character of the rock as a whole is plain at a glance.

In addition to the fragments of feldspar, others of quartz (which are frequently enlarged) and a greater or less amount of interstitial material are found. In these specimens it is evident that the induration which has often occurred is caused almost wholly by the enlargement of quartz fragments and the separation of finely crystalline quartz in the interstices; thus completely filling the spaces which originally existed between the loosely piled fragments and making the rock as compact and strong as though it were a granite. The green and gray colors of the rock (in the absence of ferrite) are due to the secondary products of the feldspar, chlorite, biotite, etc.; green when chlorite, gray when muscovite and biotite are preponderant. The original conditions and secondary changes of the simplest of the greywackes is thus plain. They were quartz feldspar sediments, mingled in places with a clayey matter, perhaps also with a small quantity of fragmental mica and some ferrite. They reached their present condition by a secondary enlargement of quartz fragments; the deposition or formation in situ of interstitial, finely crystalline quartz, accompanied with a micaceous or chloritic alteration of the feldspar—the first two being processes already fully described by us.[1]

Another phase of fresh greywacke (Pl. XXXIX, fig. 1) contains very little or no quartz. It is chiefly composed of large fragments of feldspar with their alteration and replacement products. The greater portion of this feldspar is orthoclase, although microline and plagioclase are present. The method of alteration and the minerals produced in this rock from the feldspar are precisely the same as in the quartzose greywacke just described. This is the phase of rock from which the mica slates and mica schists have been produced.

In a *biotitic greywacke* in which the alteration has gone still farther (Pl. XXXIX, fig. 2), fragments of feldspar with its secondary products compose most of the section The alterations of feldspar to biotite and quartz are beautifully shown. The freshest of the feldspar grains are surrounded and more or less deeply penetrated by secondary biotite. In many cases, the original outlines of the grains of feldspar are lost, although often the complex aggregate of resulting biotite folia and quartz, mingled with the remaining feldspar, retain very perfect general roundish or oval forms. Often the entire surfaces of the feldspars include very numerous particles of the biotite and quartz—the former usually much the more plentiful—there remaining through such areas, here and there, little spots of feldspar which act as a unit in each area. With a low power such areas appear to be roundish aggregates of biotite. It is only with a higher power that the remaining feldspar and its true relations to the biotite are discovered. As from a single large particle of feldspar many individuals of quartz and mica are formed, the result of the alteration is to make the rock a finer grained one.

As the alteration proceeds farther a *muscovitic biotite slate* is produced (Pl. XL, figs. 1 and 2). Macroscopically this phase of rock is mottled dark gray and black, quite massive. The mottling is due to more or less distinct roundish areas, which show in a greater or less degree cleavage. In some of the specimens the roundish areas are distinctly outlined, and in these cases the cleavage is eminent. In others, these areas are indistinctly outlined, and in such the cleav-

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[1] Bull, U. S. Geol. Survey, No. 8. R. D. Irving and C. R. Van Hise. On Secondary Enlargement of Mineral Fragments in Certain Rocks.

age is less plain. Under the microscope the cleavage areas seen macroscopically are found to be well rounded and partly altered feldspars, mostly of the species orthoclase. These feldspars are set in a groundmass which consists of intimately mingled minute grains of quartz and brown folia of biotite with a considerable quantity of ferrite. In some specimens the quantity of matrix is considerable, even equal or greater in quantity than the feldspar fragments. In other cases, however, the feldspar areas were set very close together with room for little other material. The partial decomposition of the fragmental feldspar has resulted in the formation of very numerous small folia of biotite, fewer larger ones of muscovite, and also quartz. In some specimens most of the original feldspar grains are yet chiefly unaltered, and in these the mottling and cleavage, seen macroscopically, is most distinct. In other specimens, nearly every feldspar grain has almost wholly altered to mica and quartz, and in such specimens, those which are most completely altered, and now therefore consist of a complex interlocking aggregate of quartz and mica, with little or no remaining feldspar, are with great difficulty separated from interstitial material. Many also are doubtless so completely changed as to be indistinguishable from the matrix. In the matrix of the rock it is usually quite impossible to determine if any of the quartz is fragmental. In some specimens some grains are certainly so, as evidenced by rounded cores and secondary enlargements. The biotite of the matrix is in part plainly secondary to feldspar and is precisely like that found in the larger feldspars. Doubtless much of this matrix is due to the decomposition of fragmental feldspars, which were smaller than those which yet remain partly unaltered, and which have therefore completely altered to mica and quartz. The feldspar plainly shows this rock to have been fragmental, and the alteration of feldspar to both biotite and muscovite upon a large scale is most beautifully shown. The large quantity of dark brown and black ferrite has doubtless furnished the iron required for the formation of the biotite. The peculiar spotted appearance of the sections, the distinctness of the spots varying with the freshness of the feldspar, viewed without the microscope, gives a clear idea, when taken in connection with their appearance under the microscope, of the processes by which the rock reached its present condition.

Macroscopically a *nearly crystalline muscovite biotite schist* is fine-grained, grayish and quartzose, with small mica flakes visible. Under the microscope (Pl. XLI, fig. 1) the thin section shows a fine-grained groundmass of quartz and feldspar, in which are abundant muscovite and biotite. Many of the quartz grains include numerous folia of mica. The feldspar areas include quartz and both muscovite and biotite. This section, by itself, if not examined closely, would be taken to be of a completely crystalline mica schist, in which the interlocking and mutual inclusions of the different minerals are of the most intricate kind. But, like the other mica schists of the Penokee series, it is an ordinary clastic rock in which the metasomatic changes have gone very far. The large areas of quartz, including folia of mica, are in the places of feldspar fragments. As the feldspar has altered to mica the excess of silica has separated as quartz. Frequently the alteration of a single feldspar has resulted in the formation of a single ramifying individual of quartz, with several or many included folia of mica, mingled with which are detached remnants of the feldspar. In this rock in such cases the mutual interlocking of these four minerals—muscovite, biotite, quartz and feldspar—could not possibly be any more intricate in any schist, gneiss or granite. In other cases the decomposition of a feldspar has resulted in the formation of many grains of quartz as well as numerous folia of mica. In yet other cases the feldspar areas have not altered to such extent as described above. In almost every case the rounded exteriors of the clastic grains are lost, but irregular areas of considerable size often remain, which include but few folia of biotite or little replacing quartz, or both. The folia of mica are in this rock of the largest size of any found in the upper group mica schists, many of them being one millimeter in length. The biotite has a remarkably powerful dichroism, and both biotite and muscovite have well defined cleavages.

Macroscopically the *crystalline muscovitic biotite schists* are rather fine grained, finely laminated, although massive enough to break quite easily across the lamination. The individuals of quartz and feldspar are too small to be seen with the naked eye, but are distinguishable with a lens. The very abundant, black, glittering flakes of mica are large enough to be readily seen. Under the microscope (Pl. XLI, fig. 2), with a medium power, the sections show a rather fine grained, apparently completely crystalline typical mica schist. The groundmass consists chiefly of quartz, mingled with which is a considerable feldspar, both orthoclase and plagioclase. The grains of quartz vary considerably in size, but none are minute and none large. Some few of the largest, which are now very irregular in outline, contain rounded cores, proving them to be fragmental, and these cores do not include folia of mica. The feldspar present is quite fresh, many of the plagioclases exhibiting sharply defined twinning bands. Biotite in well defined folia of varying size, the larger being about one-half millimeter in length, are very abundant; muscovite is much less plentiful. The folia of mica often cut through the smaller quartz grains and into those of the feldspars, just as in a typical crystalline schist. That much of the mica is a secondary product can not be proved from the sections taken by themselves. Many grains of feldspar are, however, so cut by folia of mica as to make it probable that the latter is a secondary product, while some of the larger particles of feldspar contain throughout their areas folia of mica, and grains of quartz, which, with the remaining feldspar, gives an appearance of most intricate interlocking, which is especially strong, as in no case does the feldspar now show rounded outlines, which they once doubtless had. This mica included in the feldspar is precisely like that of the remainder of the rock—the word matrix for remainder can hardly be used; for in coarseness of grain the parts of the rock which show no trace of fragmental origin are about the same as the quartz and mica included in the feldspars, and which, taken in connection with the rocks previously described, are taken to prove that this rock, like them, were once altered sediments. Quite numerous crystals of pyrite are seen.

The rocks above described, from the fresh feldspathic greywackes to the crystalline mica schists thus constitute a graded series. The wide interval between the most plainly fragmental greywackes and the most crystalline mica schists is completely filled by almost imperceptible stages, when all the sections are taken into account and the processes which caused the alterations are clearly indicated, *the result being the production from a completely fragmental arkose rock, by metasomatic changes only, of a rock which presents every appearance of complete original crystallization, and which would be ordinarily classed as a genuine crystalline schist.*

The series of alterations above described has also been very important in the production of various black mica slates of the Penokee region. However, as tracing out these alterations has given practically the same results as presented by the rocks just described, except that the particles are much finer grained, the narration will not be repeated.

It will be later shown that between the Penokee series and the underlying complex there is a great structural break, the clastic series having been laid down by water action upon the older crystalline formations. From the description of the Upper Slate it is evident that the most of its material has been derived from a set of acidic rocks, its two preponderating constituents being quartz and acid feldspar in various degrees of comminution. There is no reason to believe that the Southern Complex, which stretches to a great distance to the southward, was ever covered throughout the whole of its extent by this newer series; and as the material of which this upper belt is composed is of precisely the character which would be expected if derived from its granite, gneiss and schist, it may be considered as probable that this is the source of the material of the Upper Slate. This hypothesis receives reenforcement when the distribution of the granitic and schistose areas is considered, and the material which they are able to supply is compared with that of the material of the Upper Slate Member at adjacent points. With the exception of a few miles in the west part of Michigan, all but the westernmost part of the newer series of rocks is directly in contact with an area of green schists. This part of the member is that in which the fine grained phyllites and greywacke slates are found. This would seem clearly to indicate that a large part of the material forming this member has been derived from the green schists. Without doubt the contiguous granite in the western part of Michigan and south of the schist areas has also furnished its quota; so that the material has come, not from the schist alone, or the granite and gneiss alone, but from both of them. In passing westward toward Bad River, as has been seen, there is a gradual change in the nature of the original material of the Upper Slate, it becoming more and more strongly feldspathic. West of Bad River practically all of it was feldspar of an acid character. By reference to Chapter I it will be noted that the Western Granite, which reaches the newer series in the vicinity of Penokee Gap, extends west and south for a long distance. The granite contains an unusually small quantity of quartz, being either a true syenite or a granite in which the quartz is usually not abundant. There is clearly a connection between the character of this upper slate belt and the underlying rock. The degradation of the latter, accompanied by natural sorting, has furnished the nearly pure feldspathic material which locally originally constituted the Upper Slate Member and made it of such a composition that it was possible by metasomatic processes to produce from it a fine grained crystalline mica schist.

CHAPTER VII.

BY C. R. VAN HISE.

THE ERUPTIVES.

The eruptives of the Penokee series are structurally of two classes. Certain of them are interbedded sheets, but apparently a much larger number are dikes, although the field relations of many exposures are not well enough known to determine to which class they belong. In that part of the iron belt west of Penokee Gap, and in the vicinity of Sunday Lake, there is every indication short of demonstration that the eruptives are really interbedded with the sediments of the Iron-Bearing Member. Whether these rocks were contemporaneous volcanic outflows or subsequent intrusions, there is no absolute proof. All the evidence at hand is of a lithological character and points to the latter rather than to the former. They are medium grained, holocrystalline, nonamygdaloidal, and do not contain minerals in two generations—properties which are ordinarily taken as indicating that the rock possessed of them have solidified at depth.

The presence of very numerous dike rocks in the Iron-Bearing Member has become apparent by exploring and mining operations. These dikes are much altered, soft, and therefore do not outcrop, so that their existence would never have been otherwise suspected. In almost every mine in the whole region, and in many test pits, dike rocks have been encountered. These vary greatly in thickness, running from those which are but a few inches to those which are 90 feet thick.

In the Upper Slate Member the eruptives outcrop with sufficient frequency to show that they are quite plentiful, but it has not been possible to determine whether they are interbedded or are in the nature of dikes. It is not at all unlikely that both dike rocks and interbedded sheets occur. Indeed, it would almost certainly be the case that some of the numerous dikes which pass through the iron belt, before reaching the upper surface of the slates would succeed in intruding themselves between the layers. At a number of localities the relations of the slates and eruptives are such as to indicate that this has actually occurred. The line between the Upper Slate

Member and the overlying Keweenawan series is most irregular in detail, and along this contact line at a number of places the slates and eruptives are mixed in a confused manner. On the ground, it is difficult to say at what point the Penokee series ends and the overlying eruptive series begins. These relations are what would be expected along the contact of a fragmental series with an overlying eruptive one.

The igneous material of the Penokee series has all unmistakably been, at the time of its eruption, one species of rock—diabase. Occasionally it varies toward a rock which might be considered a gabbro, but this is exceptional, and all plainly belong together. The degree of alteration is very great at times, large masses of rock being totally decomposed; but even the most altered phases so frequently retain their diabasic structure and can be traced into a comparative fresh rock that the conclusion is reached that they all are altered diabases. It is in the lower (ore-producing) part of the iron-bearing belt that the most altered phases are found. The diabases in the Upper Slate Member are much fresher upon the whole than those contained in the iron belt; while occasionally there is here found a fresh olivine diabase in which even the olivine is mostly unaltered. That the diabase dikes high up in the Penokee series are really continuations of the dikes which cut nearly at right angles the underlying iron formation, there can hardly be a doubt. The contrast between the two is a striking instance of the influence of environment upon the decomposition of a rock. The diabases inclosed by the impervious Upper Slate have been kept in a well preserved condition through the ages which have elapsed since their intrusion, while some of them are remarkably fresh. Other parts of the same dikes in a formation which gives every evidence of having been long subject to the action of percolating waters have been completely decomposed. It thus appears that in this case the influence of environment upon a rock has been a far more important element than age, upon its present state of preservation.

The rocks underlying the Penokee series contain here and there exposures which, in all essential respects, are like the diabases of that series. However, a part of the basic eruptives of the older series are massive, profoundly altered greenstones and schistose rocks which are believed to have been eruptives, but if so, the latter have undergone extreme metamorphism. That there should be eruptive here which do not differ in degree of alteration from those contained in the Penokee series, is what would be expected; for, through these underlying rocks must have passed the dikes which traverse the iron-bearing series itself, and doubtless the fresher greenstones represent parts of the same dikes which are found in the higher series.

The Keweenawan eruptives differ from those contained in the iron-bearing series in their very great variety, and also in their methods of alteration. The immediately overlying rock is in turn a coarse grained gabbro; a diabase; a diorite, which at times is schistose or quartzose; a melaphyr; an augite porphyrite; a porphyrite, and amygdaloid. Not only do all phases of these basic rocks here occur, but in the same locality several of these phases may be found closely associated. In short, nearly all of the kinds of basic eruptives in the Keweenaw series occur, which in the sudden alterations from one phase to another, and their intricate mingling, are typical of the series to which they belong.[1]

As a detailed study of the various phases of the eruptives of the Penokee series adds little to our knowledge of the genesis of greenstones and their metamorphism, the description of them will not be here repeated, even in abstract. Their decomposition in the iron belt is the only point which needs to be mentioned. The most altered rocks are, when not stained by iron, almost snow white, soft and greasy. Analyses show that, putting aside the small proportion of accessory constituents, they are essentially hydrated silicates of alumina, which are very close to the composition of kaolinite.

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[1] U. S. Geol. Survey, Monograph V, Copper-Bearing Rocks of Lake Superior; Roland D. Irving.

CHAPTER VIII.

By C. R. Van Hise.

THE EASTERN AREA.

The area east of the center of T. 47 N., R. 44 W., Michigan—or roughly, east of the Little Presqu' Isle—differs from the simple series described in the previous chapters in many important points. This area was the center of great contemporaneous volcanic activity, consequently the succession includes large thicknesses of lava flows and volcanic tuffs, which are not paralleled by any rocks that are found in the western area. Further, this volcanic material has greatly disturbed the water-deposited sediments in the district, so that it is difficult to certainly correlate the formations east of the Presqu' Isle with those west of it. Another point in which this area differs from the western one is that in one place the relations of the horizontal Eastern Sandstone to the Penokee series can be made out. The subject as given in the original memoir is divided into the following sections: the Iron-Bearing Member; the fragmental rocks south of the greenstone conglomerates; the greenstone conglomerates; the fragmental and ferruginous rocks north and east of the greenstone conglomerates; the greenstones; stratigraphy.[1]

Within the limits of this paper it is not possible to abstract this chapter with anything like the completeness with which the others are treated. An outline of the conclusions will be given, little or no attempt being made to give the facts or the lines of reasoning upon which they are based.

No exposures certainly belonging to the Cherty Limestone Member are found within the area, although near Gogebic Lake there are conglomeratic cherts and chert breccias which may possibly belong here. The Quartz Slate Member is not known to be continuous in this area. Typical exposures of the formation, which have near

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[1] The word greenstone is used here in its old sense to cover all the basic eruptives of the region. The term greenstone conglomerate is used because "agglomerate" would convey a false impression. The rocks covered by the term include both agglomerates and water-deposited clastics, the detritus of which is chiefly from greenstones, as well as gradations between these two extremes.

the base variegated slates, and for the upper horizon the vitreous quartzite, are found at one or two localities.

The lowest belt which has any considerable continuity is the Iron-Bearing Member. Even in this, wide gaps occur in which no exposures are known, although the formation is reasonably continuous for several miles in T. 47 N., R. 43 W., Michigan. Its typical rocks are almost exactly like those of the iron formation to the westward. There is here, however, closer relations between the original siderite and the actinolite and magnetite than to the westward. In this respect the rocks of this belt resemble very closely those of the Animikie iron-bearing formation. Magnetite is found derived directly from the siderite, and the relations of the actinolite with both the siderite and secondary quartz are very intimite. The one important point in which this part of the Iron-Bearing Member differs from that to the westward is that mingled with it is fragmental material. There are all gradations between the pure nonfragmental sediments of the iron-belt and the fragmental material of the slate formations; also there are in places interlaminations of the two. It thus is clear that during the time of the formation of the Iron-Bearing Member there were interruptions, as a result of which the belts of pure nonfragmental, water-deposited sediments are always narrow. Probably resulting from this is the fact that within this area no workable ore deposits have been found, the belt nowhere having a sufficient thickness, so that the amount of iron carbonate present was sufficient when concentrated to form large ore bodies.

All of the fragmental rocks south of the greenstone conglomerates are placed together and treated in Section II. The fact that in one place the typical phases of the Quartz Slate are found has been mentioned. In passing east and west of this point the mass of the fragmental material is sometimes interstratified with the Iron-Bearing Member, at other times north of it. Further, in one place the typical iron-bearing rocks, when traced east and west along the strike, grade into a belt in which fragmental sedimentation is apparently preponderant. This occurrence is another illustration of what has already been said with reference to the intimate mingling and alternation of fragmental and nonfragmental sedimentation in the lower horizons of the eastern area.

These exceptional facts are very plainly connected with the greenstones and greenstone conglomerates. The distribution of the latter is shown on Pl. XXI. It will be noted that both at the east and west the area narrows to a point, but its central part is of great width. It has the fragmental and iron-bearing rocks upon the south, and upon the north material quite similar. The belt is called greenstone conglomerate, because its rocks are clastic ones, in which nearly all the fragments are from basic eruptives, as is also the major portion of the matrix in which these fragments are set.

Macroscopically these rocks run from aphanitic slates to coarse conglomerates. A careful field and laboratory study shows that they vary from a material which is a basic eruptive amygdaloidal flow through various volcanic or semi-volcanic clastics, to those which are pure water-deposited rocks. The volcanic clastics include brecciated rocks, which appear to have had a lava base and contain fragments of essentially the same material, agglomerates; rocks which appear to be tuffs alone; rocks in which tuff has fallen upon water and has become mingled with more or less of ordinary mechanical sediments, and varying from this, by a gradual lessening of the tufa, to rocks which are simple mingled fragmental or nonfragmental sediments. That this region has been the center of great volcanic activity is evidenced not only by the greenstone conglomerates themselves, but by the surface porphyritic flows south of the greenstone conglomerates, as well as the porphyrites and diabases north and west of them. Contemporaneous volcanic activity is an exception in the Penokee series, and in it is believed to lie the key which explains the other exceptional characteristics of this part of the series.

North and east of the greenstone conglomerates is a continuous wide belt of fragmental rocks, which extend from near the north quarter post of Sec. 14, T. 47 N., R. 44 W., Michigan, to the easternmost point at which the Penokee succession is found, near the center of Sec. 28, just west of Gogebic Lake. The rocks south of this belt vary in their character, being in its western part a porphyrite of such a nature to indicate that it is a surface flow; through the central part of the area, a belt of greenstone conglomerate; and in the eastern part of the area, the gneisses and granites of the Southern Complex. North of the belt, until T. 47 N., R. 42 W., Michigan, is reached, are the eruptives of the Keweenaw series. At one place, just west of Gogebic Lake, the Eastern Sandstone is the overlying rock. Whether this belt of fragmentals continues east and west of the points mentioned is uncertain. It seems probable that it is the equivalent of the northern part of the Iron-Bearing Member with perhaps the lower part of the Upper Slate Member to the westward. If it runs farther east, it probably passes under the Eastern Sandstone.

The rocks of the belt are very largely clay slates which have an apparent southern dip. In places, however, they become strongly ferruginous, when a northern dip is usually found. The latter are believed to represent true bedding, and the southern dips to be secondary cleavage induced by pressure. The rocks have a wide variation in lithological character, varying from those which are pure fragmental to those which are pure nonfragmental sediments. The phases intermediate between these two extremes are those most abundant. The fragmentals are very much like those north of the iron-bearing belt in the main area, being feldspathic quartzites, greywackes, greywacke slates, clay slates, sericite slates, etc. The mingled nonfragmental materials are the various oxides of iron, siderite, and chert. The rocks then vary from those which lithologically belong to the iron-bearing belt to those which are typical of the Upper Slate. There is here the same mingling of fragmental and nonfragmental sediments that is found south of the greenstone conglomerates. The iron which occurs in these rocks in its western portion is chiefly in the form of oxide; in its central portion is mingled iron oxide and siderite; and in its eastern portion is siderite. In the intermediate phases the iron oxide is seen forming from the siderite. This is another case in which the widespread occurrence of iron oxide is due to the alteration of a ferriferous carbonate. In the eastern part of the belt, at several points, basal conglomerates and contacts occur between it and the gneisses and granites of the underlying complex. These occurrences are discussed in a later chapter and will not be further referred to here.

The eruptives of the Eastern Area are in several detached areas, some of them being of large size. A portion of them are porphyrites contemporaneous with the rocks of the series in which they are found; others have the structure of a diabase, or even that of a gabbro, and these are taken to be deep-seated rocks. Between these two extremes there is found in various parts of the area intermediate phases.

The rocks of the various belts of the Eastern Area, with the exception of the greenstone conglomerates, correspond closely in lithological characters with those of the Penokee series to the westward; the only difference of importance being that in this Eastern Area there is more frequently found mingled nonfragmental and fragmental sedimentation. The only question which could be raised is as to whether the greenstone conglomerates belong to the Penokee series; but they bear such structural relations to the sediments which certainly belong to the Penokee series, are mingled with them so intricately, and are certainly surface volcanic accumulations; so there is no sufficient reason for placing them elsewhere.

The stratigraphical evidence that the Eastern Area rocks belong to a series separated both from the schists, gneisses and granites to the south of them, and from the great range of greenstones to the north is precisely like that which proves the clastic formations to the westward to belong to a distinct series. Notwithstanding the exceptional width of the Eastern Area in certain parts, and the southern dips which are found in the slate belt north of the greenstone conglomerates, it is believed that the succession here is a simple conformable one; these apparent southern dips being really due to slaty cleavage.

The sequence of events in the region seems to have been briefly as follows: As in the main area, the complex of schists, gneisses and granites constitutes a basement upon which the Penokee succession was deposited. This basement was probably uneven, as a consequence of which deposition began earlier in some places than in others. In certain places rocks which are the equivalent of the Quartz Slate Member were deposited. Whether or not these exist as a continuous belt we have no means of judging. Above the quartz slates followed the nonclastic sediments of the Iron-Bearing Member. The deposition of this belt did not go on undisturbed, for the flow of porphyrite near the base of the series in T. 47, N., R. 43 W., Michigan, plainly is interleaved with it. This flow is doubtless the cause of the mingling of clastic and nonclastic sediments which is so characteristic of the exposures in this vicinity. After several alternations of nonclastic and clastic sediments, but long before the whole of the iron-bearing formation of the west was built up, came the great volcanic outbreak which resulted in piling up the series of flows and tuffs of the greenstone conglomerate area. The center of this volcanic activity was in the east half of T. 47 N., R. 44 W., Michigan. The disturbance extended but a comparatively short distance to the eastward, which may be due to the presence of higher lands in the lower series rocks there than elsewhere. To the westward the influence of this volcanic activity extended farther.

The accumulation of the lavas and of the greenstone conglomerates went on with great rapidity as compared with the exceedingly slow process of nonclastic sedimentation which continued to the westward. This accumulation was doubtless accompanied by simultaneous sinking of the region thus burdened. If this is the case, the bowing of the belts to the south is explained. At or near the cessation of volcanic activity, began to form the mingled clastic and nonclastic sediments which overlie them. How far upward in the Penokee series the deposition of sediments in the Western Area had gone at this time is not certain, but apparently the Iron-Bearing Member had not yet wholly formed, as is indicated by the ferruginous material in the fragmental rocks north and east of the greenstone conglomerates. Above the latter, followed probably fragmentals, which were the equivalent of the Upper Slate Member; but if this was the case, they were wholly or nearly wholly removed by erosion. After a long period of degradation began Keweenawan time. Before the Eastern Sandstone at the east end of the area was deposited the three series of the region were tilted into their present inclined position, and during this time, or subsequently, underwent enormous denudation.

If the above account represents the facts, it explains how it is that the sharply separated fragmental and nonfragmental sediments of the Western Area pass into the mingled sediments so characteristic of the Eastern Area. Throughout the greater part of the Penokee basin during the deposition of the Iron-Bearing Member the conditions were favorable to nonfragmental sedimentation. Under ordinary conditions pure sediments of this class were formed ; but in the Eastern Area this was interrupted by the intermittent volcanic activity which formed the masses of porphyrite and greenstone conglomerate. Even when these materials were not being ejected with such rapidity as to predominate over other varieties of rock, the sea was so disturbed that only for brief intervals and locally was it sufficiently clear to allow the formation of pure nonfragmental sediments. The mass of rocks above the Quartz Slate in the Eastern Area is several times thicker than the entire iron-bearing formation to the westward. However, in estimating time equivalents, we must take into account the fact that ordinary mechanical sediments may accumulate much more rapidly than nonfragmental sediments, and volcanic products far more rapidly than ordinary mechanical sediments. The great difference of thickness is then no obstacle to the correlation of the mass of mingled fragmental and nonfragmental sediments, including the interbedded eruptives and greenstone conglomerates, mainly with the Iron-Bearing Member to the westward.

CHAPTER IX.

By C. R. Van Hise.

GENERAL GEOLOGY OF THE REGION

SECTION I.—FLEXURES AND FAULTS.

In the original memoir a detailed discussion of the various flexures and faults in the Penokee series is given. In this abstract this will not be attempted. The curving of the layers subordinate to its uplifting as a whole has in the main been of so gentle a nature, that they have not been broken. There are, however, several localities at which there is a somewhat sudden turn in the trend of the layers. The most noticeable of these is west of Sunday Lake, where in passing eastward the Iron-Bearing Member swings from an east and west course north more than half a mile in a distance of a mile and a half. At Bad River and Potato River it is certain that the lower layers of the series have been broken and faulted, and there is strong indication of another fault in one place in the Eastern Area. At Bad River, if the entire dislocation is due to the fault, the throw must have been about 900 feet, taking it to be at right angles to the direction of the strike of the rocks; and, if it is diagonal, it must have been more than this. The horizontal throw at Potato River is much less, being, as determined by Mr. J. Parke Channing, 280 feet. In both of these cases the ledges on opposite sides of the fault lines are so close to each other that it is not possible to explain the discordances between corresponding formations by flexures.

SECTION II.—STRUCTURE.

The subject proper of this memoir is the conformable succession of rocks which contain the Iron-Bearing Member, and has therefore often been called the iron-bearing series. It has frequently been necessary to allude to the rocks south and north of them. The latter series has not been given a separate chapter, for the varied rocks there belonging are parts of the great Keweenaw series, which has already been treated in a separate memoir.[1] In Chapter II the former rocks have been described in sufficient detail to compare them in their

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[1] U. S. Geol. Survey, Monograph V. Copper-Bearing Rocks of Lake Superior; by R. D. Irving.

structural features and lithological characters with the various rock belts of the Penokee succession. It has been seen that these rocks are of two general types; first, massive granites, and gneissoid granites, and second, fine grained schists, which technically are gneisses. None of them can properly be said to have a sedimentary strike and dip. All but the granites have a foliation. In the case of the gneissoid granites this foliation is of the coarsest character, but the foliation varies from this to that so fine that it is only possible to detect it in the hand specimen by the direction of readiest cleavage. In these latter cases, however, in thin section, the schistose structure is just as distinct as in the coarser phases in which it is so easily recognizable. While, then, these rocks have no strike and dip in a proper sense, they have a parting to which the terms may be applied. It has been said that more often than not this foliation is approximately east and west. However, it has wide variations within short distances, and at times its folia are almost directly perpendicular to the strike of the rocks of the Penokee series. The variation in dip is still more marked, frequently within a few rods varying from a dip in one direction to that in the reverse. Further, while on the maps there are sharp lines of separation drawn between the fine-grained gneisses and the granites and granitoid gneisses, in the field there is an apparent transition rather than an abrupt change, (pp. 363–364.) From the foregoing it will be seen that if the rocks included within this belt have a distinct succession, it is an extremely complicated one, and that at present we have no data which will enable us to reach even an approximate notion of it. The only structural fact that can be certainly stated is that some of the massive granites are later than the green schists. This Southern Complex as a whole may be taken as the basement series of the region.

To the north of this complex are the belts of the Penokee series which have been described in Chapter III to VI. The first of these is the Cherty Limestone, which is found in various large exposures from near the west end of the series to the east side of T. 47 N., R. 44 W., Michigan. In its greatest development it is about three hundred feet thick. Next in order to the north is the Quartz Slate Member. In the vicinity of the cherty limestones it frequently carries a considerable quantity of material derived from that member, even becoming at times a conglomerate. The cherty limestone and slate belts are, however, in perfect conformity, so that the existence of these conglomerates only indicate that the causes which brought about a change from nonclastic to clastic sedimentation broke up a portion of the underlying rock. The existence of such conglomerates between two formations when they are otherwise in accordance, one of which has no characters showing it to be materially older than the other, indicates only a brief geological break.

The narrowness as well as the permanence of the Quartz Slate Member is strongly brought out by Pl. XXI. Here is a belt of rocks which in surface width is upon an average not more than 400 to 450 feet, and the thickness of which is not more than 350 to 400 feet. Its maximum thickness east of Sunday Lake is not more than 800 feet. In Chapter IV, pp. 371-372, the remarkable persistence of the lithological characteristics of this belt is indicated. Its lowest horizon is a green, brown, gray, or red quartz slate. Its uppermost layer is a vitreous quartzite. In whatever part of the range a section is made across the belt, its fragmental character is at once discoverable, the rocks being comparatively little changed since they were originally deposited. The induration of both the quartzite and the slates has been explained to be due to the enlargement of quartz grains and to metasomatic changes of the feldspar.

There is, then, between the Quartz Slate and the rocks to the southward the great fundamental difference between rocks which are easily provable of clastic origin, and those which are completely crystalline schists and massive eruptives. There can be nowhere a wider lithological difference in the characters of two sets of rocks than this. But more remarkable than the lithological simplicity of the Quartz Slate is its straightforward field relations. This slate, once seen, is easily recognized. It always dips to the northward, varying within narrow limits. Take the strike of any ledge, and follow the direction either to the east or to the west with a little latitude of movement, and almost invariably another ledge of like rock is found within a short distance if exposures are at all plentiful. As one traverses this range north and south, at short intervals, the complexity and variety of the lithological characters, and the strikes and dips of the rocks of the Southern Complex, and the likeness, simplicity, directness and uniformity of the Quartz Slate now just north of the granites and now in contact with the crystalline schists, is most striking. These facts impress one so strongly that it is safe to say that no one can pass through this experience without having the conviction forced upon him that there is a great structural break between the Quartz Slate and the Southern Complex to the southward. Such a general relation, it seems to me, is more significant than the direct abutment of the schistose structure of one rock against another; more significant than actual structural breaks seen in any single exposure; more significant than any basal conglomerate; yet, as will be seen, all of these subordinate proofs of unconformity have been found at various places in this region.

The relations of the massive syenites and granites to the adjacent schists and to the Quartz Slate are such as to show that the schists and massive rocks are both older than the slates. That the granites should intricately intersect the schists and yet for many miles be immediately adjacent to the fragmental quartz slate belt, yet never cut it, is inconceivable on any other hypothesis than that they were in this position before the deposition of that belt of rocks. It is, further, all but universally believed that the coarse grained granites and syenites are a class of rocks which have crystallized under great pressure, and therefore at depth. If this is true, they must have been subjected to great erosion in order that the fragmental quartz slates could have been deposited directly upon them, and they are therefore immensely older than the slates. The independent relations also of the green schists to the slates are such as show that between them is a great interval of time. It has been said that the fibers of the schists run in every possible direction, and that in certain cases they abut directly against the quartz slates. These schists may be eruptive or fragmental, but in either case their schistose structure was induced before the deposition of the slates upon them; for it is impossible that rocks could be so profoundly altered and yet the slates of much the same mineral composition in contact with them be unaffected. If they are taken to be eruptives, the time taken for their change from fresh rocks to extremely foliated altered ones must have been very great. If they are taken to be fragmental, their metamorphism to completely crystalline rocks must have taken as great a time. So that on either hypothesis they are immensely older than the Quartz Slate which overlies them; for these rocks have neither a schistose structure nor crystalline character.

West of Potato River no actual contacts between the Southern Complex and the Penokee rocks are known. At Penokee Gap the green schists are found very close to the overlying series. The latter as usual dip to the north and strike approximately east and west. The green schists to the southward also have a nearly east and west strike, but their dip is to the southward. This being the case, the fibers of the gneisses, unless there is here an exceedingly sharp fold of which there is no evidence, abut sharply against the overlying beds, and thus there is here strong, although not conclusive evidence of unconformity. At Potato River, fortunately, the underlying schists and the overlying slates are found in direct contact with each other (Fig. 40). Here the Quartz Slate, rising in low cliffs, is exposed throughout its entire thickness upon the east side of the river. For quite a distance the green schists to the southward are also exposed, and the actual contact between the two is seen on a bank at intervals for a vertical distance of 75 feet, while the contact is continuous for the lower 25 or 30 feet (Fig. 41.) The slates are all of the normal character, dipping to the northward at an angle of about seventy degrees. The green schist has no proper dip and strike, and yet it has a strongly schistose character. Its fibers abut almost perpendicularly against the layers of the slate, as shown by Fig. 42, reproduced from a carefully made drawing on the ground. So sharp is the junction line between the two rocks that it can usually be located to the fraction of an inch. The upper surface of the green schist at the beginning of the deposition of the conglomerate is seen to have been somewhat irregular, and between it and the ordinary slates is a layer of basal conglomerate varying from a few inches to several feet in thickness. It, however, quickly grades into the ordinary slate of the region, as though this place were at the bottom of a comparatively level, shallow sea rather than adjacent to a shore. This conglomerate contains a few white quartz and jasper pebbles, the former sometimes being ten inches in diameter; but the great mass of the fragments, and especially all of the large bowlders (which reach occasionally five feet in greatest length), are from the underlying green schist. Moreover, the conglomerate proves that the schistose character of the underlying rock had been fully attained before the deposition of the slates; for the schistose structure of the fragments are as well developed as in the ledge below. The green schist fragments of the conglomerate are generally longest in the direction of schistosity. Now, fragments of this sort, when broken from the basement rock and laid down as a part of the conglomerate, would naturally lie with their longer direction parallel to the horizon; and this has been the case, for, as shown in Fig. 42, nearly all of the larger fragments lie with their greatest length parallel to the then sea floor—that is, *the schistose structure of the fragments is at right angles to that of the ledge from which they were derived.* Now, if this schistose structure had been developed subsequent to the formation of the conglomerate, it would have been parallel in both the fragments and basement rocks. So far as a basal conglomerate and unconformity in structure at a single place can indicate a great time gap between two formations, the Potato River unconformity indicates such a gap.

At the west branch of the Montreal green schists are again found in contact with the rocks of the Quartz Slate. The exposure is here of a smaller size, but so far as can be made out the relations are precisely as described in the previous paragraph. At two places in T. 47 N., R. 46 W., Michigan, contacts between the Southern Complex and the Penokee rocks are found. Here they are between granite and chert breccias belonging to the limestone member, the ledges of granite being faced by the breccia which penetrate its clefts and hollows. The breccias are in most respects like those described as common in the Cherty Limestone Member. They, however, contain numerous simple and complex fragments of granite débris which are certainly derived from the adjacent rock to the southward.

Passing eastward, the next contact between the Southern Complex and the rocks of the Penokee series is east of Sunday Lake, where the green schist of the lower and the quartzite of the Penokee series are found together. The fibers of the schist do not correspond to the strike of the overlying quartzite, but abut against it at a rather sharp angle.

At two localities in Secs. 23 and 24, T. 47 N., R. 43 W., Michigan, the rocks of the Southern Complex approach very close to those of the Penokee series and beautiful basal conglomerates are found in the latter. The underlying rock is here a coarse gneissoid granite. One phase of basal conglomerate, called a recomposed granite, in the field and hand specimen, so closely resembles the crystalline rocks of which it is the cemented debris that the two might readily be confused. When examined in thin section they are readily distinguished, the fragmental character of the one and the thoroughly crystalline character of the other being apparent. This recomposed rock varies into a coarse conglomerate containing, besides the numerous granite fragments, pebbles of white quartz and a green schist, and then upward into the ordinary slate and quartzite of the region. That the material of this fragmental rock is here derived from the underlying gneiss and gneissoid granite there can be absolutely no doubt, the major portion of the fragments being precisely like these rocks.

Near the center of Sec. 28, T. 47 N., R. 42 W., Michigan, the easternmost known exposures of the Penokee succession occur, and here is a beautiful instance of a basal conglomerate in direct contact with the underlying granite. The profile of the rock exposures here

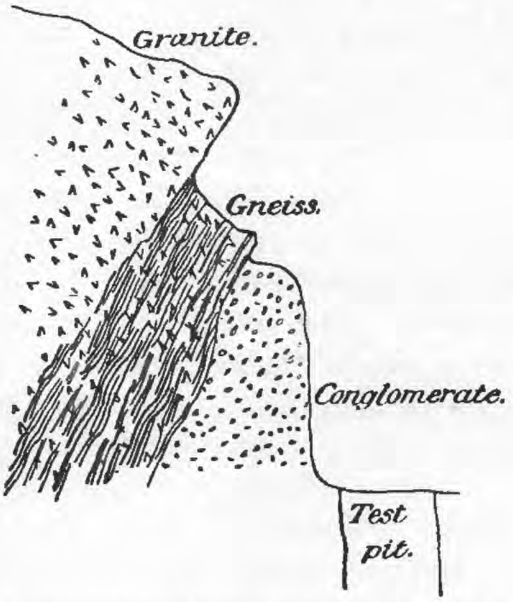

FIG. 43.—Basal conglomerate in contact with granite in Sec. 28, T. 47 N., R. 42 W., Michigan.

is shown by Fig. 43. The granite and gneissoid granite have evidently formed a cliff against which the basal conglomerate has been deposited. The contact between the gneiss and conglomerate strikes north thirty degrees west, and the gneiss dips back into the hill at an angle of seventy-five degrees, so that the contact between the two gives the gneiss an appearance of overhanging the conglomerate. If the strata were turned back to their original position, this would not be the case; we should have a conglomerate resting upon an ordinary slope. The hill faces north of east. The conglomerate upon the face of the cliff, at its upper part, is about six feet in thickness, and its face is nearly vertical. The granite schist ledge continues beyond the point at which the conglomerate is found, for some distance, in a direction south thirty degrees east. At intervals along this face conglomerate is found. At times it is so fine grained as to become an ordinary quartzite. The underlying rocks in this vicinity are both of the granitic and schistose classes, the former, however, being predominant; which explains the fact that the conglomerate is mostly composed of granite debris, but also contains fragments of green schist. It might be concluded from this exposure that the conglomerate was beneath the granite, if the nature of the fragments of the conglomerate and the subsequent tilting of the rocks were disregarded. We have here, however, nothing but what is known to occur at any sea cliff in which its debris becomes a part of an unconformable newer series of rocks. In the immediate vicinity of this cliff, to the northwest, is a ravine in which the contact between the crystalline and fragmental series is again found. The fragmental rock is at this place a recomposed granite which so closely resembles the rock from which it is derived that it is impossible in the field to locate the exact junction line. In thin section the fundamental difference between the two rocks is apparent at a glance. Here practically all the material of the fragmental rock was derived from the granite immediately underlying it.

A little farther to the northeast (near the center of the north half of the northwest quarter of section 28) a chert conglomerate is found in several places but a few paces from the granite. These chert conglomerates are in all essential respects like that found in T. 47 N., R. 46 W., Michigan, already described.

From the foregoing it appears that there are definite proofs of stratigraphic breaks between the Southern Complex and the Penokee series at ten places. Two of these breaks (see Pl. XXI), both being actual contacts accompanied by basal conglomerates, are above the Western Schist Area, the lowest area of the upper series here being the Quartz Slate. Two of the breaks, both again being contacts accompanied by basal conglomerates, are above the Central Granite Area, the lower rocks of the upper series here being the Cherty Lmestone Member. One of the breaks is above the Eastern Schist Area, the contact being found but no basal conglomerate appearing. The lowest layer of the upper series is here the quartzite, which occasionally appears below the Cherty Limestone Member. Finally, five of the breaks are above the Eastern Granite Area, basal conglomerates or recomposed granites occurring at each locality, while at two of the places are actual contacts. The lowest member of the upper series is in four cases a slate, and in the other cases a chert breccia. When it is remembered that it is exceedingly difficult and unusual to find actual contacts between unconformable series, even when there is the same certain general evidence of the unconformity that there is in this region, the above number must be considered extraordinary. It is also noticeable that the breaks are widely distributed, and in about an equal number of cases the schists and granites are the underlying formations.

But there is yet further evidence as to the greatness of this unconformity. It is certain that the complex basement upon which the newer series was laid down was essentially horizontal. When it is considered that this basement complex is here resistant massive granite and there soft foliated schistose rocks, it is plain that in order that this should be the case it is necessary to suppose that the forces of erosion had nearly exhausted themselves—i. e., that a "base level" of erosion had been nearly attained. When we perceive what is involved in this, it strongly reenforces what has gone before as to the great time gap which must have intervened between these older formations and the lower fragmental rocks. The proof of the existence of this nearly horizontal plane lies in the exceedingly small irregularity in thickness of the lower belts of the Penokee series. The difference of elevation in the basement throughout its whole extent east and west can not have been more than a few hundred feet. The Cherty Limestone Member is found here and there in detached layers. Its maximum thickness is three hundred feet. It seems that the sea in which it was formed was not deep, and that it contained large islands, between which were deposited the nonfragmental sediments which made up those beds. But deposition of material not exceeding three hundred feet in thickness had practically filled up all the depressions; for the next layer, the Quartz Slate, averaging three hundred or four hundred feet in thickness, at no point is known to be much below this normal amount. It forms a continuous belt throughout most of the extent of the series, and where missing has apparently been swept away by erosion, as have all the higher members at such places.

A rock basin composed of diversified crystalline schists and massive rocks ninety miles in diameter, and having no elevations greatly exceeding three hundred feet is rare, and it is universally believed that the complex areas in which this is the case have been subjected to enormous denudation. The amount of erosion in such regions is often compared to the amount which will be necessary to reduce lofty mountains to mere stumps. Before the beginning of the deposition of the Penokee series, it is plain that the Southern Complex was thus brought near to a plain.[1]

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[1] The time gap implied by such an unconformity as the above is fully discussed by Prof. R. D. Irving, U. S. Geol. Survey, 7th Annual Report, pp. 390–443. Suffice it here to say that it is clearly shown that an unconformity of this sort indicates "a lapse of time long enough to cover (1) the folding of the lower series, (2) its elevation into a land surface, (3) a long-continued denudation," and (4) its depression under the sea. "In other words, it indicates an interval of more or less extended orographic movement with its accompanying * * * denudation." In this case it is plain that the orographic movement is of a most extended character.

Thus far the relations of the Southern Complex to the two lower members of the Penokee series and the relations of the latter to each other have been spoken of. Above the Quartz Slate follows in perfect conformity the Iron-Bearing Member. The uppermost deposition of the former has been said to be a coarsely crystalline quartzite. It is plain that at the final stage of the deposition of this member there was a clear sea, only well rolled quartz-grains being deposited. This implies sorting of the material and therefore less rapid accumulation. It is probable that this change of condition was accompanied by a gradual sinking of the sea bed. Naturally, following the clearing up of the water, have come the nonfragmental sediments of the iron belt. As has been shown, pp. 401–402, they are analogous to limestone formations in many respects. Above the iron-bearing formation next succeeded a great thickness of fragmental upper slates. The relations between the Iron-Bearing Member and the Upper Slate are the same as the relations between the former and the underlying Quartz Slate; that is, they are two formations which are in perfect conformity, as is shown by the strike and dip of many exposures in both belts. The four members mentioned, with contemporaneous eruptives, constitute the Penokee series. By an examination of plate XXI, it is seen that they are not all continuous throughout the region traversed by them; but wherever the series is present, one formation follows another, except in the Eastern Area, in the order mentioned in conformable succession, so that they are properly placed together as a group of formations.

North of this Penokee series are found the eruptive and fragmental rocks of the Keweenaw series. That there is a great time gap between the Southern Complex and the Penokee series has just been shown. That there is also a time interval, although not so vast a one, between the Penokee and the overlying Keweenaw series, is equally clear. In any single section this discordance is not plain, for the Keweenaw rocks north of the Penokee series, like the latter, have as a whole a northern dip at a high angle.[1] The eruptive character of the basement member of the Keweenaw series for most of the distance, and its northern inclination, make it more difficult to prove an unconformity between the two than between the Penokee series and the Southern Complex, the evidence resting entirely upon broad field relations.

Beginning at the west, the Keweenaw rocks are found very close to the underlying granites. Some distance east of this point, in T. 44 N., R. 6 W., Wisconsin, the first known exposures of the Penokee series are found. From this narrow beginning the series gradually widens for some miles eastward, when exposures are lost in the east part of T. 44 N., R. 6 W., Wisconsin. South of Bladder Lake the

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[1] U. S. Geol. Survey, Monograph V. Copper-Bearing Rocks of Lake Superior, pp. 225–234; by R. D. Irving.

series reappears and rapidly widens, until at Tyler's Fork it is 14,000 feet thick, the upper member of the series being more than 12,000 feet of this amount. This is the present maximum thickness of the series, and from here eastward it gradually narrows until the Upper Slate belt entirely disappears a short distance west of Sunday Lake, the Keweenaw series there coming directly in contact with the Iron-Bearing Member. East of Sunday Lake the latter is itself not more than one-third of its thickness a short distance either to the east or west. In the Eastern Area the series is again of great thickness for some distance, but near the east side of T. 47 N., R. 43 W., Michigan, is reduced to a thickness of not more than 2,500 or 3,000 feet.

That the Penokee series should have been deposited to a thickness of about 14,000 feet at Tyler's Fork, and at other points should be only 1,000 feet thick, or entirely absent, is not at all probable. This is especially true as it is the lower 1,000 or 1,500 feet of the series which is found whenever any part is present. As already explained, the persistence of the Quartz Slate and Iron-Bearing Members in nearly uniform thicknesses shows that at the time of their deposition there was for this distance an approximately level basin. If no part of the upper slates and iron formation have been swept away by erosion, we must believe that there began before the end of the latter period an orographic movement which formed a synclinal trough, the center of which was at Tyler's Fork, and thus a great thickness of upper slates there accumulated; while to the east and west the thickness became less and less until it finally disappeared, as well as a part or the whole of the lower members of the series. That a great earth movement of this sort could occur without disturbing the perfect conformity of the formation of the series is impossible. The discordance in the strikes of the layers would indicate the change, but as all the members are in perfect accordance, one layer has followed upon another without disturbance. This being the case, the Penokee series was originally probably of quite uniform thickness, and doubtless this thickness was maintained both east and west of the points at which the series can now be traced; for there are many reasons for believing that this region was a part of a great basin which extended to the Marquette region on the east and to the quartzites of the Chippewa Valley on the west.

The relations just sketched can have but one meaning—that separating the Penokee and Keweenaw series is a great unconformity. During this intervening period the rocks of the Penokee series were raised above the sea, and there suffered long continued denudation until in places the entire succession was carried away, exposing the underlying rocks. How thick the series as a whole was at the beginning of this erosion there is no means of knowing, but the amount of material removed at Numakagon Lake was 14,000 feet more than at Tyler's Fork, while the difference in amount of erosion between the last place and Sunday Lake is scarcely 1,000 feet less. Probably the series must have everywhere been thicker than at the present time at any place. During the progress of this erosion it is possible that the series was gently bent into a synclinal trough, the center of which was in the vicinity of Tyler's Fork and the eastern end near Sunday Lake. This suggestion is made as giving an explanation of the difference in the amount of erosion, those parts naturally being eroded most which were at highest elevations. Also it appears to be the fact, from the continuity of the Copper Range north of the Penokee series, that this great outflow was practically simultaneous for this whole distance, which would not likely have been the case had not the surface at that time been approximately horizontal.

The time gap, then, between the Penokee and the Keweenaw series must have been sufficient for a widespread orographic movement and deep denudation—a vast lapse of time; so that while the unconformity between these two series is not nearly so great as between the Penokee series and the Southern Complex, yet it stands as one of the greater time gaps in geological history.

The only remaining terrane in which we are concerned in this memoir is the Eastern Sandstone, which (as shown by Pl. XX), extending from Keweenaw Bay to quite a distance west of Agogebic Lake, conceals a broad strip of the older formations. The basal conglomerates, at the junction of the Penokee series and the Southern Complex, just west of Gogebic Lake, have already been described. In this interesting locality is still another basal conglomerate which belongs to the Eastern Sandstone. In the test pits close to the outcrops of the Penokee series and the Southern Complex the conglomerate is coarse, the matrix of which is somewhat indurated, it being necessary to resort to blasting in sinking. The character of the pebbles indicates that they have been derived from the Southern Complex, the Penokee, and the Keweenaw series. From the last are coarse, red, indurated sandstones, amygdaloids, coarse grained basic eruptives, quartz porphyries, and other varieties of rock. From the Penokee series the pebbles are more numerous than from either of the others, as would be naturally the case since the exposed conglomerate is in contact with these rocks. The pebbles belonging here are lean ore, banded jasper, magnetitic schist, chert, chert breccia, recomposed granite and quartzite, the induration of which is due to the enlargement of quartz grains. From the Southern Complex pebbles and bowlders are also very numerous, comprising white vein-quartz, gneiss, granite, and many varieties of crystalline schists. The pebbles from all of these sources are characteristic of the series from which they are derived. It is to be remembered that in this locality no crystalline schist, gneiss or granite has been found anywhere except in the Southern Complex; no jasper, magnetitic schist, chert breccia, lean ore, or recomposed granite has been found in other than the Penokee series, while quartz porphyry and certain phases of the basic eruptives have been found nowhere but in the Keweenaw series; so the evidence is as clear as any lithological evidence can be that the various pebbles have been derived from the sources assigned them. The test pits show that so far as the rock has any stratification, it lies in a horizontal position, and the character of the basal conglomerate alone would be sufficient to prove that we have to deal with the Eastern Sandstone. Farther, the relation of the underlying rock to the sandstone is shown in one test pit. After passing through a thickness of twenty-four feet of the conglomerate just described, the shaft penetrated the chert breccia of the Penokee series, clearly proving that this rock is earlier than the conglomerate. Again, a short distance northeast of these test pits are others in sandstone, the rock of which in every respect is like the ordinary red Eastern Sandstone, and which show, so far as it is possible in a test pit, the rock to be in a horizontal position. The Penokee series is not absolutely cut off by the sandstone, but its thickness at one point in the northwest part of Sec. 28, T. 47 N., R. 42 W., Michigan, can not be more than two hundred or three hundred feet, and it is probable that farther south the entire succession is overlain by it.

It is clear, then, in the upward passage to this Eastern Sandstone another great unconformity has been passed. The whole Keweenaw and Penokee series must have been tilted and suffered vast erosion in order that the base of the latter and the underlying series—once probably buried under many thousands of feet of sediments—could reach the surface and furnish fragments to the sandstone. Since the sandstone is horizontal, it is plain that the two upper series were tilted to their present inclination and eroded before its deposition. This unconformity is one, then, which in magnitude is probably equal to, if not greater than, the geological break between the Penokee series and the Southern Complex.[1]

The reason is now more apparent than at any time before for giving this Penokee series a separate memoir. It stands out as a region in the Lake Superior country unique in its simplicity and isolation. It is a great series of water-deposited sediments, the origin of which

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[1] The discordance between the Eastern Sandstone and the Keweenaw series has been long maintained by eminent geologists while denied by others. The last exhaustive and convincing treatment of this question is by Prof. Irving and Pres. Chamberlin, Bull. No. 23, U. S. Geol. Survey. Upon Keweenaw Point it has been maintained that the pebbles in the sandstone do not imply a great break because of eruptive origin. At Gogebic Lake are nearly all the phases of pebbles of the three great series of rock of the region. That they should be abundantly contained in the sandstone in the condition which they are now found in situ can not be explained upon any other hypothesis than a great unconformity.

has been for the most part determined. It has simply been tilted to the northward at an angle most convenient to determine the succession of belts. It is without any subordinate fold whatever, so that, traversed anywhere, excluding the Eastern Area, if sufficient exposures are found the succession of its belts can be made out, one following the other in perfect conformity. It is plain that its entire thickness of 14,000 feet was laid down in a sea with a bottom not varying more than a few hundred feet in elevation. This series is terminated on the east by the unconformably overlying horizontal Eastern Sandstone ; it is terminated on the west by its being entirely swept away by erosion, the Keweenaw series directly overlying the Southern Complex. It is marked off from the underlying granitic and gneissic rocks by one of the greatest unconformities of geology. It is marked off from the Keweenaw series to the north by another unconformity inferior only to that just mentioned.

The Penokee series furnishes an instructive lesson as to the depth to which rocks can be buried and still be slightly affected by metamorphosing processes.[1] The series itself is 14,000 feet thick. It was covered before being upturned by a great thickness of Keweenaw rock. This series at the Montreal River is estimated to be 50,000 feet thick. Adding this to the known thickness of the Penokee series, we have a thickness of 64,000 feet, or more than twelve miles. The Penokee rocks were then buried to a great depth, the exact amount depending upon their horizon and upon the stage in Keweenaw time when the tilting and erosion which brought them to the surface was inaugurated. That the synclinal trough of Lake Superior began to form before the end of the Keweenaw period, and consequently that the Penokee rocks were not buried under the full succession, is more than probable. However, they must have been buried to a very great depth—at least several miles—and thus subjected to high pressure and temperature, notwithstanding which they are comparatively unaltered. In the Quartz Slate, near the bottom of this pile, the feldspars have, it is true, in large measure decomposed to chlorite, mica and quartz. Also the quartzite of the upper part of this formation has been indurated by the enlargement of the quartz grains. The alterations in parts of the Iron-Bearing and Upper Slate Members have locally been more extensive. But the clastic character of the fragmental belts is usually seen at a glance under the microscope. The pressure to which these rocks have been subject, the amount of which one dares hardly estimate in figures, has not been sufficient to distort the quartz grains in any degree, nor has it been sufficient to give a schistose structure to the quartz slates. It is a probable deduction from these facts that the weight alone of any ordinary amount of

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[1] U. S. Geol. Survey, Mon. V. Copper-Bearing Rocks of Lake Superior, p. 230 ; by R. D. Irving.

superincumbent rock is not sufficient to develop schistose structure. The schistosity found in the various fragmentals of the Marquette, Menominee and Vermillion Lake regions, must have been developed in connection with the dynamic pressure of folding to which they have been subjected.

SECTION III.—CORRELATION.

Throughout this memoir the terms Laurentian and Huronian have been avoided. These words have been so differently used by different writers that it was thought best to free the discussion from misapprehensions which would result from their use. The structural relations of the series considered are so perfectly distinct that no evidence or use of names from other localities is necessary in order to make out the succession of belts within the Penokee series itself, or the relations of this series to the underlying and overlying rocks. Before closing, however, it is necessary that some reference be made to other series which have been designated as Laurentian and Huronian, and an indication given as to our judgment as to their proper use, and where the series considered would fall under that usage. Before entering into this discussion, a comparison will be made with the Animikie series (see Pls. XX and XLII), the equivalency of which with the Penokee rocks is as clear as the equivalency of any two areas of detached rocks in a single geological basin can possibly be in which is lacking clear paleontological evidence. Underlying both the Animikie and the Penokee series is a complex of granites and schists, the unconformity between which and the Animikie and Penokee rocks is of the most pronounced character. That the Animikie series is thus separated from the underlying rocks has been seen by all who have visited the region, and considering this general agreement, the proof of this unconformity will not be here repeated. Further, the Penokee and the Animikie rocks have a parallelism in lithological characters which is most remarkable. This parallelism has already been discussed, but the main facts are here repeated. Not only is there a general likeness between the specimens from the two regions, but almost every phase of rock from the Animikie series can be matched by spcimens from the Penokee region. In the Animikie region the formations underlying the Iron-Bearing Member, if there are such, are not exposed, and consequently the rocks from the lower formations of the Penokee series have not known corresponding Animikie equivalents. But the Animikie series is flat-lying, and equivalent lower formations may be found if, in the future, the iron-bearing belt is cut through. Beginning with the iron formation the parallelism is almost exact. The iron beds upon Gunflint Lake are in the lower parts jasper, magnetite-actinolite schist, and cherty ferruginous rocks containing more or less iron carbonate. Higher up are thick layers of thinly bedded, cherty ferriferous carbonate. All these varieties of rock are found in the iron formation of the Penokee series and at many places the order of succession is the same. Above the iron-bearing belt in both regions is a great thickness of fragmental clay slates and greywacke slates which are again practically identical in character in both regions. It is true that in the western part of the Penokee region mica schists have developed from these slates, but the original condition of these rocks was essentially like that of the unaltered phases. Above both series follow the Keweenaw rocks. In both regions, in passing at any place from the underlying rocks to the Keweenaw series in section, the two are in apparent conformity; but, when the contact between the iron-bearing and the Keweenaw series is followed for some distance in either case, this apparent conformity is found to be illusory. That is, the Keweenaw series is now found to come in contact with one member of the underlying series and now with another, until in both regions at one or more places the entire iron-bearing series are cut off, the Keweenaw rocks coming directly in contact with the basement complex. This means that between the deposition of the Penokee and Animikie series[1] and the outflows of Keweenaw time there intervened a period of erosion, which was sufficient in places to remove their entire thicknesses and to cut in some places quite deeply into the older rocks themselves. There is, then, an immense time gap between these series and the overlying Keweenaw rocks, although this unconformity does not approach in the length of time involved to that separating them from the underlying schists and granites.

Gunflint Lake, where the Iron-Bearing Member of the Animikie rocks has its most typical development, lies almost directly north of the middle of the Penokee series upon the opposite side of Lake Superior. The latter is a simple unfolded succession of layers dipping to the northward under the lake; the Animikie is another such succession dipping to the southward under the same body of water. There is then little doubt, considering all these facts, that the two series represent a single period in the history of the synclinal trough which forms the basin of Lake Superior.[2] The relations and likeness of the Penokee and the Animikie series have been dwelt upon at length as showing the breadth of the geological basin in which

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[1] For full discussion of the proof of the unconformity between the Animikie and Keweenaw series, see 7th Annual Report, U. S. Geol. Survey, pp. 417–423. On the Classification of the Early Cambrian and pre-Cambrian Formations; R. D. Irving.

If the Keweenaw series simply was in contact with the gneisses and granites, it might be held that we have only to do with an overlap, but its contact now with one horizon of the Animikie, now with another, can be explained only by an unconformity.

[2] U. S. Geol. Survey, Mon. V. Copper-Bearing Rocks of Lake Superior, by R. D. Irving.

the deposition of like rocks was taking place simultaneously. The equivalency here shown is a long step in understanding the equivalency of other rocks in the Lake Superior basin.

As is well known, in the Northwestern States and Canada, are other areas containing fragmental quartzites, greywacke and greywacke slates, mica schists and mica slates, and the unique phases of rock of the iron-bearing formation. These are known as the Original Huronian region, the Marquette-Felch Mountain-Menominee Iron Bearing region, the St. Louis Slates, the Chippewa Valley Quartzites, the Black River Iron-Bearing Schists, the Baraboo Quartzites, the Sioux Quartzites, and the Folded Schists of Canada, including the Vermilion Lake Series. Prof. Irving has maintained, in a series of able papers, the separability of the above-mentioned rocks from older series of crystalline schists and granites, and the equivalency of age of all of these upper series, excluding a portion of the Folded Schists of Canada.[1] Here there will be no attempt to give an exhaustive account of the reasons advanced by him for this equivalency, but a brief summary of his argument seems necessary.

All the rocks contained in the above series are included in the classes of the Penokee and Animikie series. It has been seen that the latter are of three kinds: those which are easily shown to be clastic, those which are nonclastic, water-deposited sediments, and those which are of eruptive origin. In the Original Huronian, Marquette, Felch Mountain, Menominee, Vermilion Lake, and Baraboo regions all of these varieties of rocks are found, and no others. This excludes many of the crystalline schists which in these regions, as in the Animikie and Penokee areas, are adjacent to the fragmental rocks, but which, as is believed, do not belong with them.

A careful field and laboratory study of the rocks of the Original Huronian has shown it to consist in great part (1) of fragmental quartzites, the induration of which has been caused by the deposition of interstitial silica; (2) of greywackes and greywacke slates, which at times are conglomeratic (Logan's slate conglomerates), the induration of which is due to the deposition of interstitial silica and metasomatic changes in the feldspar. In other words, these rocks are in every respect like the slates, greywackes, and quartzites of the Penokee series. So far as yet known in the original Huronian an iron-bearing belt is not there largely developed, but there is found in the region considerable beds of limestone and chert which are the parallel of the Cherty Limestone, and in essential character are like

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[1] Mon. U. S. Geol. Survey, vol. V. Copper-Bearing Rocks of Lake Superior; Am. Jour. Sci., vol. 29, pp. 237-249, Divisibility of the Archæan in the Northwest; Seventh Annual Report U. S. Geol. Survey, On the Classification of the Early Cambrian and pre-Cambrian Formations; Am. Jour. Sci., vol. 34, pp. 204-249, Is There a Huronian Group?; U. S. Geol. Survey, Explanatory and Historical Note by R. D. Irving to Bulletin No. 62, The Greenstone Schist Areas of the Menominee and Marquette Regions of Michigan, by Dr. George H. Williams.

the original Iron-Bearing Members of the Penokee and Animikie regions, the only difference being that in the latter a portion of the original material was carbonate of iron.

The remarkable lithological likeness between the Penokee rocks and those of the Marquette, Menominee and Felch Mountain districts is so great that most geologists who have visited the former and one or more of the latter have considered them as equivalent. There is in them, as in the Penokee region, heavy beds of fragmental rocks, in part quartzite, and in part greywacke, greywacke slates and mica schists, the induration and alteration of which are almost exactly parallel to those of the Penokee series. Further, the iron-bearing beds in each district present an almost exact reproduction of the different phases of rock which are found in the Penokee and Animikie iron-bearing belts, the chief difference being a variation in proportion of the phases present rather than in kinds of rock.

The Sioux Quartzites, the Baraboo Quartzites, the Chippewa Valley Quartzites, and the St. Louis Slates also present thick beds of fragmental rocks, like those of the Penokee region. The supposed absence of ferruginous rocks in these regions has been used in the past as an argument against the correlation of them with the Penokee series, but this absence has no particular weight, because such beds, as compared to the fragmental rocks, are insignificant in amount; and further, it is quite possible that such nonfragmental water-deposited formations may in the future be found in several or all of these regions. The probability of this is rendered greater by the fact that explorations for iron have very recently developed beds of this sort between the two quartzite ranges of Baraboo, a district in which they were before supposed to be absent. The rocks here found are the exact parallel of the iron-bearing beds of the Penokee and other Lake Superior iron-bearing regions.

The likeness of the ordinary fragmentals of the various regions is strange enough if they are not all parts of one great series, but the likeness of the rocks of the iron-bearing formations in the various areas is very remarkable on any other hypothesis. The many phases of these peculiar rocks and their genesis have been spoken of in detail. While it can not be said that in all these regions each of the phases has been found, it is true that in each area, with one or two exceptions, many of them with manifest evidence of the same origin are known.

The equivalence of the rocks of these various areas is also supported by the great lithological contrast which they present to the older associated rocks. Underlying the Penokee, Animikie, and Original Huronian series are older crystalline schists and gneisses. The clearness with which the granite-gneiss complex is separated by its lithological characters from the clastic formations has been recognized by every one in the Animikie region. It has been seen that a similar complex is marked off with equal sharpness in the Penokee region. The same lithological difference between the Original Huronian rocks and the underlying crystallines is also manifest. There is no difficulty in separating the Chippewa Valley and St. Louis fragmentals from the not distant crystalline complex, while the latter class of rocks is not known in the Sioux and Baraboo regions. The work of Dr. George H. Williams and Prof. Irving[1] has shown that the green schists penetrated by granites in the Marquette and Menominee regions are to be set off lithologically from the water-deposited rocks of the iron formation, being for the most part intensely altered eruptives. The only region in which there is any considerable difficulty in carrying out the distinction is that of Vermilion Lake. Here the closeness of the folding and the degree of alteration is greater in the clastic formations than elsewhere, as a result of which it is difficult in many places to make a sharp division upon the above basis. But even here the easily recognized clastics and the crystallines of the granite-gneiss complex are both developed on a great scale; so that the doubt applies only to a comparatively small proportion of the rocks of the region, which are somewhat intermediate in character. Consequently, with a somewhat wide familiarity with the other regions about Lake Superior, we have a good deal of confidence that the same fundamental division which elsewhere prevails will be here found to apply. Thus while in some cases it is with difficulty that the associated crystalline schists of the adjacent granite-gneiss complex are separated from the clastic series, in all but two of the regions in which the basement complex is covered by newer formations there are the same two great classes of rocks, (1) granites, granitoid gneisses, gneisses and crystalline schists—none of which can readily be traced in origin to a water-deposited sediment; and (2) water-deposited sediments, including both fragmental and nonfragmental kinds. The clastics have often been subsequently widely modified, but can generally be traced without great difficulty back to their original condition. No one, I think, can make a careful field and laboratory study, with the assistance of microscopic methods, of these rocks, without becoming convinced of the fundamental character of this classification.

The lithological argument, then, for the general equivalence of these various series in the same geological basin rests, first, upon the essential likeness of the clastic beds constituting them; and, second, upon their separability from completely crystalline adjacent rocks.

Prof. Irving, in one of the papers referred to,[2] has in detail pre-

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[1] Bulletin U. S. Geol. Survey, No. 62: The Greenstone Schist Areas of the Menominee and Marquette Regions of Michigan, by Geo. H. Williams; with an introduction by R. D. Irving.

[2] A Classification of the Early Cambrian and pre-Cambrian Formations of the Northwest.

sented the arguments which go to show that in each district these clastic beds are separated by great unconformities from the underlying schists, gneisses and granites. The proof thus presented has been elaborated in this memoir with reference to the Penokee series. The evidence of great time gaps between the clastic series and the underlying crystalline series is less clear in the other regions of the Northwest than in the Penokee and Animikie regions. However, general field relations, the difference of the relations of the granites to the crystalline schists and to the clastics, actual local unconformities, basal conglomerates, the fragments of which are from the underlying crystallines, are all cited as proofs of the general unconformity maintained to prevail between these clastic and nonclastic series.

Further, the relative geographical positions of the Penokee to the Marquette-Menominee-Felch Mountain and the Chippewa Quartzite regions are such as to strongly suggest that they were once connected. It has been seen that the Penokee series at the east is cut off by the unconformably overlying Eastern Sandstone; but east of the south end of Gogebic Lake there are here and there outcrops of slate which are like the Upper Slate of the Penokee district, and not far to the east, the narrow belt spreads out into the broad area of clastic rocks of which the Marquette, Felch Mountain and Menominee districts are arms. At the west the Penokee series has been entirely swept away by erosion, the copper-bearing rocks coming in contact with the underlying gneisses and granites; but to the southwestward appear the fragmental quartzites of the Chippewa Valley, which are believed to be its continuation.

That a definite parallelism of the various formations in all of these series should be difficult, scattered as they are over so extensive a region—the rocks on the north shore of Lake Huron are about 800 miles from those of the Sioux Valley—is not at all strange. It could not be expected that a like succession would be found in each of the areas, even if they all in a single basin belong to the same geologic series. In the first place, the rocks in some cases are not sufficiently tilted to make it certain that all of the layers are exposed. Further, nine-tenths or more of the surface of the country over which they are distributed is heavily covered by the drift, so that it is all but certain that formations at the rock surface have not been discovered. Still further, no satisfactory explanation has yet been made of the succession of formations in the Marquette, Felch Mountain, Menominee and Vermilion Lake regions.

So it is not yet known how far the order which prevails in one of the regions is equivalent to that which prevails in the others. I suspect that future investigations will show that this likeness is greater than has been suspected. But even supposing the discordances are as great as the present known facts might lead one to suppose, it would not be any very strong evidence against the reference to one series of all these detached areas; for it is not to be expected that the same conditions of sedimentation would prevail at all times in a geological basin 800 miles in diameter. While in one part of the basin fragmental sedimentation was going on, it would be very strange if chemical or organic sedimentation was not elsewhere taking place. It is all but demonstrated that the Penokee and Animikie series are the geological equivalents of each other in the broadest sense of the term. It is not necessarily true that sedimentation began or ended simultaneously in both regions, but only that in the main they stand as time equivalents. And considering all the relations before mentioned, it is exceedingly probable that all of these other belts of noncrystalline water-deposited rocks within this same basin are to be referred to one great period of time. How far a correspondence can be made out among their successive members can be determined only by a detailed investigation of each of the areas spoken of, such as is here attempted of the Penokee series.

The term Huronian was first given a systematic meaning as applied by Logan and Murray to the water-deposited sediments upon the north shore of Lake Huron. The term Laurentian has been applied by the geologists of Michigan and Wisconsin, to cover the granite, gneiss, and crystalline-schist complex, structurally separable from the overlying clastic series. In Canada, if I read the reports aright, the term has been made to include in the northwest only the granite and gneissoid granite. I believe the head of the Canadian Survey himself maintains that the relations between the granitoid gneisses and granites referred to the Laurentian, and the associated crystalline schists and other rocks referred to the Huronian are usually obscure, although it is believed that the Huronian is above the Laurentian. If so, the use of the term Laurentian to designate one class and the term Huronian to designate the other is really a lithological use. Such a use of these terms departs from that of Murray and Logan. It seems to us that a much better application of the terms is to return to their usage and to restrict Huronian to those water-deposited rocks which, the equivalent of the original Huronian, are marked off structurally and lithologically from the underlying complex of crystalline schists, granites, and gneisses, and to use Laurentian, or, better, Archean, for the complex and confessedly as yet inseparable rocks which underlie them. Using the terms with this significance, the Penokee series of Michigan and Wisconsin is believed to be Huronian, and the Southern Complex, Archean.

PLATES.

PLATE XXII.

PLATE XXII.—FROM THE SOUTHERN COMPLEX.

Fig. 1. Hornblende granite. Specimen 12873, slide 5504. From the northeast quarter of the southwest quarter Sec. 23, T. 47 N., R. 47 W., Michigan. South of Aurora Mine. In polarized light, X 25. The strongly feldspathic character of the granite of the Southern Complex is shown. A large proportion of the feldspar is microcline. The pegmatitic structure of quartz and feldspar is shown in one place. The dark areas are mostly hornblende. In one individual twinning is seen.

Fig. 2. Hornblende biotite syenite. Specimen 7615, slide 2070. From near the northeast corner of Sec. 27, T. 47 N., R. 47 W., Michigan. In the ordinary light, X 25. A coarsely crystalline feldspathic background is apparent. The individuals of feldspar are large and fit in much the same manner as does the feldspar in the massive syenites and granites from this vicinity; but in this rock it is cut through and through with hornblende and biotite, which are arranged approximately with their longer axes in a common direction and thus give the rock its foliation. The relations suggest the secondary development of the hornblende and biotite within the feldspar by dynamic metamorphism.

PLATE XXIII.

PLATE XXIII.—FROM THE SOUTHERN COMPLEX.

Fig. 1. Biotite gneiss. Specimen 7529, slide 1963. From a short distance south of the north quarter post of Sec. 18, T. 47 N., R. 45 W., Michigan. In the polarized light, X 25. The section is composed mainly of small particles of nearly uniform size, consisting of quartz and feldspar mingled with biotite. The roundish and yet closely fitting character of the quartz and feldspar is nicely shown. There is also seen a few larger roundish grains of quartz. This is one of the rocks of the Southern Complex which has a strong fragmental appearance, and yet there is no certain evidence that it is clastic. The particles now perfectly fit each other, therefore they could not thus have been mechanically deposited. None of them shows evidence of enlargement, so the crystalline appearance can not be accounted for in this way.

Fig. 2. Hornblende gneiss. Specimen 9060, slide 2921. From the south part of the southwest quarter Sec. 33, T. 46 N., R. 2 E., Wisconsin. In the ordinary light, X 25. The light background is composed of finely crystalline quartz mingled with a good deal of feldspar, the latter commonly being in larger areas than the quartz and having often roundish outlines. These facts are not apparent in the figure. It is introduced to show the peculiar character of the hornblende individuals. They run from minute fibers up to tolerably large blades which have extremely ragged outlines. They cut the quartz and feldspar through and through. Their appearance is such as to suggest that they are now in the process of growth, and in thin section the relations of the hornblende and quartz to the feldspar further suggest that from the feldspar these minerals have developed. If all of the minerals now present are original, the hornblende must certainly have been the first to crystallize, so thoroughly does it penetrate the others; but this is very much less probable than that it has developed as the last mineral of the rock, and subsequent to its consolidation.

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THIN SECTIONS FROM THE SOUTHERN COMPLEX.

PLATE XXIV.

PLATE XXIV.—FROM THE CHERTY LIMESTONE MEMBER.

Fig. 1. Tremolitic dolomite. Specimen 9678, slide 3165. From 1850 N., 1675 W., of the southeast quarter Sec. 22, T. 44 N., R. 5 W., Wisconsin. In the ordinary light, X 60. The finely grained part of the section shows the evenly granular appearance characteristic of the massive limestones and dolomites. In one part of the figure is more coarsely crystalline carbonate and a broad blade of tremolite. The sections chance to be so cut that this mineral appears in part as a mere film, below which the vague outlines of the particles of dolomite are seen.

Fig. 2. Concretionary chert. Specimen 9434, slide 3131. From 1923 N., 1940 W., of the southeast corner Sec. 14, T. 47 N., R. 45 W., Michigan. In polarized light, X 60. A fine grained chert. The minute mosaic characteristic of chert, when viewed in the polarized light, is nicely shown. The material is arranged in a vague, concretionary fashion, areas composed of very finely crystalline silica being surrounded by borders of more coarsely crystalline quartz. Although imperfectly shown in the figure, the latter has to some extent the radial fibrous arrangement of chalcedony.

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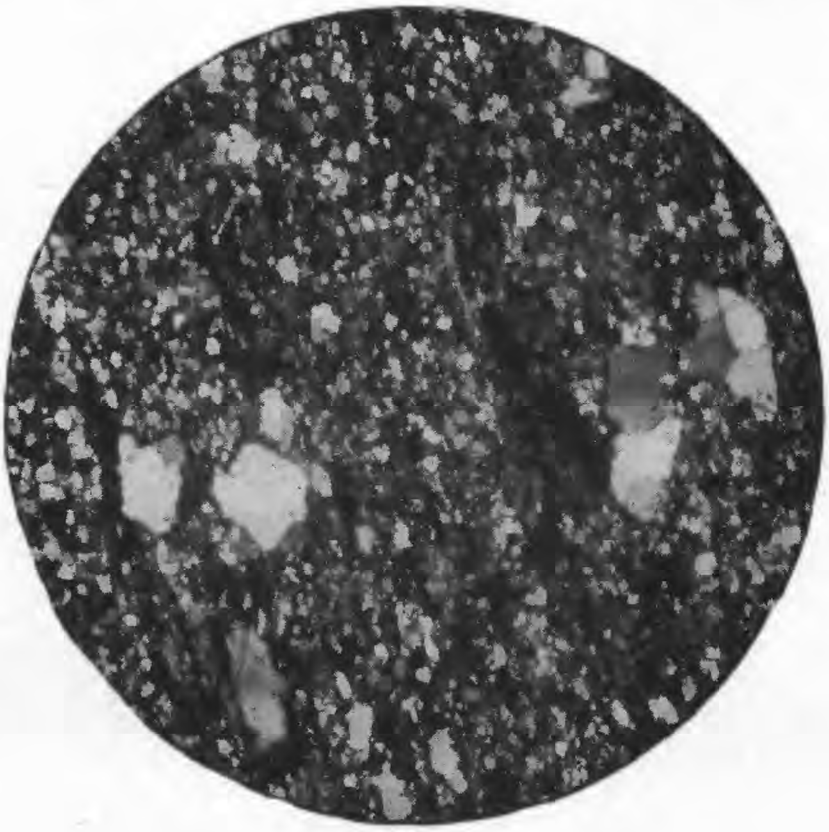
[1] In this and succeeding plates locations are given north and west from the southeast corner of the section in steps of 2,000 to the mile.



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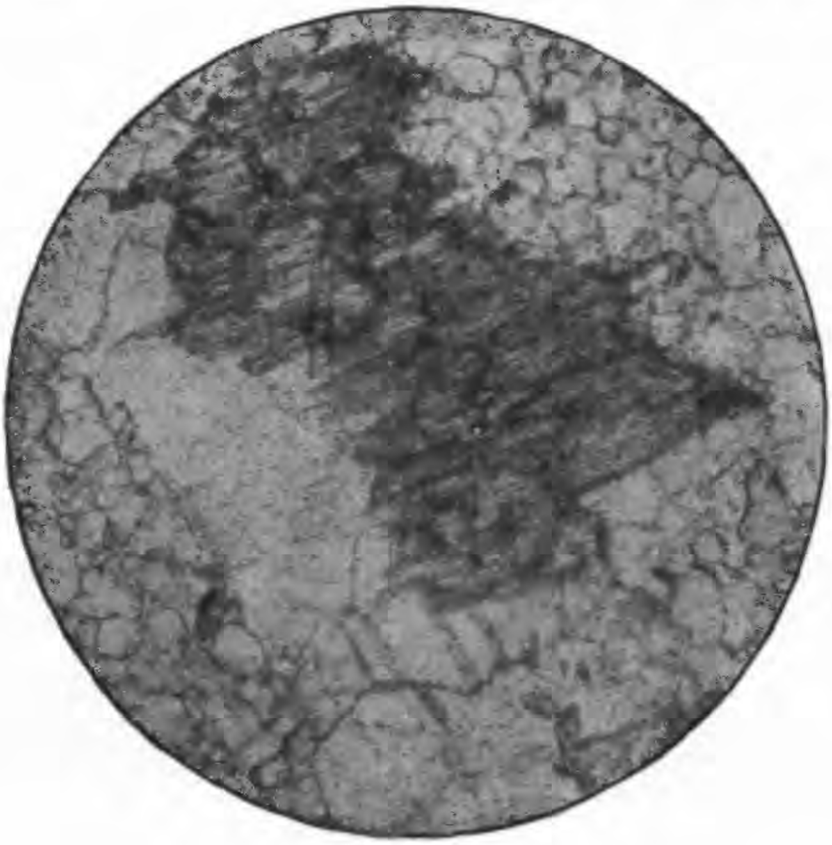
THIN SECTIONS FROM THE SOUTHERN COMPLEX.

PLATE XXV.

PLATE XXV.—FROM THE BASE OF THE QUARTZ SLATE MEMBER.[1]

Fig. 1. Chert, containing fragmental quartz. Specimen 9534, slide 3140. From 1480 N., 1200 W., Sec. 14, T. 44 N., R. 3. W., Wisconsin. In polarized light, X 30. The background of the section is composed of finely crystalline, nonfragmental quartz. In it are contained large well rounded grains of fragmental quartz, one of which has plainly received a second growth. In the lower part of the figure is a complex rounded area of chert not greatly different from the matrix in which it is set.

Fig. 2. Cherty slate. Specimen 9641, slide 3310. From 1460 N., 1185 W., Sec. 13, T. 47 N., R. 46 W., Michigan. In polarized light, X 60. The background of the section is an ordinary chloritic slate. It contains, however, in certain layers numerous large, well rounded fragments of quartz and chert, both of which are well shown in the figure.



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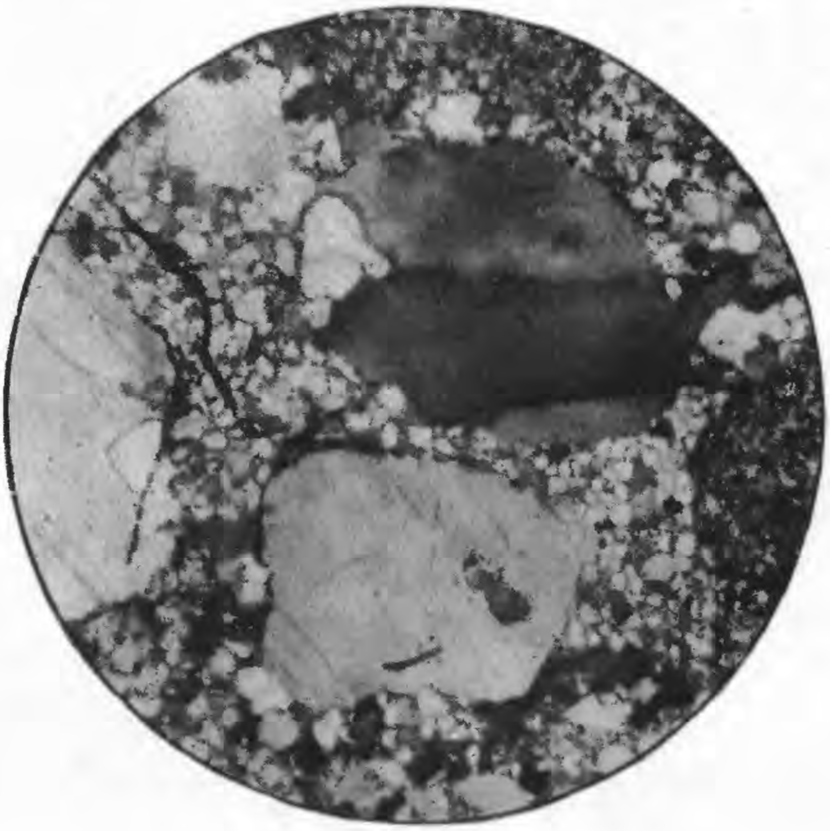
THIN SECTIONS FROM THE CHERTY LIMESTONE MEMBER.

PLATE XXVI.

PLATE XXVI.—FROM THE QUARTZ SLATE MEMBER.

Fig. 1. Greywacke slate. Specimen 9442, Slide 3071. From 385 N., 1600 W., Sec. 10, T. 47 N., R. 45 W., Michigan. In the polarized light, X 60. The figure represents a typical average grained greywacke slate. The rounded fragments are in about equal quantity quartz and feldspar. Chlorite is the chief interstitial mineral. The orthoclase is in most cases separable from the quartz, in that it lacks the perfect clearness and uniformity of color which each grain of that mineral shows. The striated feldspars are nicely shown.

Fig. 2. Sericitic and chloritic slate. Specimen 9523, Slide 3091. From 775 N., 760 W., Sec. 16, T. 47 N., R. 46 W., Michigan. In the polarized light. X 60. The section illustrates one of the rather uniform, fine grained feldspathic quartz slates. The small roundish areas are in part quartz and in part feldspar. The dark material is mostly chlorite, and grains of quartz and feldspar which chance to be cut nearly perpendicular to the optic axes.



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THIN SECTIONS FROM THE BASE OF THE QUARTZ-SLATE MEMBER.

PLATE XXVII.

PLATE XXVII.—FROM THE QUARTZ SLATE MEMBER.

Fig. 1. Biotitic chlorite slate. Specimen 9565, Slide 3098. From 1540 N., 1180 W., Sec. 14, T. 44 N., R. 3 W., Wisconsin. In the polarized light, X 60. Many small, oval and angular particles of quartz are contained in a matrix, consisting very largely of chlorite, with which is, however, a small amount of biotite. The angularity of the quartz grains is very noticeable. This is in some cases due to the enlargement of the quartz grains, but often they were thus angular when deposited. The figure has a more crystalline appearance than the section from which it was taken, from the fact that the cores of the quartzes which have undergone a second growth are not strongly marked off from the enlargements, although in thin section they are easily distinguished.

Fig. 2. Quartzite. Specimen 9082, Slide 2780. From 1000 N., 210 W., Sec. 19, T. 45 N., R. 1 E., Wisconsin. In the polarized light, X 25. The rock is a vitreous quartzite, and yet the figure shows with perfect distinctness the outlines of each of the original rounded grains of sand. The cause of the present strong and vitreous character of the quartzite is clearly shown. Each of the grains of quartz has added to itself other quartz, until they have met and interlocked with similar growths from other grains. This is a fine instance of the induration of a sandstone by simple enlargement of the original grains.

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THIN SECTIONS FROM THE QUARTZ-SLATE MEMBER.

PLATE XXVIII.

PLATE XXVIII.—FROM THE IRON-BEARING MEMBER.

Fig. 1. Sideritic and ferruginous chert. Specimen 9474, Slide 3082. From Sec. 13, T. 47 N., R. 46 W, Michigan. In the ordinary light, X 60. The section shows the alteration of iron carbonate into iron oxide. The background is chert. Upon one side of the figure are rhombohedra of little altered siderite. Upon the other are black pseudomorphous areas, which are composed of somewhat hydrated hematite. Between the two are graduation phases.

Fig. 2. Concretionary chert. Specimen 9048, Slide 2886. From southeast quarter Sec. 27, T. 46 N., R. 2 E., Wisconsin. In the polarized light, X 25. In the background are beautiful concretions, which are composed of concentric rings of iron oxide and chert. One concretion particularly is very fine, showing many closely packed concentric rings. The cherty background appears as a fine mosaic. In and about the concretions the quartz is more coarsely crystalline than the average of that in the matrix. In a few places silica is seen breaking across the rings of the concretions, showing either that silica has been introduced, or at least that to some extent it has been rearranged.

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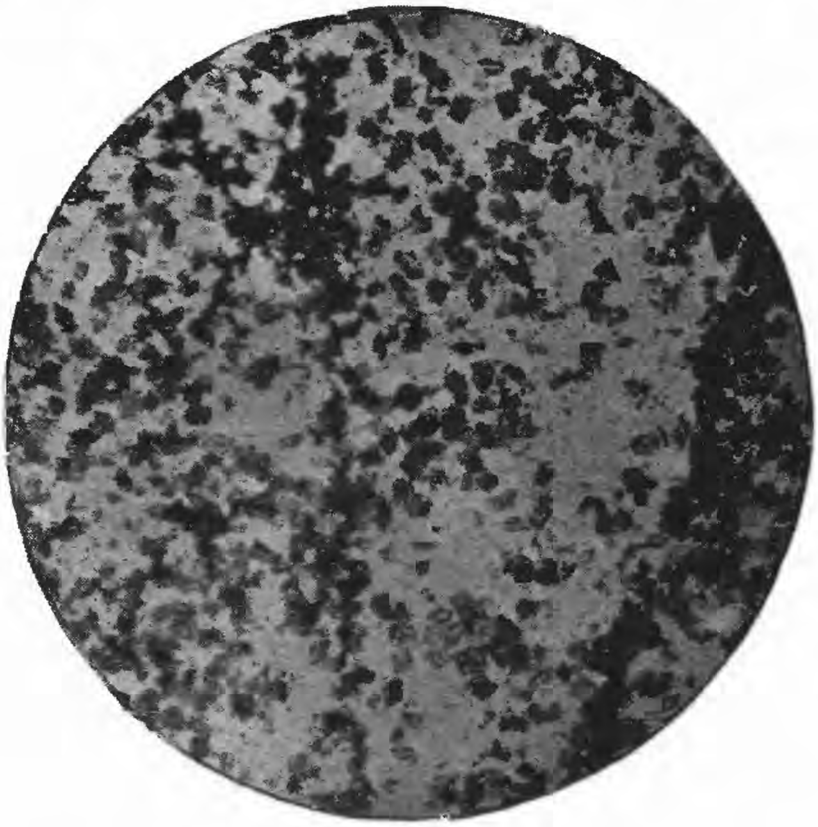
THIN SECTIONS FROM THE QUARTZ-SLATE MEMBER.

PLATE XXIX.

PLATE XXIX.—FROM THE IRON-BEARING MEMBER.

Fig. 1. Ferruginous chert. Specimen 9081, Slide. 4206. From the southeast quarter Sec. 24, T. 45 N., R. 1 W., Wisconsin. In the polarized light, X 25. A completely crystalline cherty background contains areas which are in part roughly oval or roundish, but are more largely exceedingly irregular. These areas are composed of quartz and iron oxide, the latter being mostly hematite, the remainder magnetite. The regular areas suggest concretions, the history of which has been given. The irregular areas resemble fragments, but are probably pseudo-fragments which have formed within the rock itself. They doubtless represent original iron carbonate areas. This carbonate has largely changed to oxide, but has also to some extent been leached out, thus leaving cavities. After or before the completion of this process silica has entered and filled the cracks and cavities. The result of this oxidation, solution and silicification has been to put in the place of well defined areas of iron carbonate the exceedingly irregular forms presented by the figure.

Fig. 2. Actinolitic schist. Specimen 9555, Slide 3190. From Penokee Gap; northwest quarter Sec. 14, T. 44 N., R. 3 W., Wisconsin. In the polarized light, X 25. A typical rock of this type. A completely crystalline quartzose background contains very numerous minute needles of actinolite and many particles of magnetite, the latter being roughly concentrated into bands, one of which and a part of another is shown in the figure. The intricate manner in which the quartz is cut by needles of actinolite is to be noted.



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THIN SECTIONS FROM THE IRON-BEARING MEMBER.

PLATE XXX.

PLATE XXX.—FROM THE IRON-BEARING MEMBERS OF OTHER SERIES.

Fig. 1. Cherty iron carbonate. Specimen 8726, Slide 3367. From Vermilion Lake, Minnesota. In the polarized light, X 25. The figure shows very finely the alternation of bands of chert and iron carbonate. The darker belts are nearly pure siderite and the lighter ones almost pure chert, although they are seen to contain minute rhombohedra of carbonate. The intricate manner in which the quartz anastomoses, cutting the carbonate bands, shows that silica has been introduced since the deposition of the carbonate, or else extensively rearranged, or both. The figure is here introduced in order that the cherty carbonates of other districts may be compared with those of the Penokee Series.

Fig. 2. Cherty iron carbonate. Specimen 10172, slide 3422. From Dawson's Road, Port Arthur, Canada, Animikie series. In the ordinary light, X 60. The figure well illustrates the appearance of one of the richer Animikie cherty carbonates. Throughout most of the section iron carbonate is the chief constituent, and the manner in which the individuals are packed together is well shown; when surrounded by chert they show perfect rhombohedral forms. Alteration of iron carbonate to iron oxide has begun.

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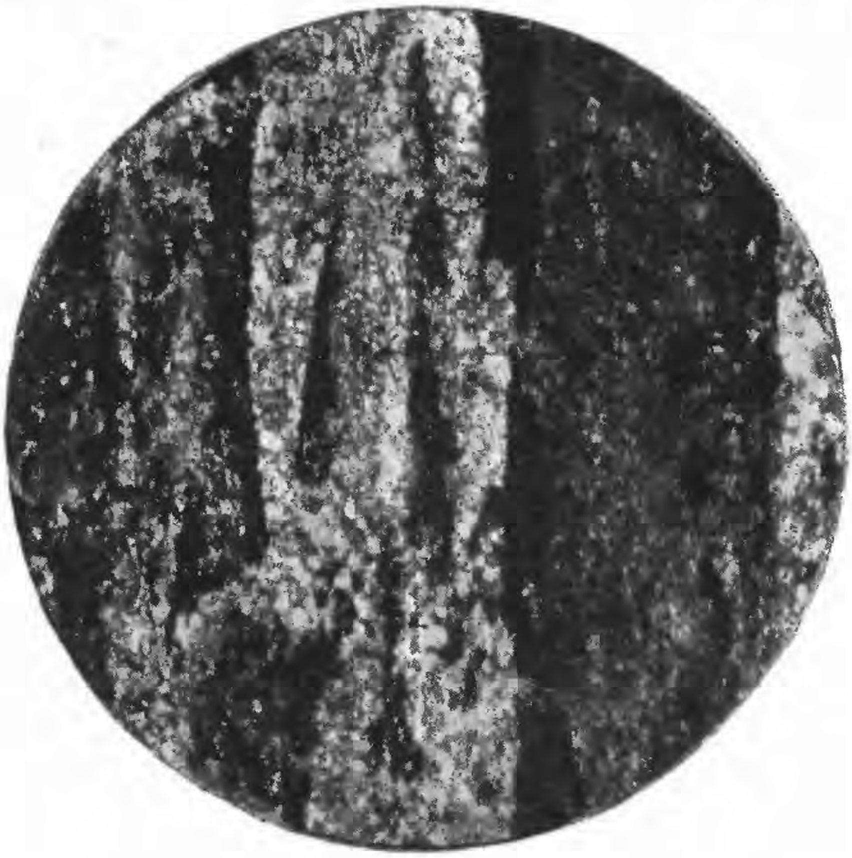
THIN SECTIONS FROM THE IRON-BEARING MEMBER.

PLATE XXXI.

PLATE XXXI.—FROM THE IRON-BEARING MEMBERS OF OTHER SERIES.

Fig. 1. Sideritic chert. Specimen 6138, Slide 1173. From north shore of Gunflint Lake, T. 65 N., R. 3 W., Minnesota; Animikie series. In the ordinary light, X 25. The figure illustrates the formation of iron oxides pseudomorphous after siderite. A background of chert contains numerous small roundish and rhombohedral areas of siderite and iron oxides. Between the little and wholly altered siderite a complete gradation is seen.

Fig. 2. Actinolite-siderite slate. Specimen 10579, slide 5188. From the east side of north arm of Gunflint Lake, Minnesota; Animikie series. In the polarized light, X 25. The section is from one of the typical Animikie slates. It is designed to show the termination of a thick layer of nearly pure chert. The slaty part consists of actinolite, siderite and the three oxides of iron mingled with a little chert. In the cherty background of the lozenge-shaped area are rhombic outlines of siderite. The light-colored border between the slate laminæ and the chert is mostly actinolite, which is suggestive that the latter mineral has resulted from a reaction between the silica and siderite. The laminæ of the slate are seen to curve about the chert area. A short distance from this nodule the laminæ are parallel.



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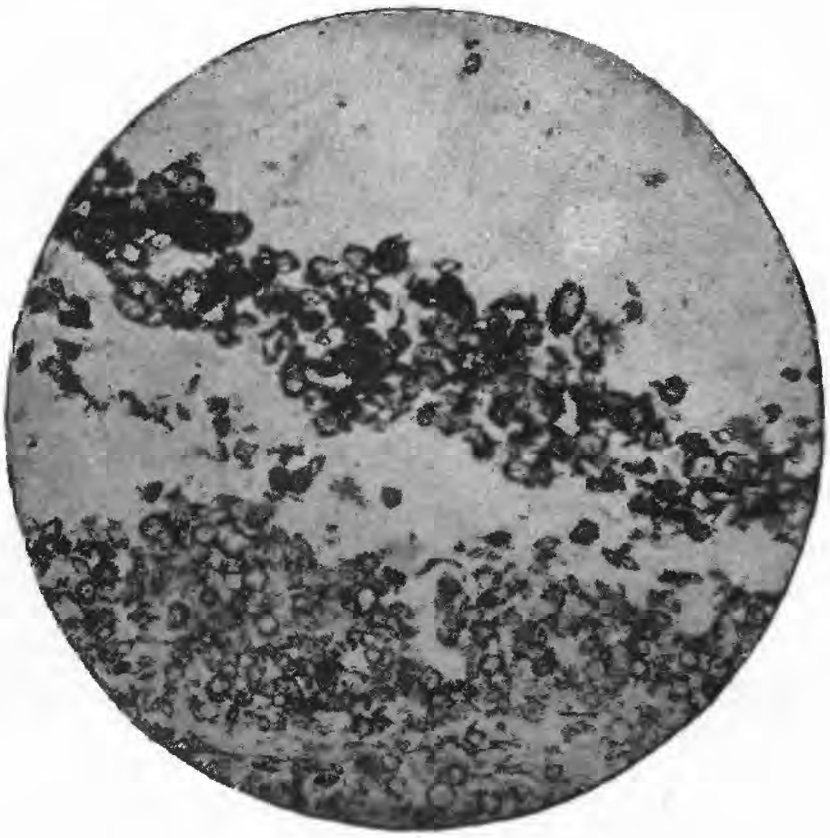
THIN SECTIONS FROM THE IRON-BEARING MEMBERS OF OTHER SERIES.

PLATE XXXII.

PLATE XXXII.—FROM THE IRON-BEARING MEMBER OF THE PENOKEE AND OTHER SERIES.

Fig. 1. Cherty iron carbonate. Specimen 9814, Slide 3880. From Lawrence County, Ohio. In the ordinary light, X 25. The beginning of the alteration of siderite to limonite and hematite, and also the beginning of the formation of concretions are here seen. The background is finely crystalline and amorphous silica. This cherty iron carbonate from Ohio is remarkably like that from the Penokee series shown in the next figure.

Fig. 2. Sideritic chert. Specimen 7622, Slide 2072. From the Montreal River, between Michigan and Wisconsin. In the ordinary light, X 25. A background of chert contains numerous rhombohedra of siderite of greatly varying sizes. The siderite has altered to a considerable extent to oxide of iron, but illustrates the formation of concretions. In some cases the oxide of iron, while it is scattered somewhat irregularly through the areas, as a whole retains the form of the original siderite areas, although the space once occupied by the siderite is taken in part by silica. The large area in the middle of the figure shows particularly well the manner of the formation of concretions. Enough siderite remains so that the rhombohedral cleavage is nicely shown. Upon the outer part of the area is a tolerably continuous ring of black oxide of iron, beyond which are other imperfect rings of red and black oxides. The alteration in the interior of the area has to some extent followed the cleavage lines, and we thus have an explanation of the irregular forms in the interiors of the concretions of the previous figures. It is to be further noted that the rings in the concretions do not conform to the shape of the original siderite areas, but are regular ovals.



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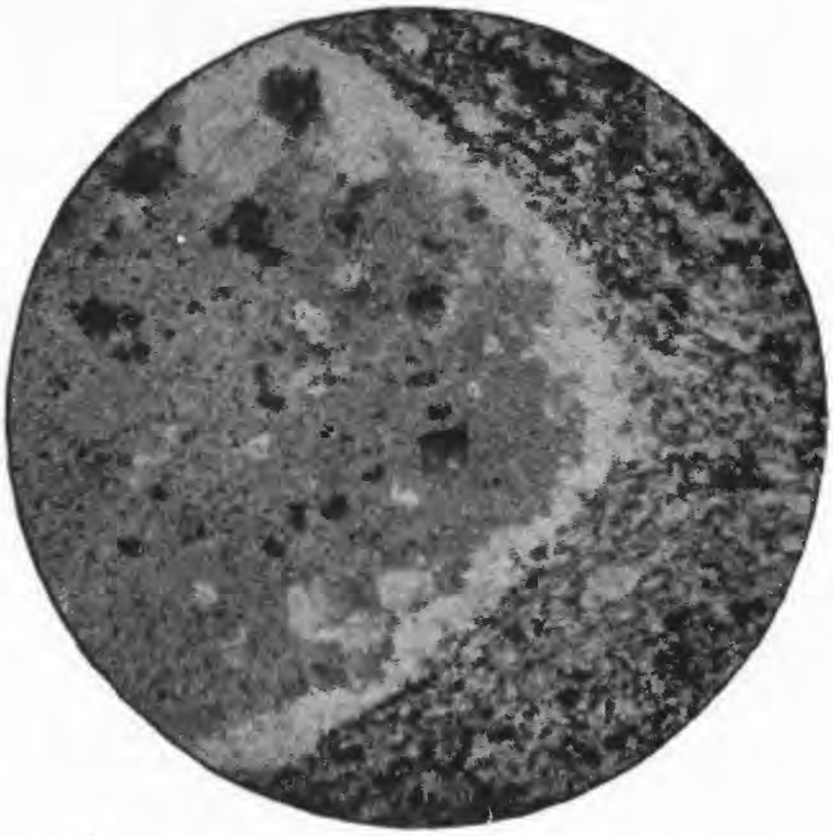

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THIN SECTIONS FROM THE IRON-BEARING MEMBERS OF OTHER SERIES.

PLATE XXXIII.

PLATE XXXIII.—FROM THE IRON-BEARING MEMBER OF THE PENOKEE AND OTHER SERIES.

Fig. 1 Concretionary chert. Specimen 10577, Slide 4997. From the north side of Gunflint Lake; Animikie series. In the ordinary light, X 60. Veins of chert intricately intersect the oxides of iron in such a manner as to show that the silica entered after the iron oxides had formed. The magnetite in the concretions is sometimes in nearly continuous bands, but in other parts is mingled intimately with the hematite. If the large area takes the place of one of iron carbonate, at different times the circumstances were favorable for the production of each of the iron oxides in preponderating quantity.

Fig. 2. Magnetitic concretionary chert. Specimen 9625, Slide 3150. From Tyler's Fork, northeast quarter Sec. 33, T. 45 N., R. 1 W., Wisconsin. In the ordinary light, X 60. A cherty background contains roundish oval and roughly rhombic outlined areas. The iron oxide in these areas is mostly magnetite, which is mostly in the form of crystals. The magnetite is often concentrated upon the exteriors of the areas projecting somewhat into the cherty background. The forms of the areas at once suggest the carbonate areas of Pl. XXXII, figs. 1 and 2, and each doubtless now occupies the place once taken by siderite. In the alteration to magnetite the individuals grew beyond the outer borders of the siderite areas, but the forms as a whole were maintained. A considerable amount of silica must have entered, as the magnetite occupies but a small part of the space once taken by the carbonate.

PLATE XXXIV.

PLATE XXXIV.—FROM THE IRON-BEARING MEMBER OF THE PENOKEE AND OTHER SERIES.

Fig. 1. Banded magnetitic jasper. Specimen 12791, Slide 5477. From Sec. 11, T. 47 N., R. 45 W., Michigan. In the ordinary light, X 25. The white background is a completely individualized but finely crystalline chert. The part containing the abundant red hematite is in hand specimen a brilliant red jasper. These jaspery bands alternate with the black ones, which, instead of hematite, consist of magnetite mostly in well defined crystals. The change from magnetite to hematite is gradual.

Fig. 2. Actinolitic and sideritic slate. Specimen 10580, Slide 5189. From the Gunflint beds, Animikie series. In the ordinary light, X 60. The section illustrates a phase of the iron formation in which all of the minerals, quartz, siderite, magnetite and actionolite are together. The colorless part is the cherty background, which is completely, although finely, crystallized. The siderite is represented by the vague rhombohedral areas, which include numerous minute particles of gray and black material, presumably oxides of iron. This material is the most abundant one in the section. The magnetite occurs as usual with its characteristic crystal outlines, and in places is included in such a manner in the siderite as to suggest its formation from that mineral. The actinolite is scattered here and there in minute blades and needles, being particularly abundant on one side of the figure.

PLATE XXXV.

PLATE XXXV.—FROM THE IRON-BEARING MEMBER OF THE PENOKEE AND OTHER SERIES.

Fig. 1. Actinolitic slate. Specimen 7012, Slide 2081. From southwest quarter Sec. 23, T. 65 N., R. 4 W., Minnesota; Animikie series. In the ordinary light, X 25. The relations of the magnetite, actinolite and quartz are here nicely shown. The magnetite is plainly the first mineral to crystallize, having frequently crystal outlines, and being included within both the other minerals. The close association of actinolite and magnetite is again illustrated, the two combined having usually roundish or oval forms. The silica cuts the section in such a manner as to give it in places vein-like forms, which must have developed subsequently to the formation of the magnetite and actinolite.

Fig. 2. Actinolitic slate. Specimen 9555, Slide 3190. From Penokee Gap, northwest quarter Sec. 11, T. 44 N., R. 3 W., Wisconsin. In polarized light, X 165. The section is a typical actinolite slate. The quartz is completely crystallized. The magnetite has mostly well defined crystal outlines, and is manifestly the first mineral to crystallize, being scattered uniformly through the section without any regard to the actinolite and quartz, and therefore included by both of them. The actinolite is in its characteristic blades and sheaf-like forms, having a radial arrangement of its fibers. It is plainly the second mineral to crystallize, as needles of actinolite everywhere penetrate the quartz, but never the magnetite. The quartz constitutes a background for the magnetite and actinolite, and includes them in such a manner as to make the conclusion certain that it must in the main have crystallized subsequently to the formation of the magnetite and actinolite.

PLATE XXXVI.

PLATE XXXVI.—ORE DEPOSITS.

Fig. 1. Longitudinal section of south deposit, Colby Mine, looking south. This figure shows a very large deposit of ore which was found at the surface, but which, in following eastward, was found to pass under the ferruginous chert. So far as this figure goes, no indication of a dike is seen, but a drill hole put down from one of its deeper levels has passed through a thick dike rock.

Fig. 2. Longitudinal section of north deposit, Colby Mine, looking south. This deposit, before it had been developed to such a depth as the south deposit, reached a dike, and a little farther north this same dike reaches the surface of the ground.

Fig. 3. Cross-section of north and south deposits, Colby Mine. The perpendicular line running through the figure is drawn because the two parts of the section are no exactly upon the same plane. They differ from this so slightly, however, that the true relations of the ore bodies to the surrounding rocks are shown by the combined figure.

Fig: 4. Longitudinal section of Trimble Mine, looking south. This is a case in which the main deposit of ore is above three parallel dikes very close to each other. This deposit, like many others, is found at the surface, but when traced to the eastward, passes below the ferruginous chert. Above the lower dike, a little farther to the west, is a considerable ore deposit.

Fig. 5. Cross-section of Trimble Mine, showing quartzites, ferruginous chert and dike rocks.

FIG. 1.

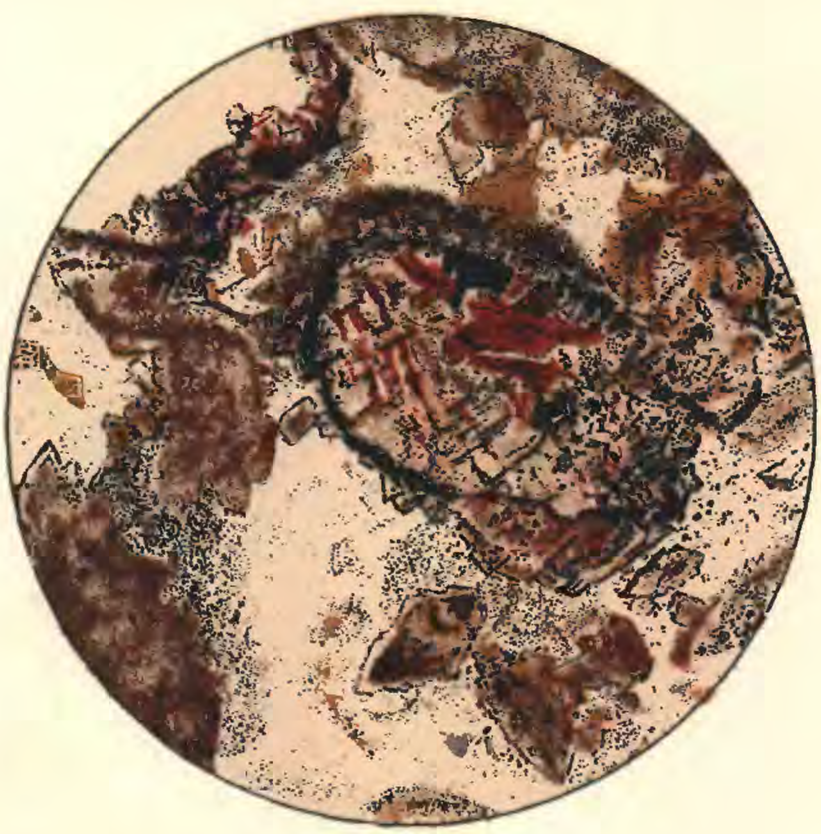


FIG. 2.

THIN SECTIONS FROM THE IRON-BEARING MEMBER OF THE PENOKEE AND OTHER SERIES.

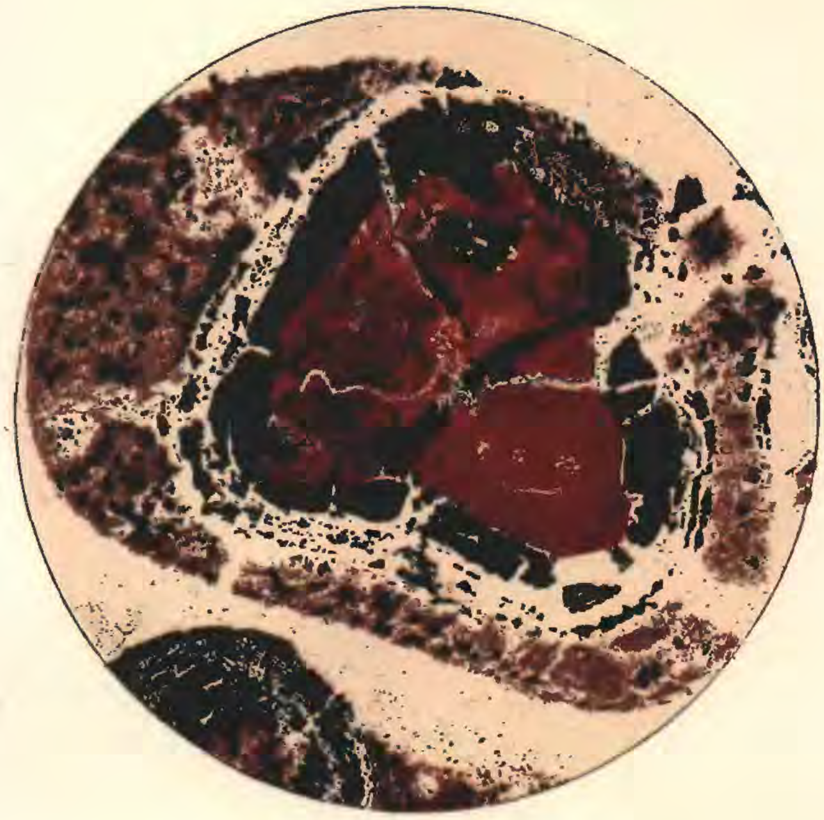


FIG. 1.

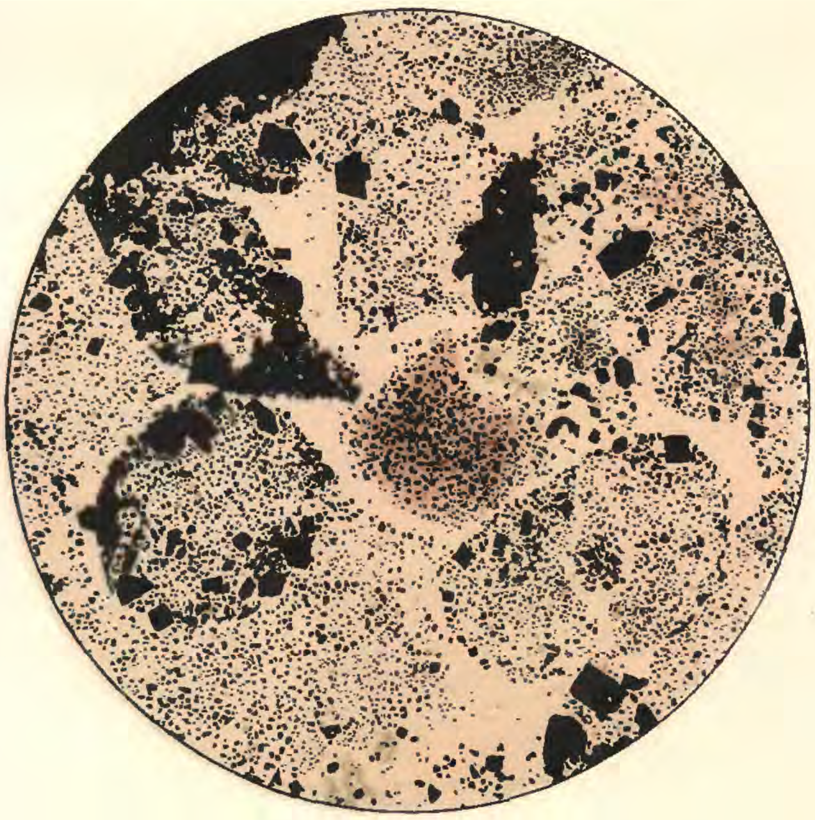


FIG. 2.

THIN SECTIONS FROM THE IRON-BEARING MEMBER OF THE PENOKEE AND OTHER SERIES.

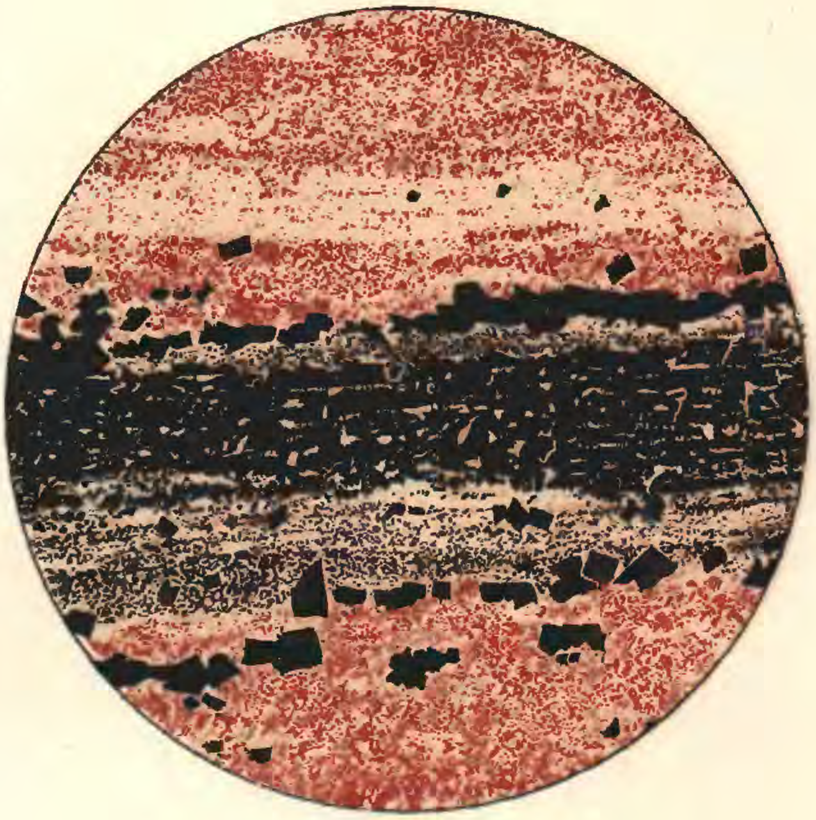


FIG. 1.

FIG. 2.

THIN SECTIONS FROM THE IRON-BEARING MEMBER OF THE PENOKEE AND OTHER SERIES.

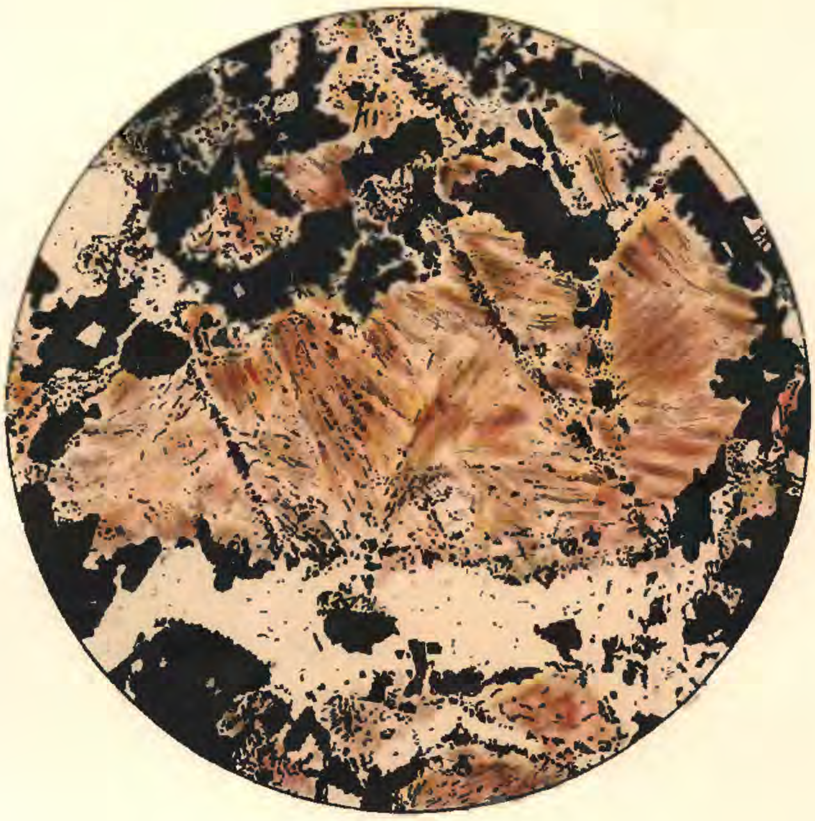


FIG. 1.

FIG. 2.

THIN SECTIONS FROM THE IRON-BEARING MEMBER OF THE PENOKEE AND OTHER SERIES.

PLATE XXXVII.

PLATE XXXVII.—ORE DEPOSITS.

Fig. 1. Longitudinal section of Pence Mine, looking south. A strong dike carries above it a heavy deposit of ore, which was reached by two shafts immediately upon passing through the drift. Just above this same dike, a little farther to the west, no ore is found.

Figs. 2, 3, and 4. Cross-sections of Pence Mine at Father Hennepin and Nos. 2 and 1 shafts. The relations of the dike rock, quartzite, ore deposits, drift material, and ferruginous cherts in this mine are by these sections clearly shown.

Fig. 5. Cross-section of Minnewawa Mine, showing the same relations of quartzite, dike rock and ore bodies; and also a faulting of the foot-wall quartzite where cut by the dike rock.

Fig. 6. Section designed to show variation from unaltered carbonate to ferruginous chert and ore bodies in passing from higher to lower horizons, and to illustrate the manner of ore concentration.

PLATE XXXVIII.

PLATE XXXVIII.—GREYWACKES FROM THE UPPER SLATE MEMBER.

Fig. 1. Biotitic and chloritic greywacke. Specimen 9109, Slide 4418. From the northeast quarter Sec. 12, T. 45 N., R. 1 W., Wisconsin. In the polarized light, X 25. A typical fine grained biotitic and chloritic greywacke. The fragmental character of the quartz is plain, although many of the smaller particles are quite angular. The fragmental feldspar was originally as abundant as the quartz, but the figure does not well show this, as most of the grains of this mineral are extensively altered to biotite and chlorite.

Fig. 2. Biotitic greywacke. Specimen 9598, Slide 3334. From southeast quarter Sec. 15, T. 45 N., R. 1 W., Wisconsin. In the polarized light, X 60. The large roundish area in the center of the figure was once a single fragmental feldspar, but it is almost wholly decomposed, and thus forms an interlocking mass of mica and quartz. In this case detached areas of quartz thus formed are seen to be a unit over a considerable area. This figure illustrates the crystalline character which can result from the alteration of fragmental feldspar. Many individuals of mica and quartz have been produced from a single feldspar, and as they form simultaneously by the alteration, they interlock as completely as if they were original crystallizations, and also with the residual feldspar in case there is any.

PLATE XXXIX.

PLATE XXXIX.—GREYWACKES FROM THE UPPER SLATE MEMBER.

Fig. 1. Biotitic and muscovitic greywacke. Specimen 9544, Slide 3092. From northwest quarter Sec. 11, T. 44 N., R. 3 W., Wisconsin. In the polarized light, X 60. The section is one of the least altered feldspathic fragmental rocks. Large rounded areas of feldspar make up most of the section, although smaller particles of fragmental feldspar and quartz are contained. The incipient alteration of the feldspar to the micas is observed, and the smooth outlines of the fragmental grains have already been lost by alteration. This is the original phase of rock, the alterations of which carried to the extreme have produced the crystalline mica schists.

Fig. 2. Biotite slate. Specimen 126, Wright. From the northeast quarter Sec. 9, T. 44 N., R. 3 W., Wisconsin. In the polarized light, X 25. The section is from a rock which was originally like Fig. 1. The alterations of the feldspar to the mica and quartz has been carried to a greater degree. The regular outlines of the original areas are wholly lost, so that while they have a general roundish or oval form, their exteriors are minutely angular. The micas are much more abundant at and near the exteriors of the grains of feldspars than in the interiors, although the alterations have extended quite to the centers.

PLATE XL.

PLATE XL.—MICA SLATES.

Fig. 1. Biotite slate. Specimen 128, Wright. From the northwest quarter Sec. 9, T. 44 N., R. 3 W., Wisconsin. In the polarized light, X 25. The original condition of this rock was precisely like that of Pl. XXXIX, figs. 1 and 2. The series of alterations there shown have, however, gone much further. The fragmental character of the feldspars are quite lost. They have been penetrated by the formation of muscovite and biotite until they are most irregular in form, only a single grain approximately retaining its oval outline. As a further result of this process a considerable proportion of interstitial crystalline quartz and mica, as compared with the two previous figures, is found, which has come directly from the decomposition of the feldspar.

Fig. 2. Biotite slate. In the polarized light, X 25. This figure is taken from part of the same section as the last, in which the alterations just described have gone still further. The crystalline character of the developing rock is better shown. There remain, however, areas of feldspar which act as a unit, although they are cut in every direction by the alteration products, quartz and mica.

PLATE XLI.

PLATE XLI.—MICA SCHISTS.

Fig. 1. Muscovitic biotite schist. Specimen 2039, Wisconsin. From the northeast quarter Sec. 6, T. 44 N., R. 2 W., Wisconsin. In the polarized light, X 60. The processes of alteration described in the previous figures have here gone so far as to leave but little trace of original fragmental feldspar. Areas of feldspar, however, remain in the section, which, while cut by quartz and mica, so as to give all of the minerals a most crystalline material, yet polarize as a unit.

Fig. 2. Biotite schist. Specimen 153, Wright. From the northeast quarter Sec. 4, T. 44 N., R. 3 W., Wisconsin. In the polarized light, X 60. The section is a typical biotite schist from the Upper Slate Member. The examination of the thin section shows no evidences of fragmental origin. It is composed almost wholly of mica and quartz, the two minerals interlocking in the most intricate fashion. Taken alone it could not be shown that this rock and those represented by the preceding figures were derived from fragmental feldspathic sediments, but taken in connection with the previous figures and the formation in which they are found, it is certain that they have been produced by the alteration of such a rock. The figures of the previous plates, XXXIX, XL, and those of this plate constitute a graded series, which illustrate well the series of alterations by which there has been produced from a completely fragmental rock, composed chiefly of feldspar, a rock which is a typical crystalline schist.

PLATE XLII.

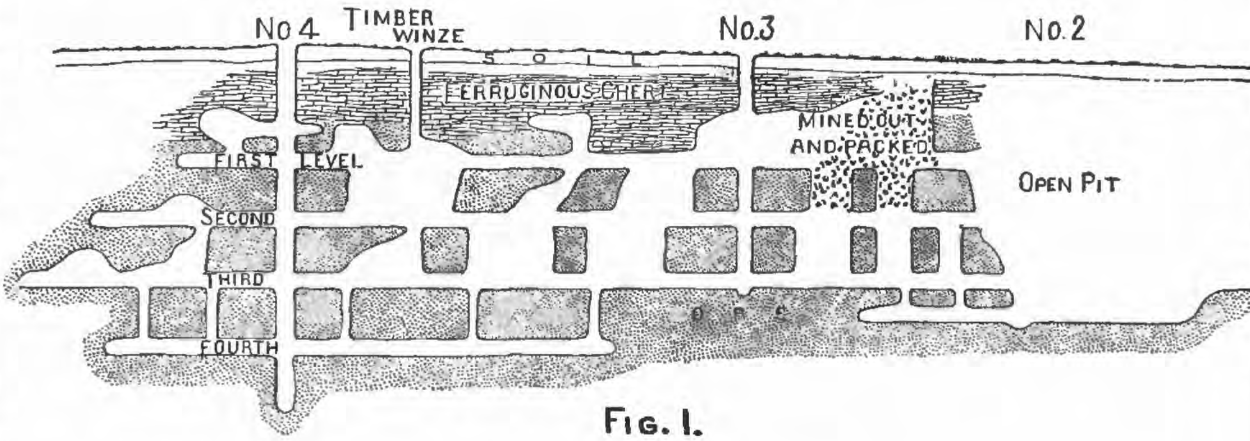


FIG. 1.

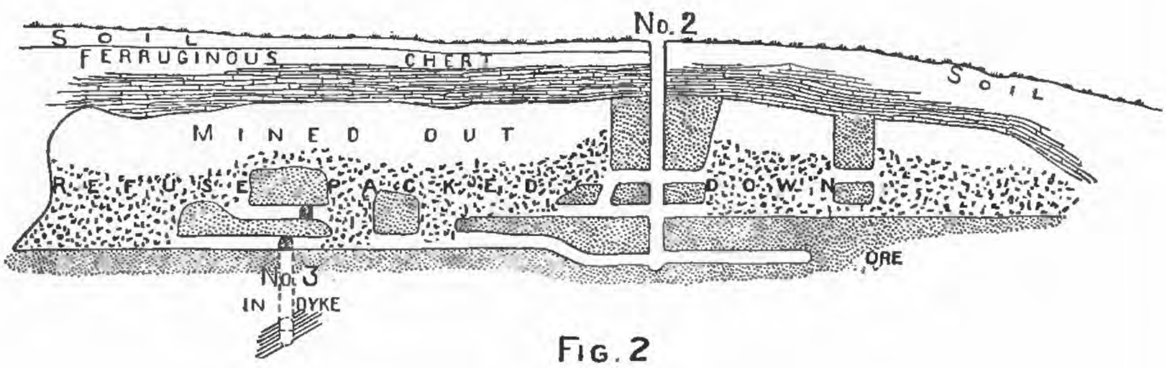


FIG. 2

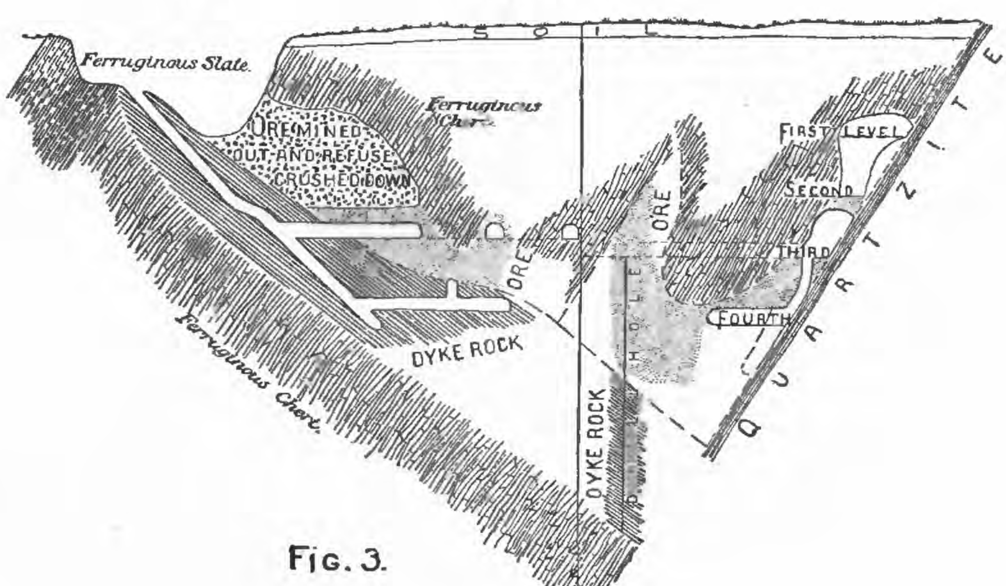


FIG. 3.

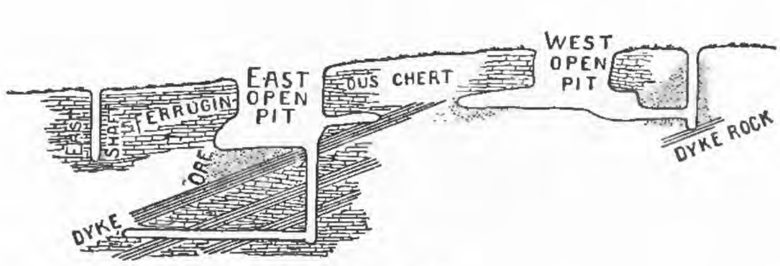


FIG. 4.

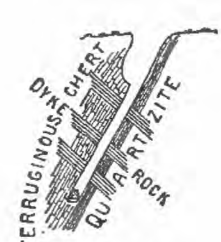
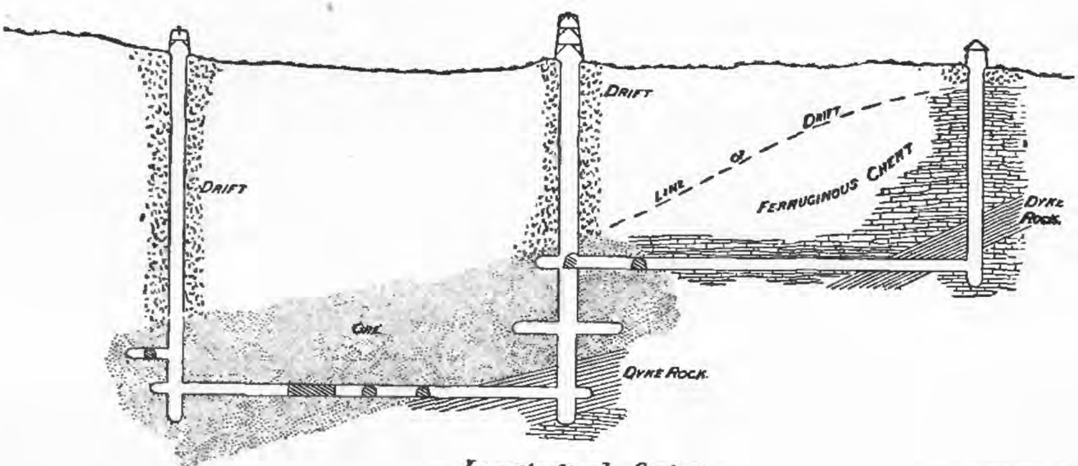


FIG. 5.

ORE DEPOSITS.



Longitudinal Section.

FIG. I.

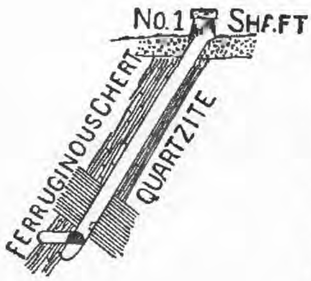


FIG. 4.

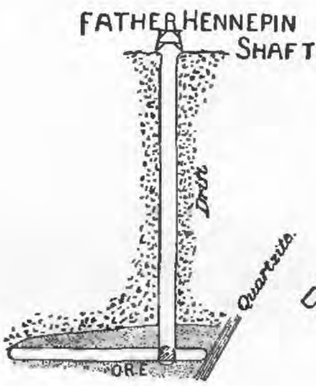


FIG. 2.

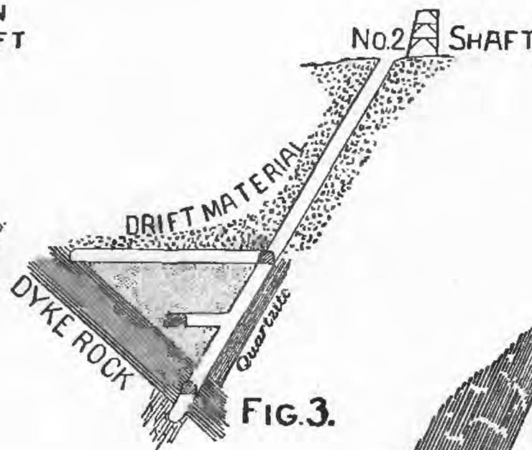


FIG. 3.

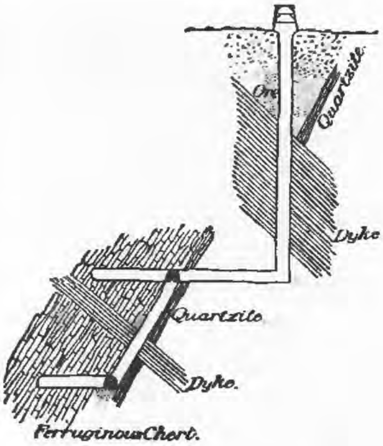


FIG. 5.

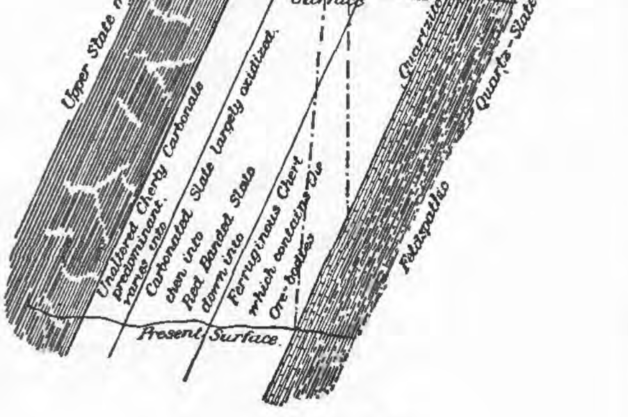
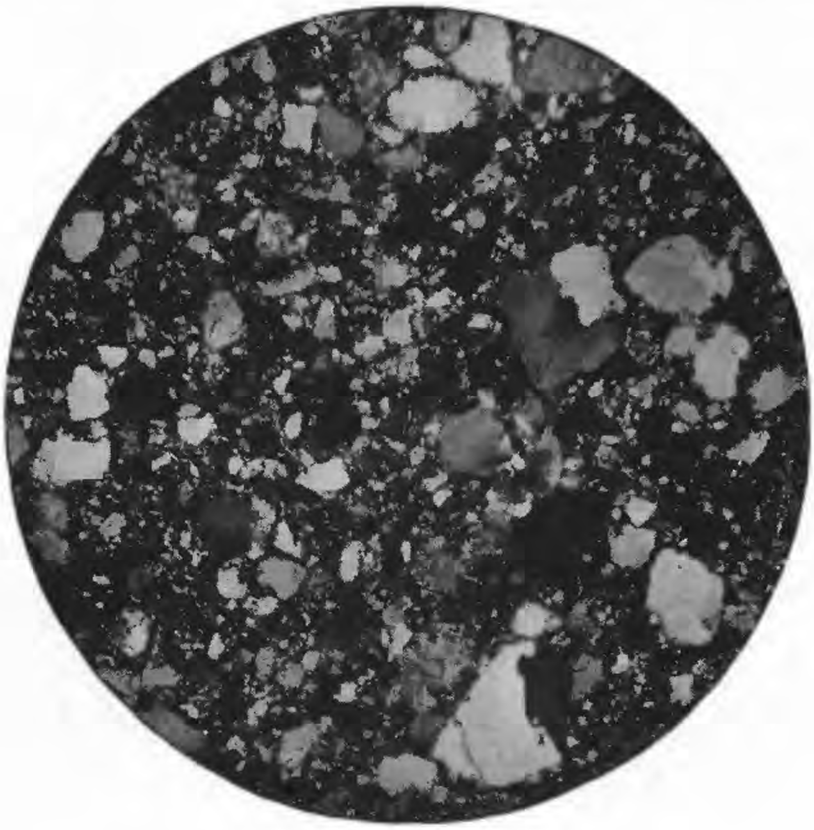


FIG. 6.



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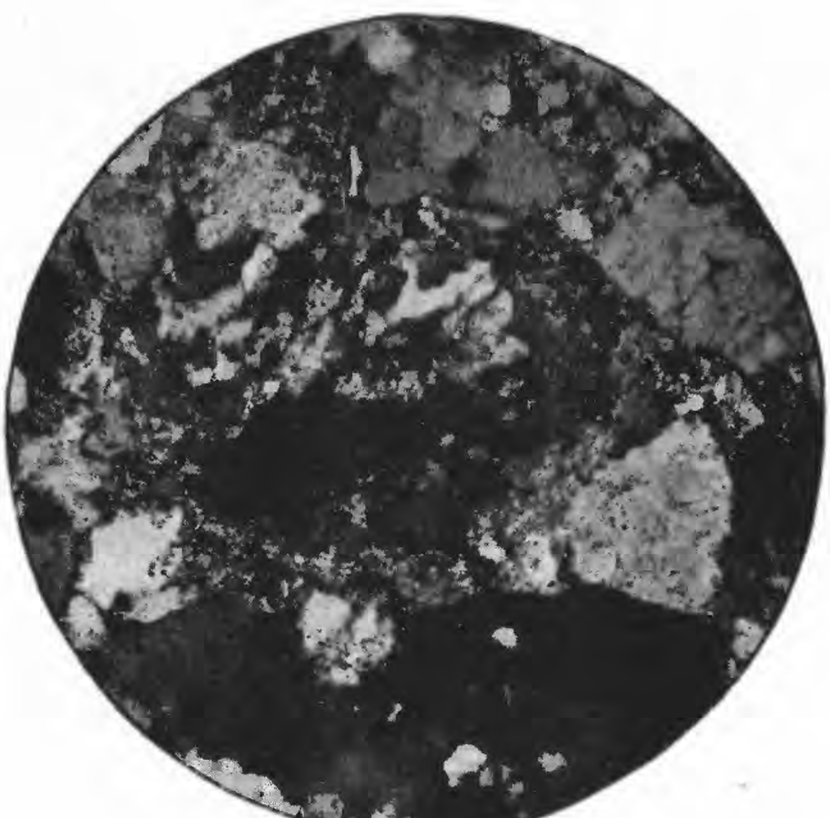

2

THIN SECTIONS OF GRAYWACKES FROM THE UPPER SLATE MEMBER.

1

2

THIN SECTIONS OF GRAYWACKES FROM THE UPPER SLATE MEMBER.

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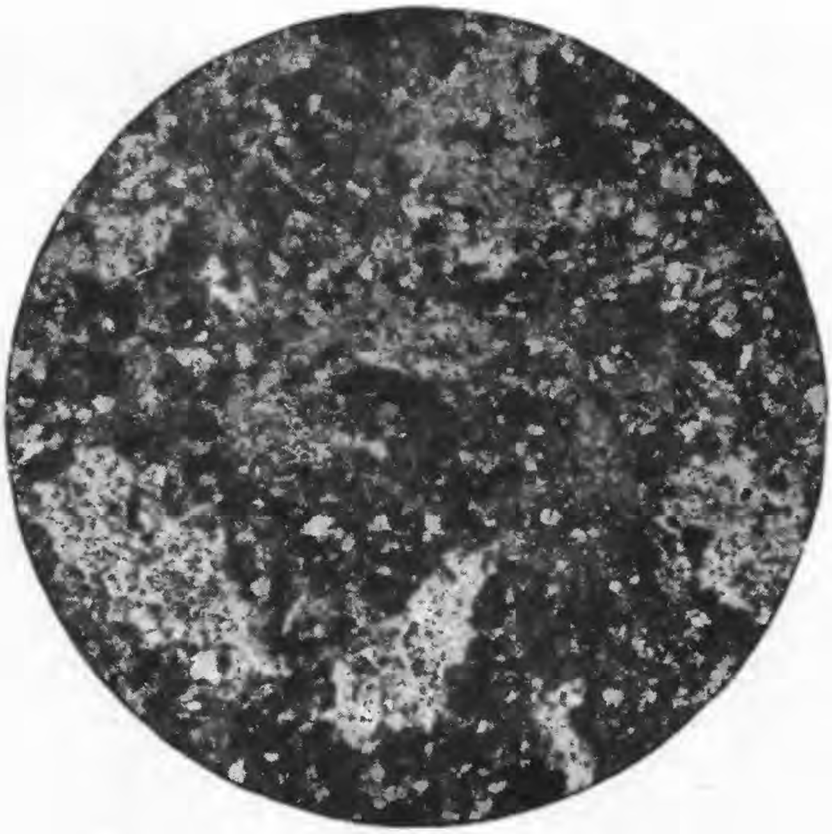
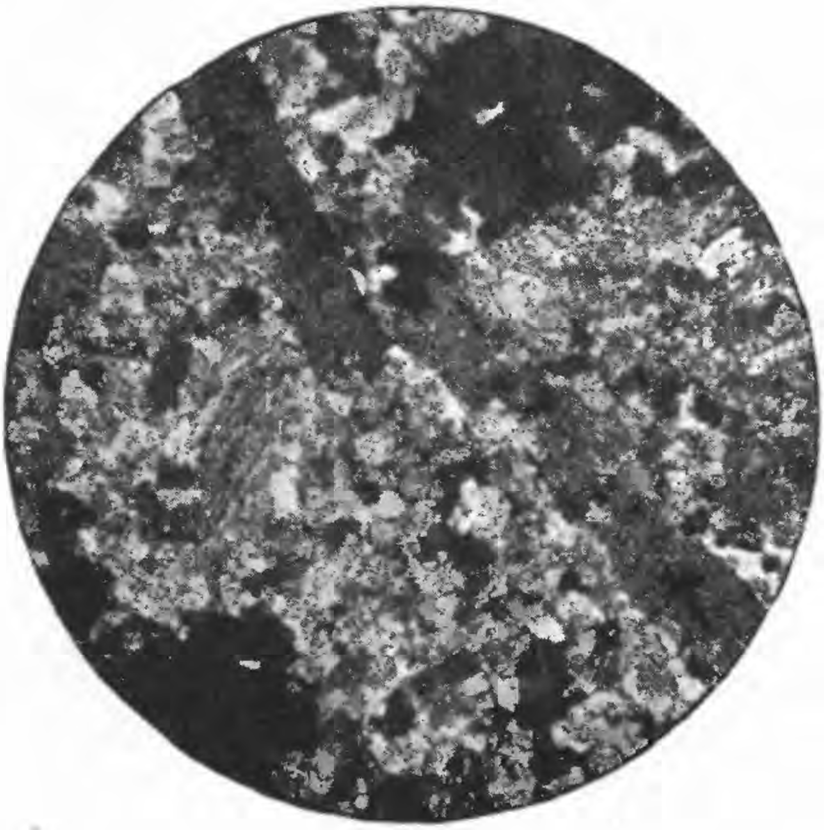


2

THIN SECTIONS OF MICA SLATES.



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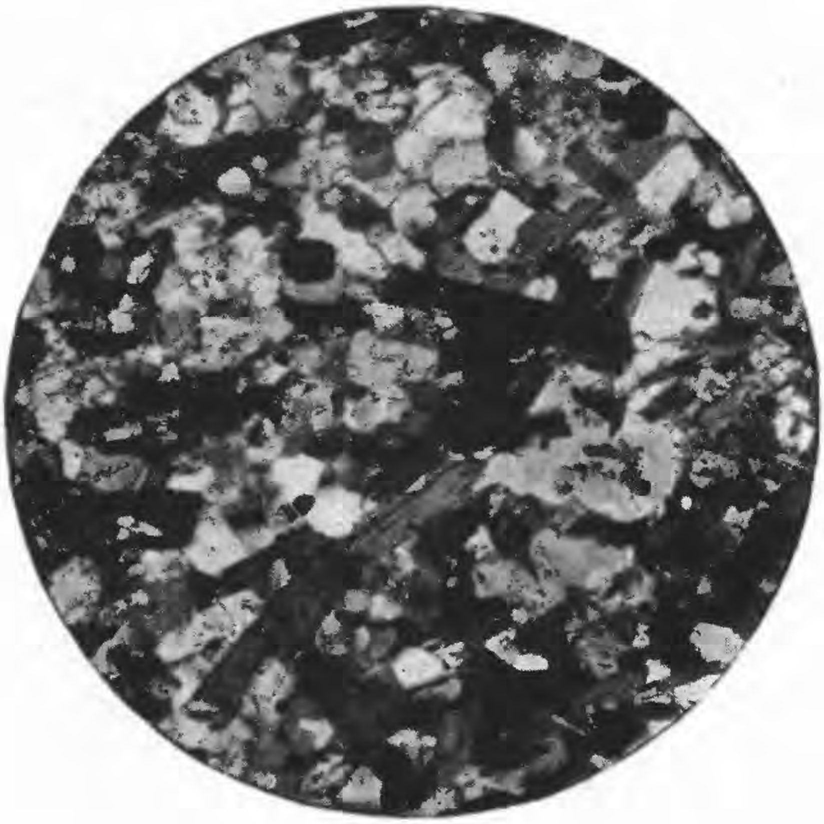


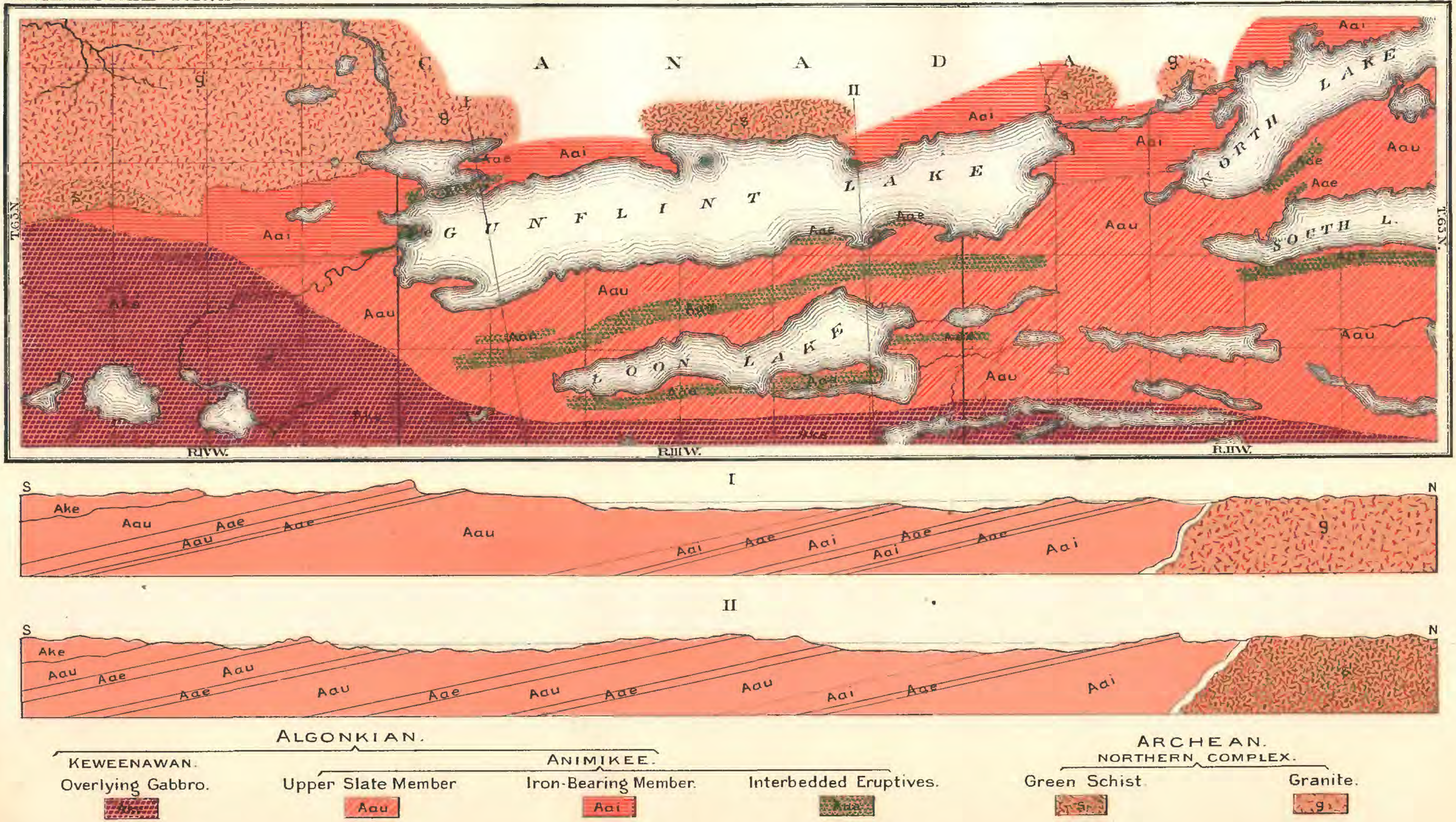
2

THIN SECTIONS OF MICA-SCHISTS.

THE FAUNA OF THE LOWER CAMBRIAN OR OLENELLUS ZONE.

BY

CHARLES D. WALCOTT.



GEOLOGICAL MAP OF GUNFLINT LAKE AND VICINITY, MINN.

Scale of Map 1 inch = 7920 feet. Scale of Sections 2 inches = 1980 feet.

DISTRIBUTION OF THE CAMBRIAN STRATA AS SHOWN BY SURFACE OUTCROPS IN NORTH AMERICA

By C. D. Walcott

100 50 25 0 100 300 600 STATUTE MILES.

Scale.

CONTENTS.

ILLUSTRATIONS.

THE FAUNA OF THE LOWER CAMBRIAN OR OLENELLUS ZONE.

BY CHARLES D. WALCOTT.

I. DEFINITION OF TITLE.

A living fauna, as known to the zoologist, is the assemblage of animals embraced within a given geographic province or area, and includes all animal life associated on account of climate or physical boundaries. Some of the species may range from province to province and form a part of several faunas, while others are limited to a particular portion of some faunal area.

In the study of the extinct faunas, buried in the rocks, the same general principles of classification prevail, with the added restriction of vertical or time range as defined by the progressive zoologic changes in the faunas.

There is not a sufficient assemblage of species found in the oldest rocks in which animal life has been detected to constitute a fauna that can be characterized either as distinct from the succeeding fauna or as belonging to that fauna. At present the first recognized fauna occurs in the lowest division of the Cambrian Group. In nearly all the localities where this lowest zone is recognized a peculiar genus of trilobites, Olenellus, is found; and thus the names Olenellus Fauna and Olenellus Zone have come into general use. By the paleozoologist the fauna is called the Olenellus or Lower Cambrian Fauna. To the geologist the series of rocks in which the Olenellus fauna occurs is known as the lower division of the Cambrian group or Olenellus Zone.

II. SCOPE OF PAPER.

It is proposed to present (1) a list embracing titles of the more important books and papers relating to the subject; (2) a historical review of the work done on the rocks and fossils now included in the Olenellus Zone; and (3) the general results of the study of the fauna by the geologist and paleozoologist, or its physical and biological history and character as far as known. The geologist considers it as found in certain rocks at a distinct geologic horizon and studies its geologic relations. The paleozoologist treats of it in its relations to the animal world, past and present.

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[1] Prof. C. H. Hitchcock claims to have written this portion of the report, although it is included in a chapter headed E. Hitckcock, sen.

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CHRONOLOGICAL ARRANGEMENT OF THE PRECEDING LIST BY AUTHORS.

1818. Eaton, Amos.
1819. Dewey, C.
1820. Dewey, C.; Eaton, Amos.
1822. Eaton, Amos.
1824. Dewey, C.; Eaton, Amos.
1828. Eaton, Amos.
1830. Eaton, Amos.
1832. Eaton, Amos.
1836. Sedgwick, Adam.
1838. Sedgwick, Adam.
1841. Rodgers, H. D.; Emmons, E.
1842. Emmons, E.
1843. Jukes, J. B.
1844. Emmons, E.
1845. Adams, C. B.; Bayfield, H. W.
1846. Emmons, E.
1847. Adams, C. B.; Hall, J.
1848. Adams, C. B.; Haldeman, S. S.
1849. Emmons, E.
1850. Fitch, Asa.

1853. Thompson, Zadoc.
1856. Emmons, E.
1859. Emmons, E.; Hall, J.
1860. Emmons, E.; Hall, J.; Marcou, J.
1861. Barrande, J.; Billings, E.; Hall, J.; Hitchcock, C. H.; Hunt, T. S.; Marcou, J.; Rogers, W. B.
1862. Hall, J.; Hitchcock, C. H.
1863. Logan, W. E.
1865. Billings, E.; Logan, W. E.
1866. Hicks, H.; Salter, J. W.; Whitney, J. D.
1867. Hicks, H.; Salter, J. W.; Hitchcock, C. H.
1868. Hicks, H.; Meek, F. B.; Perry, J. B.; Torell, O.
1869. Nathorst, A. G.
1870. Hitchcock, C. H.; Torell, O.
1871. Ford, S. W.; Hicks, H.; Harkness, R.; Linnarsson, G.; Torell, O.
1872. Billings, E.; Ford, S. W..
1873. Dana, J. D.; Ford, S. W.; Hall, J.; Sedgwick, Adam.
1874. Billings, E.; Meek, F. B.; White, C. A.
1875. Brögger, W. C.; Ford, S. W.; Gilbert, G. K.; Hicks, H.; Hitchcock, C. H.
1876. Ford, S. W.; Linnarsson, G.
1877. Dana, J. D.; Emmons, S. F.; Ford, S. W.; Hall, J.; Hicks, H.; Linnarsson, G.; Whitfield, R. P.; Wing, A.; Lundgren, Bernhard.
1878. Ford, S. W.; Hunt, T. S.
1880. Ford, S. W.; Kjerulf, Theo.; Marcou, J.; Roemer, F.
1881. Barrande, J.; Ford, S. W.; Hicks, H.; Nathorst, A. G.
1883. Hague, Arnold; Hunt, T. S.; Linnarsson, G.; Walcott, C. D.
1884. Ford, S. W.; Hitchcock, C. H.; Hunt, T. S.; Walcott, C. D.; Whitfield, R. P.
1885. Dana, J. D.; Perkins, G. H.; Walcott, C. D.
1886. Brögger, W. C.; Hunt, T. S.; Walcott, C. D.
1887. Dana, J. D.; Holm, G.; Hunt, T. S.; McConnell, R. G.; Matthew, G. F.; Walcott, C. D.
1888. Bigot, A.; Foerste, A. F.; Hitchcock, C. H.; Lapworth, Charles; Marcou, J.; Schmidt, F.; Shaler, N. S.; Walcott, C. D.; Woodward, H.
1889. Lapworth, Charles; Walcott, C. D.; Lundgren, Bernhard; Matthew, G. F.; Foerste, A. F.
1890. Matthew, G. F.

IV. HISTORICAL REVIEW.

NORTH AMERICA.

GEOLOGIC INVESTIGATION.

The first attempt in America to assign strata, now referred to the Lower Cambrian, to a definite position in a series of stratified rocks, was made by Prof. Amos Eaton, in 1818, in his "Index to the Geology of the Northern States." In the second edition (1820) he added to the details, and, four years later, published an elaborate section[1] extending from the Atlantic coast line, west, across Massachusetts and New York, to Lake Erie. In this section the relation of the Lower Cambrian "granular quartz" to the "Primitive" gneiss is shown; also the relation of the "transition argillite" to the supposed unconformable calciferous sand-rock of the first greywacke.

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[1] Geol. and Agric. Survey of the district adjoining the Erie Canal, pt. 1, 1824.

The portion of the section crossing the outcrops of Cambrian rocks is of such historic interest that it is here reproduced.

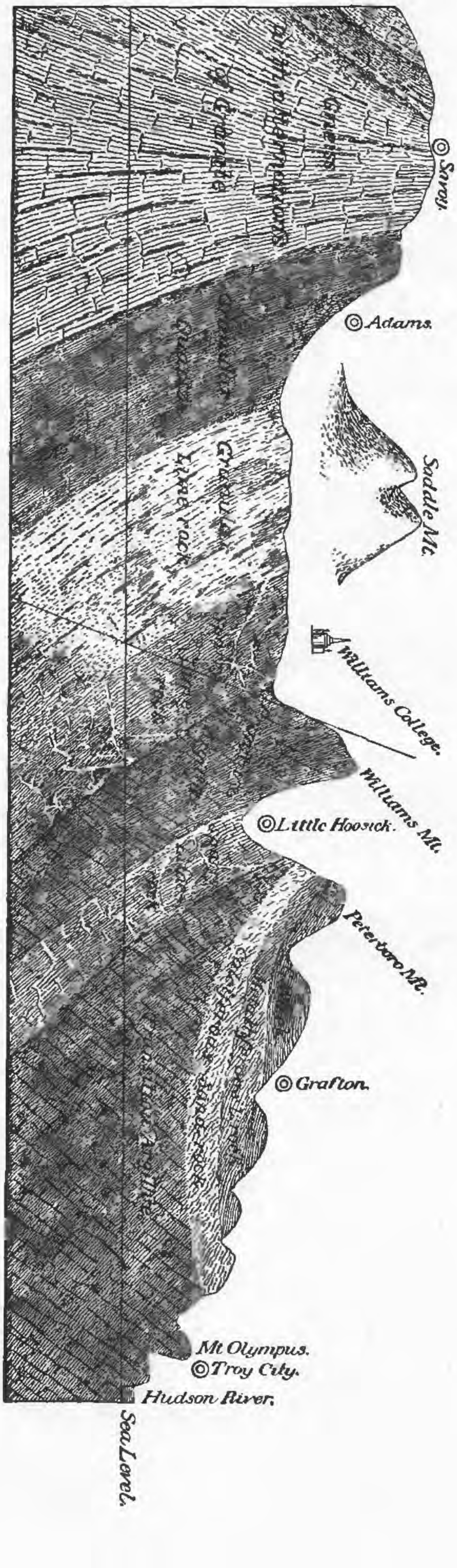

FIG. 44.—Section of strata from the Hoosac Mountains to the Hudson River; after Eaton.

As now known the Granular Quartz = Cambrian. The Granular lime rock = Trenton—Chazy—Calciferous limestone. The Primitive argillites of Williamstown Mountain = Hudson shales. The Transition argillite is nearly all Cambrian, with the exception of a small portion near the Hudson River. The Calciferous sand-rock belongs to the Transition argillite series. The Greywacke of Peterboro Mountain is of Upper Cambrian age, and the Metalliferous lime-rock is of Lower Ordovician age. The representation of the geographic distribution and stratigraphic position of the Calciferous sand-rock, Metalliferous lime rock and Greywacke is theoretical, with the exception of the presence of the Greywacke or Peterboro Mountain.

As now known the primitive argillite of the Williamstown range is the Taconic slate of Emmons and the equivalent of the Hudson Terrane or Upper Ordovician of the New York section. The transition argillite is mostly of Lower Cambrian age, and the so-called calciferous sand-rock and greywacke of the section, represented as resting on the upturned edges of the argillite, are portions of the same series to which the argillite belongs. Near the Hudson River a profound fault has thrust the Lower Cambrian strata over on to the Lower Ordovician rocks. The oversight of the true relations of these rocks and a dependence upon their lithologic characters led Prof. Eaton to commit the error that so long remained alive through the writings of Dr. E. Emmons, Prof. Jules Marcou, and Dr. T. S. Hunt.

Prof. Eaton reviewed his work from time to time until 1832,[1] when his final scheme of classification appeared. It is reprinted in the following tabulation, with the equivalents of his formations as known in the nomenclature of to-day.

Eaton's nomenclature (1832).	1889.
II.—Lower secondary:	
3. Corniferous limerock	Upper Helderberg.
Geodiferous limerock	Niagara.
2. Millstone grit and rubble } Second greywacke	Oneida, Clinton, Medina.
1. Second greywacke slate }	Utica, Hudson.
II.—Transition:	
3. Metalliferous limerock	Trenton.
Calciferous sandrock	Calciferous.
Sparry limerock	Trenton, Chazy.
2. Millstone grit and gray rubble } First greywacke	Middle Cambrian, Ordovician and Silurian.
Greywacke slate }	Hudson.
1. Argillite { Roof slate Wacke slate Clay slate }	Considerable Hudson, but includes a great mass of Lower Cambrian in Rensselaer County, N. Y.
I.—Primitive:	
3. Granular limerock	Ordovician limestone, Calciferous-Chazy-Trenton.
2. Granular quartz	Lower Cambrian.
1. Granite, mica slate, hornblende, and talcose rock	Algonkian, pre-Cambrian, and Archean.

The stratigraphic position of the "granular quartz," (2) of the Primitive, is correctly represented, and it is now known to contain *Olenellus sp. ?* A large portion of the strata referred to the "Argillite," (1) of the transition, is also known to carry *Olenellus asaphoides* and to belong to the Lower Cambrian terrane. In the text

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[1] Geol. Text Book, 2d Ed., pp. 68–78.

the "greywacke slate," (2) of the transition, is described as resting unconformably upon the upturned edges of the "argillite" (1) and it is so represented in the section. This is essentially the same as the section of 1820, and as in the more detailed section of 1824. (Ante, Fig. 44, p. 527.)

Rev. Chester Dewey studied the geology of the vicinity of Williamstown, Mass., and, in 1819,[1] published a short sketch of the mineralogy and geology of this region. He followed this in 1820,[2] by a geologic section from the Taconic range in Williamstown to the city of Troy, on the Hudson. In this section the relations of the quartz formation to the mica slates of the Archean are shown, and in a general way the Lower Cambrian slate is described and referred to the transition argillite. In 1824,[3] he described the formations more in detail. His work was contemporaneous with that of Prof. Eaton, but it does not exhibit so comprehensive a grasp of the subject.

Dr. E. Emmons, a pupil of Prof. Eaton, adopted the order of succession of the strata as proposed by Eaton, and separated the "granular quartz" (2), "granular limerock" (3), and "argillite" (1), to form a distinct series of rocks between the "granite" (1) and the "greywacke" (2) of the Transition. To this series of rocks he gave the name "Taconic," as numbers 3 and 1 are largely developed in the Taconic range of mountains. His central idea was that the rocks were non-fossiliferous and beneath the zone of animal life, and were separated, by their mineralogical characters, from the subjacent and superjacent rocks.[4]

In the summer of 1844,[5] Dr. Asa Fitch, a practicing physician, who was better known as an entomologist, discovered fossils in a black slate in Washington County, N. Y., which was referred by Dr. Emmons to the Taconic slate or "argillite" (1), of Eaton. Dr. Fitch sent the fossils to Dr. Emmons, who described from them two species of trilobites, under the names of *Atops trilineatus* and *Elliptocephala asaphoides*.[6] These are the first two described species of the Olenellus fauna. It was not until 1856[7] that Dr. Emmons published

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[1] Sketch of the mineralogy and geology of the vicinity of Williams's College, Williamstown, Mass. (With a map.) Am. Jour. Sci., vol. 1, 1819, pp. 337–346.

[2] Geological section from Taconick range, in Williamstown, to the city of Troy, on the Hudson. Am. Jour. Sci., vol. 2, 1820, pp. 246–248.

[3] A sketch of the geology and mineralogy of the western part of Massachusetts and a small part of the adjoining States. Am. Jour. Sci., vol. 8, 1824, pp. 1–60.

[4] Gazetteer of the State of New York; J. Disturnell, I, Albany, 1842, pp. 11-12. Emmons claims the authorship of this paper. Am. Quart. Jour. Agric. and Sci., vol. 4, 1846, p. 208, 2209.

Nat. Hist. New York; Geology, pt. 2; Survey Second Geol. Dist., 1842, pp. 135–164.

[5] Trans. N. Y. State Agric. Soc., vol. 9; Hist. Top. and Agric. Survey, county of Washington, 1850, p. 865.

[6] Taconic System. 4° pamphlet, pp. 19–21, 1844.

[7] Am. Geology, vol. 1, pt. 2, pp. 49-94.

Prof. Eaton's view, that the "argillite" (1) was uncomformably beneath the "greywacke slate" (2), and thus, as he supposed, formed a natural boundary to the upper part of his Taconic system.

In 1860[1] M. J. Barrande identified the fossils, described by Emmons as belonging to the first or primordial fauna, and gave them a fixed position in the geologic scale on paleontologic evidence. He accepted the theory of Eaton and Emmons, that the "argillite" (1) was uncomformably beneath the "greywacke slate" (2), and credited Dr. Emmons with the discovery of the stratigraphic position of the fossils. M. Barrande was misled by the evidence advanced by Dr. Emmons, which was based on the erroneous interpretation of the geological structure by Eaton, in 1824, and followed by Emmons in 1856.[2] The credit of the discovery should be given to M. Barrande.

The review of the results obtained by geologists and paleontologists, other than those mentioned, may be arranged under two general heads: geologic investigation and paleontologic investigation. Within these the geographic distribution is shown by the method of arrangement.

Newfoundland.—Among the early geologic observers Prof. J. Beete Jukes[3] studied the strata about Conception Bay, Newfoundland, and described the relations of the strata now referred to the Olenellus zone to the unconformably subjacent strata of the Algonkian. He mentions the red shales in which the Olenellus fauna occurs, as well as the green and dark shales of the Paradoxides zone.

A little later Captain Bayfield[4] described a sandstone with subjacent red and white limestone, on the straits of Belle Isle, which he stated contained a species of Cyathophyllum. This is the first notice of the Lower Cambrian rocks containing Archæocyathus, and it is the second recorded discovery of fossils of the Olenellus zone.

Eighteen years later Sir William E. Logan[5] described the strata referred to the Olenellus zone in Labrador and Newfoundland, and referred the rocks to the Potsdam group on the authority of the pale-

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[1] On the primordial fauna and the Taconic system, by Joachim Barrande, with additional notes by Jules Marcou. Proc. Boston. Soc. Nat. Hist., vol. 7, 1860, pp. 371-376.

[2] Dr. Emmons was a pupil of Eaton and must have known of the view advanced by him in 1824. I am not aware, however, that he credits it to Eaton in any of his publications. Dr. T. S. Hunt mentions (The Taconic Question Restated; Am. Nat., vol. 21, 1887, p. 120, par. 10), that Emmons came forward as the champion of the views of Eaton, but I have been able to discover only one reference to the work of Eaton, and that is merely a list of "Prof. Eaton's classes" of rocks. (No coal in the New York Rocks; Am. Jour. Agric. and Sci., vol. 6, 1847, p. 128.)

[3] General Report of the Geological Survey of Newfoundland, London, 1843, pp. 79-81.

[4] On the Junction of the Transition and Primary Rocks of Canada and Labrador. Quart. Jour. Geol. Soc. London, vol. 1, 1845, pp. 450-459.

[5] Geol. Survey Canada; Rep. Prog. from its commencement to 1863, chapter xi, pp. 287-297.

ontological determinations of Mr. Billings. In the report of the Geological Survey of Newfoundland for 1864 (appendix) he published a table of the Lower Silurian formations in North America, in which the limestone and sandstone on the straits of Belle Isle, on White Bay, Newfoundland, and the slates of St. Albans and Georgia, Vermont, are referred to the Lower Potsdam and to a horizon above the St. John group. This scheme of classification remained unaltered by American geologists until the investigations, by the writer, in Newfoundland during the summer of 1888, proved that the Lower Potsdam fauna of Billings and Logan was beneath that of the St. John group, and was not a portion of the Potsdam fauna.[1] Sir William E. Logan[2] also described the conglomerate beds at Bic, and Trois Pistoles, on the south shore of the St. Lawrence river, where bowlders of limestone were found containing fossils of the Olenellus fauna. The shales in which the bowlders occur are of Lower Ordovician age and contain other bowlders, in which the Upper Cambrian and Lower Ordovician faunas respectively occur.

In the summer of 1888 the writer made a careful study of the Cambrian section in Newfoundland, and determined the Olenellus zone to be beneath the Paradoxides zone and not above it, as arranged by Logan in his scheme of 1864. A detailed section of the Cambrian strata on Conception Bay was published[3] with lists of the fossils occuring at the different horizons in it.

New Brunswick.—The determination of the Lower Cambrian or Olenellus horizon in New Brunswick is of recent date and there is still a little uncertainty as to the actual presence of the fauna. Mr. Matthew reported in 1886 the discovery of *Olenellus* (?) *kjerulfi* in the lower portion of the Cambrian section in the St. John Basin,[4] stating that its position in Europe is beneath that of the beds carrying Paradoxides. On the report of the discovery of the *Olenellus kjerulfi* by Mr. Matthew, Mr. Ford[5] stated that in view of the analysis of the fauna as it occurs in the Cambrian rocks of Sweden, *Paradoxides kjerulfi* was at the base of the series in Sweden and in New Brunswick, but that the trilobite was not a true Olenellus but a Paradoxides. By this interpretation the Olenellus fauna was left in the Middle Cambrian above the Paradoxides zone. Mr. Matthew subsequently explained that he had based the identification of *Paradozides kjerulfi* on fragments that "may belong to this species."[6]

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[1] The Stratigraphical Succession of the Cambrian faunas in North America. Nature, vol 38, p. 551.

[2] Geol. Survey Canada: Report of progress from its commencement to 1863, p. 260.

[3] Am. Jour. Sci., 3d ser, vol. 37, 1889, pp. 374–392; vol. 38, 1889, pp. 29–42.

[4] Matthew, G. F., Note on the occurrence of *Olenellus* (?) *kjerulfi* in America. Am. Jour. Sci., III, vol. 31, 1886, pp. 472, 473.

[5] Ford, S. W., Note on the age of the Swedish Paradoxides beds. Am. Jour. Sci., 3d ser., vol. 32, 1886, pp. 473–476.

[6] Matthew, G. F., On the kin of *Paradoxides* (*Olenellus ?*) *kjerulfi.* Am. Jour. Sci., 3d ser., vol. 33, 1887, pp. 390–392.

Mr. Matthew continued his investigation in the rocks beneath the Paradoxides zone in the St. John series and discovered a series of sandy shales and red sandstones and gray flags some 1,200 feet in thickness that form a series beneath the true Paradoxides bearing slates.[1] The lower beds of the series carry trails and casts of marine worms and of branching organisms of doubtful relations. This paper was followed a little later by an article on the "Classification of the Cambrian rocks of Acadia," in which the classification of the Cambrian system in Acadia and Newfoundland is as follows:

"Series A.—The Basal Series or Eteminian.
"Series B.—The St. John Group or Acadian.
"Series C.—The Lower Potsdam or Georgian.
"Series D.—The Potsdam Sandstone and Limestone."

Mr. Matthew presents the argument in favor of the view that the Georgian fauna is older than that of the Acadian; and also the evidence in favor of the opposite view that the Acadian is beneath the Georgian, and concludes that the fauna indicates the greater age of the Acadian series.[2] On learning of the discovery of the position of the Olenellus fauna beneath the Paradoxides zone in Newfoundland the terranes were tabulated as follows:

D.—Upper Cambrian, Potsdam series, localities unknown.
C.—Middle and Lower Cambrian, Acadian series, St. John, etc.
B.—Lower Cambrian, Georgian series, C. Breton.
A.—Basal Cambrian, Etcheminian series, St. John, etc.

Of the Olenellus fauna he says: "Though this fauna is found north, east, and west of New Brunswick, having been recognized in Quebec, Cape Breton, and Massachusetts, it has not been found in the Province of New Brunswick, notwithstanding that there are there no less than 1,600 feet of Cambrian measures beneath the Paradoxides beds." He then proceeds to point out the position in these underlying beds where he thinks the fauna will be discovered.[3] Six months later Mr. Matthew published an article "On the Cambrian organisms in Acadia," in which it is stated that he has obtained more definite traces of the Olenellus fauna in the beds subjacent to the Paradoxides fauna.[4] In September of the same year an article appeared under the title of "How is the Cambrian divided?—A plea for the classification of Salter and Hicks." In this Mr. Matthew argues for the uniting of the Olenellus or Lower Cambrian and Para-

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[1] Matthew, G. F., On the Classification of the Cambrian rocks of Acadia. Can. Rec. Sci., vol. 3, 1888, pp. 71–81.

[2] Matthew, G. F.. On a basal series of Cambrian rocks in Acadia. Can. Rec. Sci., vol. 3, 1888, pp. 21–29.

[3] Matthew, G. F., On the classification of the Cambrian rocks in Acadia. Supplementary note. Can. Rec. Sci., vol. 3, 1889, pp. 303–315, 371, 372.

[4] Matthew, G. F., On the Cambrian organisms in Acadia. Can. Rec. Sci., vol. 3, 1889, pp. 385–387.

doxides or Middle Cambrian, as one division of the Cambrian, and thus divides the Cambrian into two great divisions only.[1]

In the complete paper on "Cambrian Organisms in Acadia"[2] Mr. Matthew describes the section on Hanford Brook and Caton's Island, in which the strata referred to the Lower Cambrian or Basal series occur. These are considered to be unconformably subjacent to the strata carrying the Paradoxides fauna. The associated fauna is fully described and illustrated in the memoir.

Vermont.—In the Vermont or Lake Champlain area, Prof. C. B. Adams,[3] in 1845, described the occurrence of roofing slates in southern Vermont, which he referred to the Taconic slate of Emmons, without further attempt to assign them to a geologic horizon. In 1847,[4] he mentioned his studies of the "Red Sandrock"[5] and noted the discovery of fragments of trilobites, which Professor Hall identified as Conocephalus. He next assigned the "Red Sandrock" to the Upper Silurian, correlating it with the Medina sandstone.[6]

Dr. E. Emmons[7] correlated the "Red Sandrock" with the Potsdam sandstone and Calciferous sandrock, and considered it to be unconformably superjacent to the Taconic slates at Snake Mountain, and at Sharp Shins, near Burlington, Vt.

Prof. William B. Rogers,[8] commenting upon a paper by Prof. C. H. Hitchcock,[9] agreed with him in referring the "Red Sandrock" of Vermont to the horizon of the Medina sandstone of the Silurian, basing his correlation on stratigraphic evidence. Professor Hitchcock, in the same year, described,[10] in the "Geology of Vermont," the "Red Sandrock" series and a quartz rock, leaving in doubt the horizons to which they were to be referred. The Georgia Terrane appears to have been largely correlated with the Hudson River group as then understood.

In 1861[11] Mr. E. Billings noted the correlation of the "Red Sand-

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[1] Matthew, G. F., How is the Cambrian divided?—A plea for the classification of Salter and Hicks. Am. Geol., vol. 4, 1889, pp. 139–148.

[2] Trans. Roy. Soc. Canada, vol. 7, sec. 4, 1890, pp. 135–162.

[3] First Ann. Rep. on the Geology of Vermont. Burlington, 1845, pp. 35, 36, 41–43, 50, 61.

[4] Third Ann. Rep. Geol. Vermont, 1847, pp. 14, 31. (See Geol. Survey Vermont, vol. 1, 1861, pp. 339, 340.)

[5] This terrane contains the Olenellus fauna, and is at the base of the Lower Cambrian in Vermont.

[6] On the Taconic Rocks: Am. Jour. Sci., 2d ser., vol. 5. 1848, pp. 108–110.

[7] Am. Geology, vol. 1, pt. 2, 1856, pp. 88, 89.

[8] Notes on the Geological Structure of western Vermont: Boston Soc. Nat. Hist., Proc., vol. 7, 1860, pp. 237–239.

[9] Age of the Rocks of part of Emmons's Taconic System: Boston Soc. Nat. Hist., Proc., vol. 7, 1860, pp. 236–237.

[10] Geology of Vermont, Report, vol. 1, 1861, pp. 326–357.

[11] On some Rocks and Fossils occurring near Phillipsburg, Canada East: Can. Nat., vol. 6, 1861, pp. 323–328.

rock" with the Medina sandstone, and assigned it, on the evidence of the included fossils, to the Potsdam Terrane, to which horizon it has since been referred by most authors who have had occasion to mention it. Mr. Billings also corrected the statement of Professor Hall that the trilobites of the Georgia slate were from the Hudson Terrane, and referred them to the Primordial or Lower Potsdam. This transferred the Georgia series and the associated "Red Sandrock" to the Cambrian.[1]

Sir William E. Logan studied a section in the vicinity of Swanton, Vermont, in which the Georgia slates, with the Olenellus fauna. occur above the "Red Sandrock"[2] beds, and the latter are white and red dolomites with sandy layers. In another section, near the boundary line between the United States and Canada, he found the "Red Sandrock" series largely developed.[3]

In 1867 Prof. C. H. Hitchcock[4] identified the Winooski marble of Vermont with the "Red Sandrock," and stated that *Olenellus thompsoni* occurred in the superjacent slaty layers. In an historical review of the rocks of Vermont[5] he referred the Black Slate, Georgia Slate, Red Sandrock, and Quartzite to the Potsdam group. In this paper he states that these rocks were referred by Rev. Zadoc Thompson in 1842 to the Old Red sandstone and Greywacke, and by Prof. C. B Adams, in 1846, to the Medina sandstone and Hudson River group, in part. In 1875[6] he correlated the Granular quartz of Vermont with the Potsdam sandstone of New York; and, in 1884[7] published a number of geological sections crossing New Hampshire and Vermont, in which the strata of the Olenellus zone are referred to the Potsdam.

The priority for the use of the name Georgia is claimed by Prof. C. H. Hitchcock[8] on the grounds of a better definition of the series of strata now included under the term and the prior use of it as a distinct geologic name. Taking the published literature as authority, it appears that during 1861 volume 1 of the Report on the Geology

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[1] New species of Lower Silurian Fossils; on some new or little-known species of Lower Silurian Fossils from the Potsdam Group (Primordial). Geol. Survey Canada, Bulletin, 1861.

[2] Geol. Survey Canada: Report of progress from its commencement to 1863, chapter 11. pp. 280–282.

[3] Op. cit., p. 282.

[4] The Winooski Marble of Colchester, Vermont: Am. Assoc. Proc., vol 16, 1867, p. 119.

[5] The Geology of Northern New England: Vermont, 1870, pp. 1–5, and map. Note added in 1882.

[6] Remarks on the Stratigraphic Structure of the Cambrian and Cambro-Silurian rocks of western Vermont: Boston Soc. Nat. Hist. Proc., vol. 18, pp. 191–193.

[7] Geological Sections across New Hampshire and Vermont: Am. Mus. Nat. Hist., Bull., vol. 1, pp. 155–179, with map and two plates of sections. Reprinted as a pamphlet. Concord, N. H., 1884.

[8] Date of the publication of the Report upon the Geology of Vermont. Proc. Boston Soc. Nat. Hist., vol. 24, 1888, pp. 34–36.

of Vermont was printed, and on the authority of Prof. Hitchcock,[1] excerpts were distributed prior to December, 1861. It is evident that the matter was in print as early as July, 1861, as stated by Prof. Hitchcock.

Prof. Jules Marcou studied the Georgia slate and the "Red Sandrock" series of northern Vermont, and referred[2] the former to the Taconic of Emmons and the "Red Sandrock" to the Potsdam sandstone. Following the lead of Emmons, he drew an imaginary unconformity between the "Red Sandrock" and the superjacent argillites, supposing the latter to be subjacent to the "Red Sandrock." In 1888[3] he corrected, in part, the reference of the "Red Sandrock" to the Potsdam, but represented many of the arenaceous Lower Cambrian rocks as resting unconformably[4] upon the slate series, in which they are interbedded. To explain the evidence of the stratigraphy and fossils he introduced Barrande's theory of "Colonies," and thus theoretically established a remarkable and unique succession of formations in western Vermont. Prof. Marcou referred to the "Black Slates of Georgia," in 1860,[5] and in 1861,[6] used the name "Georgia Slates," in a tabular section of the rocks in Franklin County, Vermont, citing St. Albans, Georgia, Swanton and Highgate Springs as the localities visited by him.[7] In 1888 he claimed priority for the use of the name Georgia in geologic nomenclature.[7]

The writer studied and measured a section that traverses the typical locality of the Olenellus fauna, at Parker's quarry, Georgia, Vt., and discovered *Olenellus thompsoni* in the upper portion of the "Red Sandrock," and determined that the Georgia slates were conformably superjacent to the "Red Sandrock" and contained the same fauna.[8] After reviewing the literature relating to the subject the term Georgia was adopted for the lower division of the Cambrian group of rocks, and credit given to the Geological Survey of Vermont for making the first definite proposal for the use of the name and for giving the first clear definition of it as a term in geology.

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[1] Date of the publication of the Report upon the Geology of Vermont. Proc. Boston Soc., Nat. Hist., vol. 24, 1888, p. 34.

[2] Sur les Colonies dans les roches Taconiques des bords du lac Champlain. Bull. Soc. Géol. France, 3d ser., vol. 9, 1880, pp. 18–46, with map and one plate of sections.

[3] The Taconic of Georgia and the Report on the Geology of Vermont. Memoirs Boston Soc. Nat. Hist.. vol. 4, 1888, pp. 105–131, Pl. 13.

[4] Op. cit., Pl. 13, fig. 2.

[5] On the Primordial Fauna and the Taconic System, by Joachim Barrande, with additional notes by Jules Marcou. Proc. Boston Soc. Nat. Hist., vol. 7, 1860, p. 375.

[6] The Taconic and Lower Silurian Rocks of Vermont and Canada. Proc. Boston Soc. Nat. Hist., vol. 8, 1861, pp. 241, 244, 245.

[7] On some Dates of the "Report on the Geology of Vermont." Proc. Boston Soc. Nat. Hist., vol. 24, 1888, p. 87.

[8] Bull. U. S. Geol. Survey, No. 30, 1886, pp. 15–20, Fig. 1.

Prof. J. D. Dana, in 1877,[1] in giving an account of the discoveries in Vermont geology by the Rev. Augustus Wing, speaks of the "Red Sandrock" of Snake Mountain and states that the Rev. Mr. Wing correlated the "Red Sandrock" and the quartzite (granular) and referred them to the Potsdam sandstone. Prof. George H. Perkins published sections of the Winooski marble (Red Sandrock) of Vermont in 1885, and noted the occurrence of *Salterella pulchella* in the marble.[2]

New York and Massachusetts.—The area in western Massachusetts and eastern New York was studied, after Eaton and Emmons, by Prof. H. D. Rogers, who referred the quartzite, at the western base of the Hoosic Mountain, to the white sandstone (Potsdam), and the superjacent Berkshire marble (Granular limerock of Eaton) to the blue limestone (Trenton-Chazy) of the Hudson River Valley.[3] Dr. Emmons next gave an account of these rocks (ante, p. 529), and, in 1850, Dr. Fitch published[4] a geological section crossing Washington County, N. Y. He gave a very clear description of the rocks on the line of the section, including the slates that are now referred to the Lower Cambrian zone.

In connection with the study of the fossils now referred to the Lower Cambrian found in the strata of eastern New York and western Vermont, various views upon their position in the geologic series were expressed by Prof. James Hall. Those first described from near Troy, N. Y., he referred to the Hudson River Group.[5] Subsequently, when studying the trilobites found at Parker's quarry, Georgia, Vt., he referred the fossils to the Hudson River Group, supporting the reference by the statement that Sir Wm. E. Logan assigned the shales containing the fossils to the upper part of the Hudson River Group.[6] In 1861 he changed the reference of these trilobites from the Hudson River Group to the Quebec Group.[7] In a letter written to M. J. Barrande, dated Albany, April, 1862, he explains why he made the preceding references, stating that it was his own conviction that the red sandrock and granular quartz of Vermont were of the age of the Potsdam sandstone and that the schists and shales which held the trilobites he described belonged between the

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[1] An account of the discoveries in Vermont Geology of the Rev. Augustus Wing. Am. Jour. Sci., 3d ser., vol. 13, 1877, pp. 332–347, 405–419.

[2] The Winooski or Wakefield Marble of Vermont. Am. Nat., vol. 19, 1885, pp. 128–136.

[3] Some observations on the geological structure of Berkshire, Mass., and vicinity, in New York. Proc. Am. Phil. Soc., vol. 2, 1841, pp. 3, 4.

[4] Trans. N. Y. State Agric. Soc.; Hist. Top. and Agric. Survey county of Washington, 1850, pp. 821–822.

[5] Pal. New York, vol. 1, 1847, pp. 256–258.

[6] Trilobites of the shales of the Hudson River Group. 12th Ann. Rep. N. Y. State Cab. Nat. Hist., 1859, pp. 59–62.

[7] Note upon the trilobites of the shales of the Hudson River Group in the town of Georgia, Vt. 13th Ann. Rep. N. Y. State Cab. Nat. Hist., 1860, pp. 113–119.

Potsdam sandstone and the Trenton limestone. He thus changed his views in relation to the age of the rocks containing Olenellus and other trilobites, and referred them to the lower portion of what is now designated as the Lower Silurian or Ordovician. He says:

> You will understand, then, that if my views touching the relations of these rocks are exact, the valley of the Hudson River, from the highlands on the south[1] to Lake Champlain, save a small number of inconsiderable exceptions, is occupied by rocks of the Primordial Zone, that is, by rocks placed between the Potsdam sandstone and the Trenton Group. Thus the Hudson River Group in its typical localities belongs to the Primordial Period."[2]

Following this is the statement that the graptolites found in the beds formerly referred to the Hudson River Group are considered to form a portion of the Primordial fauna.

In 1871, Mr. S. W. Ford[3] published an account of a section of rocks at Troy, N. Y., in which he had found the Olenellus fauna. In 1884,[4] he further added a description of a section to the south of Troy, in Columbia County, N. Y. By the contained fauna he correlated these sections with those described by Sir William E. Logan, in Vermont, Canada, and Newfoundland.

Prof. J. D. Dana, from 1873[5] to 1877,[6] worked out, with considerable detail, the stratigraphic relation of the granular quartz of Berkshire County, Mass., to the subjacent Archean and the superjacent Silurian limestone, adding many details to the general outlines, published by Eaton, Dewey and Emmons.

Dr. T. S. Hunt, 1878,[7] gives an historical review of the rocks referred to the Cambrian and Taconic Systems, and correlates the Upper Taconic with the Cambrian, and refers the Granular Quartz to an Archean System. Again, in 1883–'84–'86,[8] he went over the same ground, but did not add any original information upon the subject. He adopted the view of Eaton that is so well expressed in the section of 1824 (Fig. 44, p. 525), and brought down to 1886 the error of the unconformity between the calciferous sandrock and the argillite.

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[1] The word is "north" in the original, but it is evidently an error. The French is "à partie des montagnes du nord."

[2] Letter of Prof. James Hall to M. Barrande. Bull. Soc. Géol. France. 2d ser., vol. 19, 1862, p. 732.

[3] Notes on the Primordial Rocks in the vicinity of Troy, N. Y. Am. Jour. Sci., 3d ser., vol. 2, 1871, pp. 32–34.

[4] Note on the discovery of Primordial fossils in the town of Stuyvesant, Columbia County, N. Y. Am. Jour. Sci., 3d ser., vol. 28, 1884, pp. 35–37.

[5] On the Quartzite, Limestone, and Associated Rocks of the vicinity of Great Barrington, Berkshire County, Mass. Am. Jour. Sci., 3d ser., vol. 6, 1873, pp. 49, 50.

[6] On the relations of the Geology of Vermont to that of Berkshire. Am. Jour. Sci., 3d ser., vol. 14, 1877, pp. 204–207.

[7] Second Geol. Survey. Penn.; E. Special Report on the trap dikes and Azoic rocks of southeastern Pennsylvania. 1878. Pt. I, pp. 32, 33, 44–46, 51–62.

[8] Mineral Physiology and Physiography; A second series of chemical and geological essays. The Taconic Question in Geology. Boston, 1886, pp. 517–686.

To the strata which Dr. Emmons included in the Taconic System in 1842, he gave the name Taconian, and referred them to a pre-Cambrian, Archean, group of rocks. With fossils known from the Granular quartz, Granular limestone, and Transition argillite this theory is now removed to historic literature.

The writer determined the Lower Cambrian age of the purple roofing slates of Washington County, N. Y., in 1886,[1] and in 1887 discovered the Olenellus fauna in situ in the Granular quartz of Vermont.[2] He mapped the strata of Washington and Rensselaer Counties, N. Y., in 1887, and collected fossils from the Lower Cambrian rocks at over one hundred localities. The map and an accompanying section, with a discussion of the work done by Dr. Emmons, was published as a contribution to the question of the use of the name Taconic in geologic nomenclature.[3] In this paper Eaton's and Emmons's theory of an unconformity between the Calciferous Sandrock of the Lower Silurian (Ordovician) and the Lower Cambrian argillites is shown to have been based on an erroneous interpretation of the stratigraphy. The position of the Lower Cambrian rocks is described in the text and exhibited in the section.

Appalachian area south of New York.—The Lower Cambrian horizon has been recognized in one place only in the Appalachian range south of New York. This is at Chilhowee Mountain, Tennessee. The Chilhowee sandstone and shale were placed under the Cambrian system by Safford in 1856.[4] The group is described as consisting of dark gray, micaceous, sandy shales and sandstones, and grayish white quartzose layers, altogether several thousand feet in thickness. The name is derived from Chilhowee Mountain, in Sevier and Blount counties. Near the upper part of the formation many beds of grayish white quartzose sandstones occur which are generally freely pierced by the peculiar rod-like fossils "(*Scolithus linearis*) of the New York Potsdam sandstone."

In the final report on the geology of Tennessee,[5] the Chilhowee sandstone is included under the Potsdam group along with the Ocoee conglomerate and slate below, and the Knox group of slates, shales, dolomites, and limestones above. In the table, on page 169, the Potsdam group is included under the Lower Silurian.

On a visit to Chilhowee Mountain, in 1889, I found that the Chilhowee sandstone was of Lower Cambrian age, from the presence of

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[1] Cambrian Age of the Roofing Slates of Granville, Washington County, N. Y Proc. Am. Assoc. Adv. Sci., vol. 35, 1886, pp. 220, 221.

[2] The Taconic System. Am. Jour. Sci., 3d ser., vol. 33, 1887, pp. 153, 154.

[3] The Taconic System of Emmons, and the use of the name Taconic in geologic nomenclature. Am. Jour. Sci., 3d ser., vol. 35, 1888, pp. 229-242, 307-327, 394-401, with map and 13 figures.

[4] Safford, J. M. A geological reconnoissance of Tennessee; 1st biennial report. Nashville, 1856, p. 152.

[5] Safford, J. M. Geology of Tennessee. Nashville, 1869, p. 182.

Lower Cambrian fossils in the banded shales at and near the summit of the formation. From the correlations made by the Rogers brothers in Pennsylvania and Virginia it is more than probable that the quartzites of South Mountain, Pennsylvania, and those resting upon the crystalline rocks in Virginia, beneath the limestones of the Calciferous, Trenton terrane, are of the same age as those of Chilhowee Mountain. This would also include the quartzites, at a similar horizon, in Georgia. The discussion of the literature pertaining to them, however, will be given in a future report, under the general description of the Cambrian rocks of the States mentioned, as there is not yet any positive paleontologic or stratigraphic evidence that the quartzites and sandstones mentioned are of Lower Cambrian age.

Massachusetts.—The discovery by Prof. N. S. Shaler[1] of a small area of Lower Cambrian strata, near North Attleborough, Bristol County, Mass., introduced the Olenellus fauna into the Atlantic Basin, south of Newfoundland. The lithologic characters of the rocks are strikingly like those of the Manuel's Brook section of Newfoundland, and several species of fossils are identical in the two localities.

In 1889 Mr. A. F. Foerste announced the discovery of Hyolithes in the limestone near East Point, Nahant. He correlates the limestone and associated shales with those of North Attleborough, and states that the species of Hyolithes appears to be the same as that found at North Attleborough. He proposes for it the name of *Hyolithes inæquadrilateralis.*[2]

Rocky Mountain province.—The earliest reference to strata containing the Olenellus fauna in the Rocky Mountain Province is by Prof. J. D. Whitney,[3] who mentioned in 1866 the discovery by Mr. J. E. Clayton of Upper Silurian or Devonian fossils at Silver Peak, Nev. The occurrence of the coral-like forms described by Mr. F. B. Meek as *Ethmophyllum whitneyi* doubtless led to this reference. The geologists of the Wheeler Survey traversed Central Nevada, and in 1875 Mr. G. K. Gilbert[4] mentioned the occurrence of Olenellus at Pioche, Nev., assigning it to the Lower Silurian. He also published the descriptions of *Olenellus gilberti* and *O. howelli*, Meek. Mr. S. F. Emmons,[5] of the Geological Exploration of the 40th Parallel, described strata of Cambrian age in the Big Cottonwood Cañon and Ophir Cañon, Utah, stating that *Lingulella ella* and *Olenellus*

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[1] On the geology of the Cambrian district of Bristol County, Mass. Bull. Mus. Comp. Zool. Harvard College, 1888, vol. 16, pp. 13-26.

[2] Boston Soc. Nat. Hist., Proc., vol. 24, 1889, pp. 261-263.

[3] Remarks on the Geology of the State of Nevada. Proc. California Acad. Sci., vol. 3, 1866, pp. 266-270.

[4] Geog. and Geol. Expl. and Sur. west of 100th Mer., vol. 3, 1875, pp. 181-183.

[5] Geol. Explo. Fortieth Par., vol. 2, 1877, 405-414, 445.

gilberti occur in the Ophir section, and in 1883[1] Mr. Arnold Hague published an abstract of his report on the geology of the Eureka district, in which he described the stratigraphic position and character of the rocks containing *Olenellus gilberti* in the Eureka district. In 1880 the writer took up the study of the Cambrian rocks in the Rocky Mountains, and in 1886[2] gave a detailed account of the Wasatch section in Utah, and the Eureka district and Highland Range sections of Nevada.

Geologists are indebted to the Geological Survey of Canada for the discovery of the Olenellus zone in the Rocky Mountains of British Columbia. Dr. Geo. M. Dawson first discovered a species of Olenellus like *O. gilberti* at Kicking Horse Lake in British Columbia,[3] and in 1887 Mr. R. G. McConnell described a section at Castle Mountain and Mount Stephen, which shows that the Olenellus fauna occurs at the base of the Castle Mountain limestone, and that the Middle Cambrian fauna occurs 2,000 feet above.[4]

PALEONTOLOGIC INVESTIGATION.

The study of the fauna began with the description of *Fucoides rigida, F. flexuosa (=Planolites marina), Gordia marina (=Planolites marina), Elliptocephala asaphoides (=Olenellus asaphoides), and Atops trilineatus (=Conocoryphe trilineatus)*, by Dr. Emmons.[5] He added another species in 1856,[6] by figuring it under the name of *Diplograpsus secalinus*. This species is described in this paper as *Phyllograptus ? cambrensis*. He described many others of Silurian age, referring them to the Taconic System.

The second description of fossils, now referred to the Olenellus fauna, was made by Prof. James Hall in the Paleontology of New York, vol. i, 1847. Under the title "Description of Fossils of the Hudson River group" the following species were described as new: *Orbicula cœlata* (p. 290), *Orbicula ? crassa* (p. 290), *Avicula ? desquamata* (p. 292), *Theca ? triangularis* (p. 313), *Metoptoma ? rugosa* (p. 306), *Palæophycus virgatus* (p. 263), and *Agnostus lobatus* (p. 258). A description and figures are given of *Olenus asaphoides*, Emmons,

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[1] Abstract of Report on the Geology of the Eureka District, Nevada. 3d Ann. Rep. Director U. S. Geol. Sur., 1881-1882, 1883, pp. 241-272, with map and plate of sections.

[2] Second Contribution to the studies on the Cambrian faunas of North America. Bull. U. S. Geol. Surv. No. 30, 1886, pp. 30-40, figs. 3 and 4.

[3] Geol. and Nat. Hist. Surv. Can., n. ser. vol. 1, 1886, p. 139.

[4] Report on the geological structure of a portion of the Rocky Mountains. Geol. and Nat. Hist. Surv. Canada, new ser., vol. 2, for 1886, 1887, pp. 28-30 D, with section.

[5] The Taconic System, Pamphlet 4°, Albany, 1844, pp. 20, 21, 24, 26, 1-67, pls. ii, v.

[6] Am. Geol., vol. 1, pt. 2, 1856, p. 104, pl. i. fig. 11.

on pp. 256, 257, pl. 67, figs. 2 a–c. In a later publication[1] he identified Conocephalus and Olenus from the Red Sandrock of Highgate, Vt., but did not assign them to a geologic horizon. In studying a collection sent to him by Rev. Zadock Thompson, Prof. Hall determined and described *Olenus thompsoni, O. vermontana, Peltura* (*Olenus*) *holopyga,* referring them to the Hudson River group.[2] He supported this reference by the statement that Sir William E. Logan referred the shales containing the fossils to the upper part of the Hudson River group. In 1860[3] he proposed the genus Barrandia to include *Olenus thompsoni* and *O. vermontana.* The genus Bathynotus was formed to include *Olenus* (*Peltura*) *holopyga.* In 1861[4] he changed the reference of these trilobites from the Hudson River group to the Quebec group; and, a little later, made a strong defense of his reference of the fossils of the Georgia slates to the Hudson River and Quebec groups, citing the authority of Sir William E. Logan for the stratigraphic position of the rocks.[5] Discovering that the proposed generic name, Barrandia, was preoccupied he substituted the name Olenellus, in 1862.[6] This is the first introduction of the name which is now given to the Lower Cambrian fauna. The last reference of Professor Hall to the fauna is the proposal of the genus Discinella for what he considered to be a small brachiopod, but which was subsequently shown by S. W. Ford to be the operculum of *Hyolithellus micans.*

The fauna of the "Red Sandrock" of Vermont was first discovered by Prof. C. B. Adams, in 1847[7], who sent the specimens to Prof. James Hall. The latter identified Conocephalus, but did not assign the fossils to any geologic horizon. Professor Adams in 1848[8] mentions the Conocephalus and also an Atrypa, like *Atrypa hemispherica* (= *Camerella ? antiquata,* Billings).

Mr. E. Billings, as paleontologist to the Geological Survey of

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[1] Letter from Prof. James Hall on certain fossils in the Red Sandrock of Highgate. Albany, N. Y., Sept. 17, 1847. Third Ann. Rep. Geol. Vermont, 1847, p. 31, Appendix C.

[2] Trilobites of the shales of the Hudson River group. Twelfth Ann. Rep. N. Y. State Cab. Nat. Hist., 1859, pp. 59–62.

[3] Note upon the trilobites of the shales of the Hudson River group in the town of Georgia, Vermont. Thirteenth Ann. Rep. N. Y. State Cab. Nat. Hist., 1860, pp. 113–119.

[4] Correction for the Thirteenth Annual Report. Fourteenth Ann. Rep. N. Y. State Cab. Nat. Hist., 1861, p. 110. "Page 113, in the title of the article, for 'Hudson River group,' read 'Quebec group.'"

[5] Rep. Geol. Vermont, vol. 1, 1861. Letter from James Hall, paleontologist, of New York, to the editors of the Am. Jour. Sci. and Arts, pp. 382–386.

[6] Supplementary note to the Thirteenth Report, etc. Fifteenth Rep. N. Y. State Cab. Nat. Hist., 1862, p. 114.

[7] Foot-note to Letter on certain fossils in the Red Sandrock of Highgate, by James Hall. Third Ann. Rep. Geol. Survey of Vermont, 1847, p. 31.

[8] On the Taconic Rocks. Am. Jour. Sci., 2d ser., vol. 5, 1848, p. 108.

Canada, took up the study and correlation of the older Paleozoic faunas, and was the first to assign and correlate the fossils described by Professor Hall, to the pre-Potsdam horizon. In 1861[1] he described a number of Lower Silurian fossils from the Potsdam group, and assigned the following species to the horizon of *Paradoxides thompsoni*, of Hall: *Palæophycus congregatus*, *P. incipiens*, *Archaeocyathus atlanticus*, *A. minganensis*, *Obolus labradoricus*, *Obolella chromatica O.* (*Kutorgina*) *cingulata*, *Orthisina festinata*, *Camerella antiquata*, *Conocephalites miser*, *C. adamsi*, *C. teucer*, *C. vulcans*, *C. arenosus*, *Bathyurus senectus*, *B. parvulus*, *Salterella rugosa*, *S. pulchella*, and *S. obtusa*. The new genera are Archæocyathus, Obolella, Kutorgina and Salterella.

A little later he published a note on the "Red Sandrock" formation of Vermont,[2] in which he refers the formation to the base of the Lower Silurian somewhere within the horizon of the Potsdam, identifying Conocephalites from it. In reprinting, in 1865 the article published in 1861[3] Mr. Billings added two new species, *Archæocyathus profundus* and *Acrotreta gemma*, and discussed the genus Archæocyathus. On page 371 of the same work he correlates the Primordial fauna of the Red Sandrock of Vermont with that of Newfoundland and Labrador and refers them to the Potsdam group, stating that there is no paleontological evidence of precise similarity of age, but the general affinities and scope of the fossils and the physical relations of the rocks prove that there can be no great difference.

In 1872 Mr. Billings returned to the study of the fossils of the older Paleozoic rocks, and noted the discovery of *Salterella pulchella* in the Winooski marble of Vermont,[4] and also describes some fossils from the Primordial rocks of Newfoundland, the following of which are now referred to the Olenellus zone: *Agraulos strenuus*, *Iphidea* n. gen., *Iphidea bella*, *Stenotheca pauper*, *Scenella*, n. gen., *Scenella*

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[1] Geol. Survey Canada, Bulletin, 1861; new species of Lower Silurian fossils; on some new or little known species of Lower Silurian fossils from the Potsdam group (Primordial zone). This paper was republished in the Geology of Vermont, vol. 2, pp. 942–955, 1862 (dated 1861); also, with some changes, in Geol. Survey Canada; Pal. Foss., vol. 1, 1865, pp. 1–18.

[2] On the age of the Red Sandstone formation of Vermont. Am. Jour. Sci., 2d ser., vol. 32, 1861, p. 232.

[3] Geol. Survey Canada, Bulletin, 1861. New species of Lower Silurian fossils. On some new or little known species of Lower Silurian fossils from the Potsdam group (Primordial zone). This paper was republished in the geology of Vermont, vol. 2, pp. 942–955, 1862 (dated 1861); also in the Geol. Survey, Canada, Pal. Foss., vol. 1, 1865, pp. 1–18, with some changes.

[4] Note on the discovery of fossils in the "Winooski marble" at Swanton, Vt Am. Jour. Sci., 3d ser., vol. 3, 1872, pp. 145, 146. Can. Nat. 2d ser., vol. 6, 1872, p. 351.

reticulata.[1] In the same year[2] he also described the following genus and species, found in bowlders and pebbles in the conglomerate at St. Simon, below Quebec. The genus Obolella and the species *Obolella gemma, O. circe, Platyceras primævum, Hyolithes americanus, H. communis, H. princeps, H. micans.* On page 240 of the same publication the genus Hyolithellus is proposed for the species *Hyolithes micans.* The work of Mr. Billings was most important, as by it various Cambrian fossils that had been referred to the Hudson and Quebec series of strata were placed in one horizon and correlated with a similar fauna from Labrador and Newfoundland. Upon the data given by Mr. Billings at various times the first classification of the Cambrian rocks was made by Sir William E. Logan.

The Olenellus fauna of northern Vermont was further enlarged, in 1884[3], by Prof. R. P. Whitfield, who described *Orthisina orientalis, Olenoides marcoui,* and *Protypus hitchcocki;* all of these were referred by him to the horizon of the Potsdam sandstone.

The oldest Phyllopod crustacean *Protocaris marshi* was described by the writer in 1884[4] from the Georgia slates of Vermont, where it was found in association with *Olenellus thompsoni* and *O. vermontana.* The latter was referred by him to a new genus, Mesonacis, in 1885[5].

Mr. S. W. Ford began, about 1868, a study of the rocks and fossils of the hills east of Troy, N. Y., from which vicinity the first fossils of the Olenellus fauna, found in New York, were obtained. These were described by Professor Hall in 1847, and referred by him to the Hudson River group. Entering into correspondence with Mr. E. Billings, and comparing the fauna that he found at Troy with that from below Quebec, referred by Mr. Billings to the Lower Potsdam, Ford concluded that the strata containing the fauna at Troy should also be referred to the Lower Potsdam.[6] In his first paper he mentions finding 18 species, 8 of which are referred to described species and 10 remained to be described. Mr. Ford published a number of papers from 1871 to 1885,[7] in which he described the rocks and fossils found in them that occur near Troy, and also a little south of Scho-

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[1] On some fossils from the Primordial rocks of Newfoundland. Can. Nat., 2d ser., vol. 6, 1872. pp. 465–479.

[2] On some new species of Paleozoic fossils. Can. Nat., 2d ser., vol. 6, 1872, pp. 213–222.

[3] Bull. Am. Mus. Nat. Hist., New York, vol. 1, 1884, pp. 139–154.

[4] Bull. U. S. Geol. Survey No. 10, 1884, pp. 50, 51, pl. x, fig. 1.

[5] Paleozoic notes; new genus of Cambrian trilobites, Mesonacis. Am. Jour. Sci., 3d ser., vol. 29, 1885. pp. 329–331, 2 figs.

[6] Notes on the Primordial rocks in the vicinity of Troy, N. Y. Am. Jour. Sci. 3d ser., vol. 2, 1871, pp. 32–34.

[7] Descriptions of some new species of Primordial fossils. Am. Jour. Sci., 3d ser., vol. 3, 1872, pp. 419–422, 4 figs.

Remarks on the distribution of the fossils in the Lower Potsdam rocks at Troy, N. Y., with descriptions of a few new species. Am. Jour. Sci., 3d ser., vol. 6, 1873, pp. 134–140.

dack Landing, in Columbia County. The paleontological work of Mr. Ford gave the first satisfactory interpretation of the geology in the vicinity of Troy. The fossils described by him are: *Archæocyathus* (*A*) *rarum*, *A.* (*A*) *rensselaericum*, *Obolella nitida*, *Scenella retusa*, *Hyolithes communis*, var. *emmonsi*, *H. impar*, *Agnostus nobilis*, *Leperditia troyensis*, *Microdiscus meeki*, *M. speciosus* and *Solenopleura nana*. One of the most interesting of Mr. Ford's studies is that on the embryonic development of *Olenellus asaphoides*. From the data obtained in this study he decided that the Olenellus fauna followed the Paradoxides fauna in time.[1]

The description of the fauna in the Rocky Mountain province began with Mr. F. B. Meek, who described *Ethmophyllum whitneyi* and *E. gracile* from material collected by Mr. J. E. Clayton, at Silver Peak, Nevada. He referred the fossils to the Lower Silurian and considered them to be related to the corals.[2] In 1874[3] he described *Olenellus gilberti* and *O. howelli* from the Primordial rocks of Nevada. These descriptions were first published in a report by Dr. C. A. White, in 1874.[4] Dr. White also described *Kutorgina pa-*

On some new species of fossils from the Primordial or Potsdam group of Rensselaer County, N. Y. Am. Jour. Sci., 3d ser., vol. 5, 1873. pp. 211-215.

Note on the discovery of a new locality of Primordial fossils in Renssalaer County, N. Y. Am. Jour. Sci., 3d ser., vol. 9. 1875, pp. 204-206.

On additional species of fossils from the Primordial of Troy and Lansingburg, Renssalaer County, N. Y. Am. Jour. Sci., 3d ser., vol. 11, 1876, pp. 369-371.

On some embryonic forms of trilobites from the Primordial rocks at Troy, N. Y. Am. Jour. Sci., 3d ser., vol. 13, 1877, pp. 265-273, 1 plate.

Note on Microdiscus speciosus. Am. Jour. Sci., 3d ser., vol. 13, 1877, pp. 141, 142.

On certain forms of Brachiopoda occurring in the Swedish Primordial. Am. Jour. Sci., 3d ser., vol. 15, 1878, pp. 364-366.

Note on the development of Olenellus asaphoides. Am. Jour. Sci., 3d ser., vol. 15, 1878, pp. 129, 130.

Note on Lingulella cælata. Am. Jour. Sci., 3d ser., vol. 15, 1878, pp. 127-129.

Descriptions of two new species of Primordial fossils. Am. Jour. Sci., 3d ser., vol, 15, 1878, pp. 124-127, 1 cut.

Note on the Trilobite, Atops trilineatus of Emmons. Am. Jour. Sci., 3d ser., vol. 19, 1880, pp. 152, 153.

On the western limits of the Taconic System. Am. Jour. Sci., 3d ser., vol. 19, 1880, pp. 225, 226.

Remarks on the genus Obolella. Am. Jour. Sci., 3d ser., vol. 21, 1881, pp. 131-134, 5 figs.

On additional embryonic forms of trilobites from the Primordial rocks of Troy, N. Y. Am. Jour. Sci., 3d ser., vol. 22, 1881, pp. 250-259, 13 cuts.

Note on the discovery of Primordial fossils in the town of Stuyvesant, Columbia County, N. Y. Am. Jour. Sci., 3d ser., vol. 28, 1884, pp. 35-37.

[1] On additional embryonic forms of trilobites from the Primordial rocks of Troy, N. Y. Am. Jour. Sci., 3d ser., vol. 22, 1881, p. 257.

[2] Am. Jour. Sci. and Arts, 2d ser., vol. 45, 1868, pp. 62-64.

[3] MSS. published by Dr. C. A. White, 1874. Geol. and Geog. Expl. and Survey West of the 100th Meridian; Prelim. Rep. Invert. Foss. p. 7.

[4] Geog. and Geol. Expl. and Survey West of 100th Meridian; Prelim. Rep. Invert. Foss., p. 7.

nula and *Acrothele subsidua*, referring them to the Primordial fauna. The Olenellus fauna was enlarged in 1877 by Messrs. Hall and Whitfield[1] describing *Lingulella ella* which was found by the geologists of the Fortieth Parallel survey in Ophir Cañon, Utah. The writer discovered several species associated with *Olenellus gilberti*, in the Eureka District, Nevada, and described *Olenellus iddingsi, Kutorgina prospectensis, Scenella conula, Stenotheca elongata*, and *Anomocare parvum.*[2] In reviewing the material collected at Silver Peak, he identified *Archæocyathus atlanticus, Archæocyathus* sp. ?, *Strephochetus* sp. ?, *Hyolithellus princeps, Kutorgina* (like *K. cingulata*), and *Olenellus gilberti*[3] and described *Ethmophyllum meeki.*[4]

The review of the Olenellus fauna by the writer, in 1886,[5] resulted in the description of the following new species: *Archæocyathus billingsi, Leptomitus zitteli, Climacograptus ?? emmonsi, Orthis highlandensis, Orthisina transversa, Scenella ? varians, Hyolithes billingsi, Microdiscus parkeri, Olenoides levis, Crepicephalus augusta, C. liliana*, and *Oryctocephalus primus.* In 1887[6] he published an account of the discovery of a number of new species of fossils in the Upper Taconic slate of Emmons in Washington County, New York. The new species described are: *Lingulella granvillensis, Linnarssonia taconica, Orthis salemensis, Modiolopsis* (*??*) *prisca, Hyolithellus micans* var. *rugosa, Aristozoe rotundata, Leperditia* (*I*) *dermatoides, Microdiscus connexus, Olenoides fordi, Solenopleura* (*?*) *tumida, Ptychoparia* (*?*) *fitchi*, and *Ptychoparia* (*?*) *clavata.*

Mr. G. F. Matthew,[7] in reviewing the Cambrian fauna from Newfoundland, described one species, *Solenopleura bombifrons*, known only from the Olenellus zone. The writer found it in great abundance about Conception Bay in 1888.

Prof. N. S. Shaler described,[8] in association with Mr. A. F. Foerste, a considerable fauna from the Lower Cambrian strata near North Attleborough, Bristol County, Massachusetts. Among the species the following are new to the fauna: *Stenotheca rugosa* var. *abrupta, Stenotheca curvirostra, Pleurotomaria* (*Raphistoma*) *attleboroughensis, Hyolithes quadricostatus, Salterella curvatus, Paradoxides wal-*

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[1] Geol. Expl. Fortieth Par., vol. 4, 1877, p. 232.

[2] Paleontology of the Eureka District, Monographs of the U. S. Geol. Survey, 1884, vol. 8, pp. 14–28, 59.

[3] Second contribution to the studies on the Cambrian faunas of North America Bull. U. S. Geol. Survey, No. 30, 1886, p, 38.

[4] Proc. U. S. Nat. Mus., vol. xii, 1889, p. 34.

[5] Bull. U. S. Geol. Survey, No. 30, 1886.

[6] Fauna of the "Upper Taconic" of Emmons in Washington County, New York. Am. Jour. Sci., 3d ser., vol. 34, 1887, pp. 187–199, pl. i.

[7] On the Cambrian faunas of Cape Breton and Newfoundland. Trans. Roy. Soc. Canada, vol. 4, section 4, 1887, pp. 147–157.

[8] Preliminary description of North Attleborough fossils. Bull. Mus. Comp. Zool., Harvard College, vol. 16, 1888, pp. 27–41, pls. 1, 2.

cotti (equivalent to *Olenellus walcotti*), *Ptychoparia mucronatus* (equivalent to *Agraulos strenuus*), and *P. attleboroughensis.* The discovery of the genus Pleurotomaria is very interesting, as it adds greatly to the vertical range of the genus. Mr. Foerste discovered a species of Hyolithes in the limestones at East Point, Nahant, Massachusetts, and proposed the name *Hyolithes inæquadrilateralis,*[1] identifying it with specimens that occur at North Attleborough. After a study of the type specimens and a number of others collected by Mr. Sears at Nahant, I think this form is identical with *H. communis* var. *emmonsi.*

The presence of the Lower Cambrian or Olenellus fauna in New Brunswick is not yet fully proved, but if the stratigraphy described by Mr. Matthew in his memoir on the "Cambrian organisms of Acadia"[2] be correct the fauna from the basal series is in all probability of Lower Cambrian age. The same memoir describes the stratigraphic position of the fauna, comparing it with the Cambrian fauna of Sweden and Russia. The new genera and species are:

Phycoidella n. g., p. 144.
Phycoidella stichidifera n. sp., p. 144.
Palæochorda setacea n. sp., p. 145.
Hydrocytium (?) silicula n. sp., p. 146.
Microphycus n. g., p. 146.
Microphycus catenatus n. sp., p. 146.
Monadites n. g., p. 147.
Monadites globulosus n. sp., p. 147.
Monadites pyriformis n. sp., p. 147.
Monadites urceiformis n. sp., p. 147.
Radiolarites, n. g., p. 148.
Radiolarites ovalis n. sp., p. 148.
Plocoscyphia (?) perantequa n. sp., p. 148.
Astrocladia (?) elongata n. sp., p. 148.
Astrocladia (?) elegans n. sp., p. 149.
Astrocladia (?) virguloides n. sp., p. 149.
Dichoplectella n. g., p. 149.
Dichoplectella irregularis n. sp., p. 149.
Hyalostella minima n. sp., p. 150.
Obolus (?) major n. sp., p. 155.
Lingulella martinensis n. sp., p. 155.
Leperditia ventricosa n. sp., p. 159.
Leperditia steadi n. sp., p. 160.

He also describes and illustrates:

Buthotrephis antiqua Brongn., p. 144.
Platysolenites antiquissimus Eichw., p. 150.
Obolus pulcher Matth., p. 151.
Volborthella tenuis Schmidt, p. 156.
Psammichnites gigas Torrell, p. 157.
Arenicolites lyelli Torrell, var. minor, p. 159.

From the material collected in Newfoundland and collections from New York and Nevada, there was added to the fauna by the writer the genera Coleoloides, Helenia, and Avalonia, and the species *Archæocyathus dwighti, Ethmophyllum meeki, Planolites annularius, Kutorgina labradorica* var. *swantonensis, Obolella atlantica, Camerella minor, Coleoloides typicalis, Hyolithes terranovicus, H. similis, Helenia bella, Agnostus desideratus, Microdiscus helena, Olenellus (M) bröggeri, Avalonia manuelensis, Zacanthoides eatoni, Solenopleura harveyi, S. howleyi.*[3]

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[1] Bost. Soc. Nat. Hist., Proc., vol. 24, 1889, pp. 261–263.

[2] Trans. Roy. Soc. Canada, vol. 7, sec. 4, 1890, pp. 135–162.

[3] Proc. U. S. Nat. Mus., vol. xii, 1889, pp. 33–46.

EUROPE.

The first discovery of fossils in strata, subsequently referred to the Olenellus Zone, in Europe, was made by Dr. A. G. Nathorst, at Andrarum, Scania, in 1868.[1] The following year he found fragments of a trilobite, which Dr. Torell named *Paradoxides wahlenbergi* in a scheme showing the position of the strata containing it to be beneath the *Paradoxides hicksi* zone.[2] In 1870 Prof. J. G. Linnarsson found a trilobite in the Cambrian beds of Norway, and in 1871[3] named it *Paradoxides kjerulfi*, but he did not connect it with the Olenellus fauna of America. The latter was first identified in Europe by Prof. W. C. Brögger, who, in 1875, pointed out the fact that the *Paradoxides kjerulfi* of Linnarsson was not a true Paradoxides, but a form more nearly related to the American genus Olenellus.[4] This view was subsequently accepted by Linnarsson.[5] In 1886 Prof. Brögger called attention to the relations of the Olenellus and Paradoxides faunas in Norway and Sweden, and argued that the Olenellus fauna of North America must be beneath the Paradoxides zone, the same as in Scandinavia.[6] Following Brögger's paper came the beautiful memoir of Holm,[7] in which it was proved beyond question that the *Parodoxides kjerulfi* of Linnarsson belonged to the genus Olenellus. This was important, as American paleontologists had not admitted the species to the genus Olenellus on the evidence advanced by Brögger.[8]

In the review of the forms referred to the Medusæ Nathorst refers *Astylospongia radiata* Linnarsson and *Agelacrinus lindstromi* Linnarsson to Medusites, and describes *Medusites favosus*, although the same species had previously been described by Dr. Torell as *Protolyellia princeps*.[9] He also suggests that Eophyton is the cast of the trail of a Medusa.[10]

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[1] Om lagerföljden inom Cambriska formationen vid Andrarum i Skåne. Öfvers. Kongl. Vetenskaps-Akad. Förhandl., No. 1, 1869, pp. 61-65.

[2] Petrificata Suecana Formationis Cambricæ Acta Univer., Lundensis. Lunds Univer., Års-Skrift., 1870, vol. 6, p. 4.

[3] Om några försteninger från Sveriges och Norges Primordialzon. Kongl. Vetenskaps-Akad. Förhandl., No. 6, 1871, pp. 789-796.

[4] Fossiler fra Öxna og Kletten. Geol. Fören. Förhandl., Bd. 2, 1875, p. 574.

[5] Om faunan i lagren med Paradoxides ölandicus. Geol. Fören. Förhandl., Bd. 3, 1877, p. 362. De undre Paradoxideslagren vid Andrarum. Sver. Geol. Unders., Ser. C., No. 54, 1883, p. 18.

[6] Om alderen af Olenelluszonen i Nordamerika. Geol. Fören. Förhandl., Bd. 8, 1886, pp. 182-213.

[7] Om Olenellus kjerulfi. Geol. Fören Förhandl., vol. 9, 1887, pp. 493-518.

[8] See Stratigraphic position of the Olenellus Fauna in North America and Europe. Am. Jour. Sci., 3d ser., vol. 37, 1889, pp. 374-392; vol. 38, 1889, pp. 29-42.

[9] Petrificata Suecana Formationis Cambricæ. Acta. Univ. Lundensis. Lunds Univer., Års-Skrift, 1870, p. 10.

[10] Om Aftryck af Medusor i Sveriges Kambriska lager. Kongl. Sv. Vetenskaps-Akad. Handl., Bd. 19, 1881, No. 1, pp. 34, pl. 6.

In Norway Professor Kjerulf described in his beautiful memoir[1] the lower portion of the Paleozoic section, giving descriptions and figures of many sections.

The discovery of the Olenellus Zone in Russia was described by Dr. F. Schmidt,[2] in 1888. The remains of a trilobite were found by Herr A. Mickwitz, in Estland, on Kunda Brook. The section was studied by Dr. Schmidt, who published it and compared it with the Cambrian section in Norway and Sweden. The list of species found is given in the paper under the head of geographic distribution.

In Britain Prof. Adam Sedgwick described a series of strata, in 1835,[3] that he called Lower, Middle, and Upper Cambrian. In this series the Lower Cambrian included Archean rocks; the Middle Cambrian embraced the roofing slates, etc. (or the Cambrian System, as defined in this paper), and the Upper Cambrian much of the Ordovician (Lower Silurian). The crystalline Archean rocks were excluded from the Cambrian in 1838,[4] and the Lower Cambrian made to include the old slate series, up to the Bala, and the Upper Cambrian, the Bala series. The lower division was subsequently separated into the Bangor group and the Festiniog group, or the Lower and Middle Cambrian. Subsequently the Lower Cambrian was made to include the Longmynd, Bangor, and Llanberis groups.[5] This is the last expression of opinion from the illustrious founder of the Cambrian System as to what strata should be included in the Lower Cambrian.

The strata embraced in the Lower Cambrian by Sedgwick were mapped and worked up, in detail, in North Wales, by the members of the Geological Survey, but it was not until Dr. Hicks began his work in South Wales that it assumed greater importance as a distinct stratigraphic division. Dr. Hicks presented the results of his investigation in a number of papers published, at intervals, from 1866 to 1886. An excellent summary of this work was given in 1881.[6]

The Olenellus fauna was first recognized and described in Britain by Prof. Charles Lapworth.[7] At the Cumley quarries, Little Caradoc, Shropshire, he obtained *Olenellus calevi* (like *O. bröggeri*), Hyolithellus, Kutorgina, Scenella, Ptychoparia, and Obolella from calcareous sandstone, in the Cumley sandstone. The stratigraphic position of the sandstone, in relation to the Paradoxides zone, was not

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[1] Die Geologie des südlichen und mittleren Norwegen. Bonn, 1880.

[2] Ueber eine neuentdeckte untercambrische Fauna in Estland. Mém. Acad. Imp, Sci. St. Pétersbourg, ser vii, vol. 36, No. 2, 1888, pp. 1–27, pls. 1, 2.

[3] Rept. Fifth Meeting Brit. Assoc. Adv. Sci., Dublin, 1836, Trans. of sec. pp. 59–61.

[4] Proc. Geol. Soc. London, vol. 2, p. 679.

[5] Cat. Coll. Cam. & Sil. Foss., Geol. Mus. Univer. Cambridge, 1873. Preface, p. xv.

[6] Classification of the Eozoic and Lower Palæozoic rocks of the British Islands. Pop. Sci. Review, new ser. vol. 5, 1881, pp. 289–308, 2 plates, and one plate of sections.

[7] Nature, vol. 39, 1888, pp. 212, 213. Advanced sheets dated Oct. 25, 1888.

known until the fauna proved that it belonged to the Lower Cambrian.

The details of the stratigraphy and lists of the fossils are given under Geographic Distribution, Section VIII, p. 566.

V. THE LOWER CAMBRIAN OR OLENELLUS ZONE, AS KNOWN TO THE GEOLOGIST.

TYPICAL LOCALITY.

The type locality of the Cambrian Group is in the ancient area of Cambria, in North Wales, where the Middle and Upper Cambrian faunas occur; and the strata corresponding in position to those containing the Lower Cambrian fauna in America are found beneath the Middle Cambrian Zone. The group is characterized by the "First or Primordial Fauna" of Barrande. In America geologists include in it a series of strata that are subjacent to the Calciferous sandrock of the Ordovician group and superjacent to strata referred to the Algonkian group, as shown in the following table:

TABLE SHOWING THE CLASSIFICATION OF THE STRATA OF THE PALEOZOIC AND SUBJACENT SYSTEMS.

System and Group.	
Paleozoic:	
Carboniferous	Permian. Coal Measures. Lower Carboniferous.
Devonian	Catskill. Chemung. Hamilton. Corniferous. Oriskany.
Silurian	Lower Helderberg. Niagara.
Ordovician,	Lorraine. Trenton. Chazy. Calciferous.
Cambrian	Potsdam. Acadian. Georgia.
Algonkian:	
Keweenawan	Keweenaw Series. Grand Cañon Series. Llano Series etc.
Huronian. Other groups	Lake Superior. Minnesota. Adirondack. Newfoundland etc.
Archean:	
Laurentian	Including Upper Laurentian.

To enable the reader more definitely to locate the Olenellus or Lower Cambrian zone, the classification of the strata embraced by the Cambrian Group in America is presented in the following table.

TABLE SHOWING CLASSIFICATION OF THE CAMBRIAN GROUP.

Cambrian		Lower Calciferous.	Lower portion of the Calciferous sandrock of New York and Canada; Lower Magnesian limestone of Wisconsin, Missouri, etc.
	Upper Cambrian.	Potsdam	Potsdam sandstone of New York, Canada, Wisconsin, Texas, Wyoming; Gallatin limestone of Montana, and a portion of Pogonip limestone of Nevada.
		Knox	Knox Shales of Tennessee; Coosa Shales of Georgia and Alabama. The Alabama section may extend down into the Middle Cambrian.
		Tonto	Tonto Calcareous Shales of Arizona.
		Bell Isle	Shales and sandstones of Great and Little Bell and Kelley's Islands, Conception Bay, Newfoundland.
	Middle Cambrian.	St. John Braintree Avalon	Shales and slates of Braintree, Massachusetts: St. John, New Brunswick, and the Avalon Peninsula of Newfoundland. Central portions of the New York and Nevada Cambrian sections, and por- *tions of the Tennessee and Alabama sections.*
	Lower Cambrian.	Georgia	Georgia Shales and "Granular Quartz" of Vermont, Canada, New York, and Massachusetts. Shales and quartzite of Chilhowee Mountain, Tennessee.
		Placentia[1]	Limestones, etc., of L'Anse au Loup, Labrador; northwest coast and peninsula of Avalon, Newfoundland; basal series of Hanford Brook, New Brunswick; and shales and limestones of North Attleborough, Mass.
		Prospect	Lower part of Cambrian section of Eureka, and Highland Range, Nevada; Upper Arenaceous Shales of Big Cottonwood Cañon, Cambrian section of Utah.

The divisions of Lower, Middle, and Upper Cambrian are recognized in America and Europe. The names of the subdivisions of these three primary divisions of the group in America are the names of typical terranes that are respectively included in each of the primary divisions. Thus, under the term Prospect, of the Lower Cambrian, are included the strata of the Olenellus zone in Nevada, Utah, and the Rocky Mountain region to the north into British America. The typical section is that crossing Prospect Mountain, in the Eureka district, Nevada. In this section the sedimentation and fauna are essentially the same as in the Rocky Mountain Province. Under the name Placentia are included the strata of the Olenellus zone of northwestern and southeastern Newfoundland, New Brunswick, and eastern Massachusetts; and under Georgia the great development of Lower Cambrian rocks in eastern New York and Vermont and along the St. Lawrence River and south of New York from New Jersey to Alabama.

The names used in the third column refer to strata that are considered to be of the same relative geologic age. Thus the Potsdam, Knox, Tonto, and Bell Island rocks are all of Upper Cambrian age; but no one of them is considered in the table as subjacent or superjacent in stratigraphic position to the other.

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[1] This is substituted for the name Terra Nova used in a former table. Am. Jour. Sci., 3d ser., vol. 37, 1889, p. 383.

BASE OF THE OLENELLUS ZONE.

The base of the Olenellus zone is considered to be where the genus Olenellus, or the fauna usually accompanying it, first appears; beneath that horizon the strata are referred to some of the pre-Cambrian groups of rocks. In some cases the underlying rocks are in layers, conformably beneath the Cambrian, and no physical separation of the two groups is possible. In other instances the subjacent rocks are the remains of the old Archean continent, near the shores of which much of the life of this portion of the Cambrian period existed. To exhibit the actual relation of the strata of the Olenellus zone to the subjacent and superjacent rocks, figures of a few typical sections are introduced. The first is that crossing Prospect Peak in the Eureka district, Nevada.

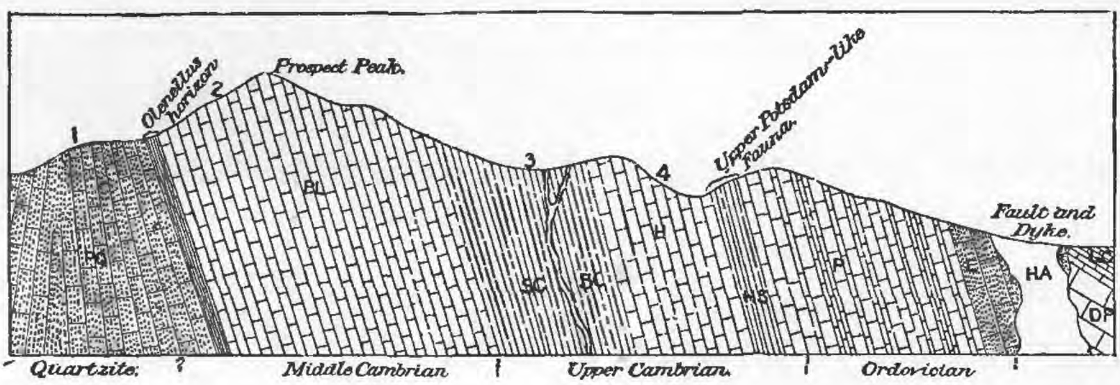

FIG. 45. Eureka section. This section includes the quartzite referred to the Algonkian on the west and conformably superjacent to it the Olenellus zone, above which the limestone of the Cambrian extends upward to the Ordovician.

The numbers on the upper line, and the letters on the section = 1&PQ, Prospect Mountain quartzite; 2&PL, Prospect limestone; 3&SC, Secret Cañon shale; 4&H, Hamburg limestone; HS, Hamburg shale; P, Pogonip limestone; E, Eureka quartzite. At this point the section is broken by massive dikes of hornblende andesite

Eureka section of Nevada.—In this section (Fig. 45) the Olenellus zone occupies a narrow belt of sandy shale and limestone that rests conformably upon a quartzite that exceeds 1,500 feet in thickness. This same quartzite occurs beneath the Olenellus zone in other sections in Nevada, and has a thickness of more than 10,000 feet in some instances. Above the Olenellus zone the limestones contain a fauna that may be referred to the Middle Cambrian, and still higher the Upper Cambrian fauna is largely developed. The layers of rock are now upturned at an angle of 70°, but as originally deposited they were level, or nearly so.

Wasatch section of Utah.—The second section is that of the Wasatch Mountain uplift in Utah (Fig. 46). The Olenellus zone occupies a thin belt of arenaceous strata just beneath the Middle Cambrian zone much as in the Eureka section (Fig. 45). Beneath it there are over 11,000 feet of strata that are referred to the Algonkian period, as no fossils have been found in them. The Upper Cambrian is absent either by nondeposition, or if deposited, the rocks have been removed by subsequent erosion. At present the basal line of the Cambrian in Utah and Nevada is drawn at the bottom of the band

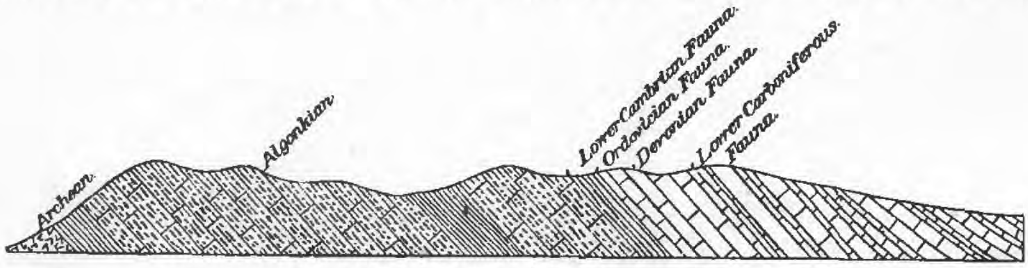

Fig. 46. Wasatch section. This crosses the Wasatch Mountains a little south of Big Cottonwood Cañon. The strata from the Archean to the band of shale carrying the Lower Cambrian fauna is referred to the Algonkian. The strata of the Olenelius zone rest conformably upon the Algonkian rocks, and are conformably subjacent to the strata containing the Middle Cambrian fauna which, in turn, are conformably subjacent to the strata containing the Ordovician fauna.

of arenaceous shales carrying the Olenellus fauna. This refers the quartzites and siliceous shales of the Wasatch and similar sections, including that of the Eureka district and Highland range of Nevada. to the Algonkian system.

Mt. Stephen section of British Columbia.—A somewhat similar section to that in the Eureka district is described by Mr. R. G. McConnell as occurring in British Columbia.[1] It crosses Cathedral Mountain and Mt. Stephen on the eastern side of the Rocky Mountains near the line of the Canadian Pacific Railway. In this section (Fig. 47) the Olenellus fauna occurs in the lower portion of the Castle Mountain limestone (A) and the Middle Cambrian fauna 2,000 feet above, and still higher in the series (B) the Lower Ordovician

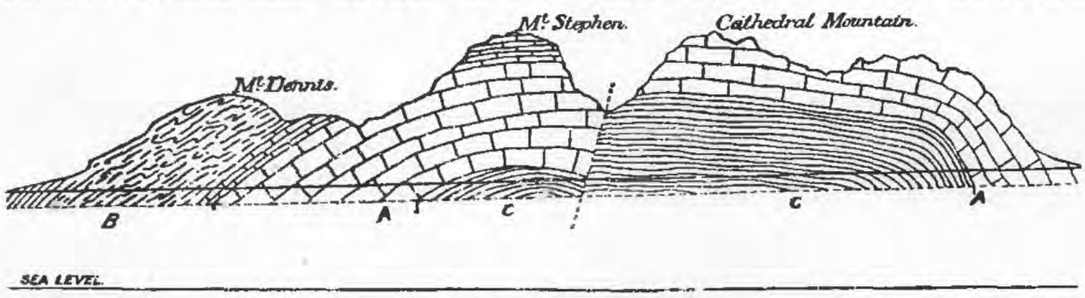

Fig. 47. Section of Cathedral Mountain and Mt. Stephens, showing (C) strata referred to the Bow River series, which are in an equivalent stratigraphic position to the Algonkian rocks of the Wasatch section. The Castle Mountain limestone (A) contains the Olenelius fauna near its base. The Middle Cambrian fauna occurs in the lower portion of the Calcareous shale (B).

fauna. The strata (C) are described by Mr. McConnell as a great series of dark colored argillites associated with some sandstones, quartzites, and conglomerates. The portion exposed has an estimated thickness of over 10,000 feet, and it corresponds in stratigraphic position and character to the pre-Olenellus strata of the Wasatch section. (See Fig. 46.)

Grand Cañon section of Arizona.—The section (Fig. 48) laid bare in the Grand Cañon of the Colorado, beneath the great unconform-

[1] Report on the Geological Structure of a portion of the Rocky Mountains. Geol. and Nat. Hist. Sur. Canada, n. ser., vol. ii for 1886, 1887, pp. 28–30 D, with section.

ity at the base of the known Cambrian, shows 12,000 feet of unaltered sandstone, shales, and limestones, that, I think, were deposited in pre-Cambrian time and should be referred to the Algonkian.

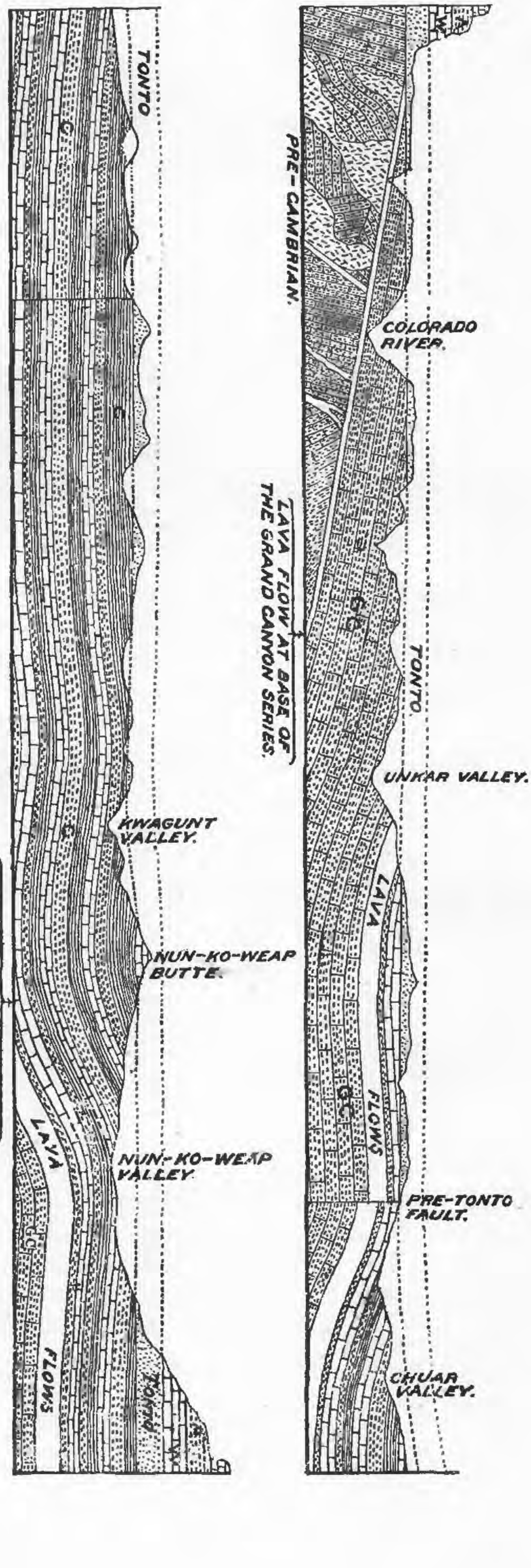

FIG. 48.—Grand Cañon Section. This section crosses the Algonkian strata nearly at right angles to their strike and illustrates the unconformity between the Cambrian and Algonkian rocks. The Cambrian (Tonto formation) has been removed by erosion on the direct line of the section, but it is shown on the sides of the cañon as indicated by the dotted lines. *GC* and *C'*, Grand Cañon and Chuar formation, or the strata referred to the Algonkian. *T*, the Tonto formation of the Cambrian. *W*, Redwall limestone of the Lower Carboniferous. *A*, Aubrey sandstone of the Carboniferous.

The entire section of pre-Cambrian strata is unbroken, and the sandstones, shales, and limestones are much like those of the Ordovician section of New York. In a bed of dark argillaceous shale, 3,550 feet from the summit of the section, I found a small Patelloid or Discinoid shell, a fragment of what appears to be the pleural lobe of a segment of a Trilobite, and an obscure, small Hyolithes, in a layer of bituminous limestone. In layers of limestone, still lower in the section, an obscure Stromatoporoid form occurs in abundance.[1] These fossils indicate a fauna, but do not tell us what it is. A similar series of rocks (Fig. 49) occur unconformably beneath the Cambrian, in Llano County, Tex. Fossils have not been reported from them.[2]

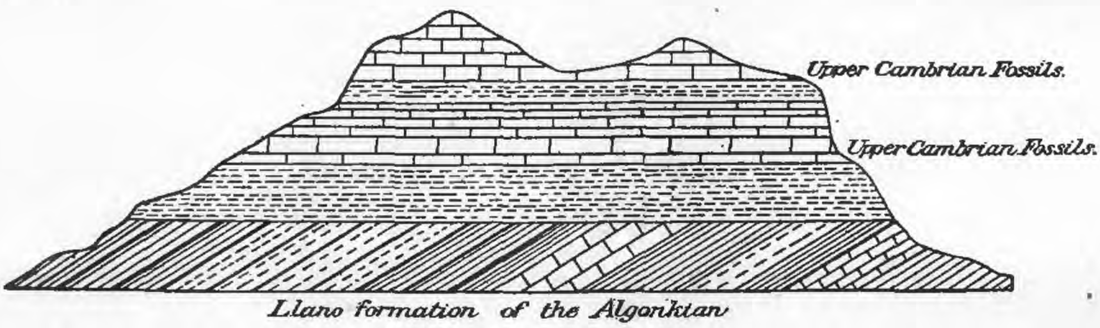

FIG. 49.—Section of Packsaddle Mountain, Texas, illustrating the same unconformable relation of the Cambrian to the Algonkian as shown by Fig 48. The lower horizontal sandstone of the Cambrian is equivalent in position and lithologic characters to the Middle Cambrian lower Tonto sandstone of Arizona, but no fossils have been found to further establish the correlation; the limestone capping the mountain may possibly pass up into the base of the Ordovician, but the typical fauna has not been found in it.

Eastern New York section.—The most puzzling of all the sections is that of eastern New York where the Olenellus fauna ranges through a great thickness of shales and slates—I have estimated it at 14,000 feet—but such a range for a species or subfauna is without precedent, and I wish to review the section before giving a final opinion. The vertical range *is very great* and the base of the Cambrian is unknown.

Vermont section.—In the northern Vermont section the Olenellus zone extends from the upper portion of the limestone through a considerable thickness of shales as shown by the section, Fig. 50. Beneath the Olenellus zone there are about 700 feet of conformably bedded limestones that have not yielded characteristic fossils.[3]

[1] Am. Jour. Sci., 3d ser., vol. 26, pp. 437–442, 1883.

[2] Notes on Paleozoic rocks of Central Texas. Am. Jour. Sci., 3d ser., vol. 28, pp. 431–432, 1884. By an error in the sketch the strata are represented as dipping in the wrong direction. The dip at the point where the section crosses is 15° to 40° south (loc. cit., p. 431). A misprint in the description of the figure refers 5 to the Potsdam *sandstone* instead of *limestone*.

[3] As this is going through the press I wish to record my discovery, in August, 1890, of Salterella and fragments of a trilobite about 500 feet lower down in this section.

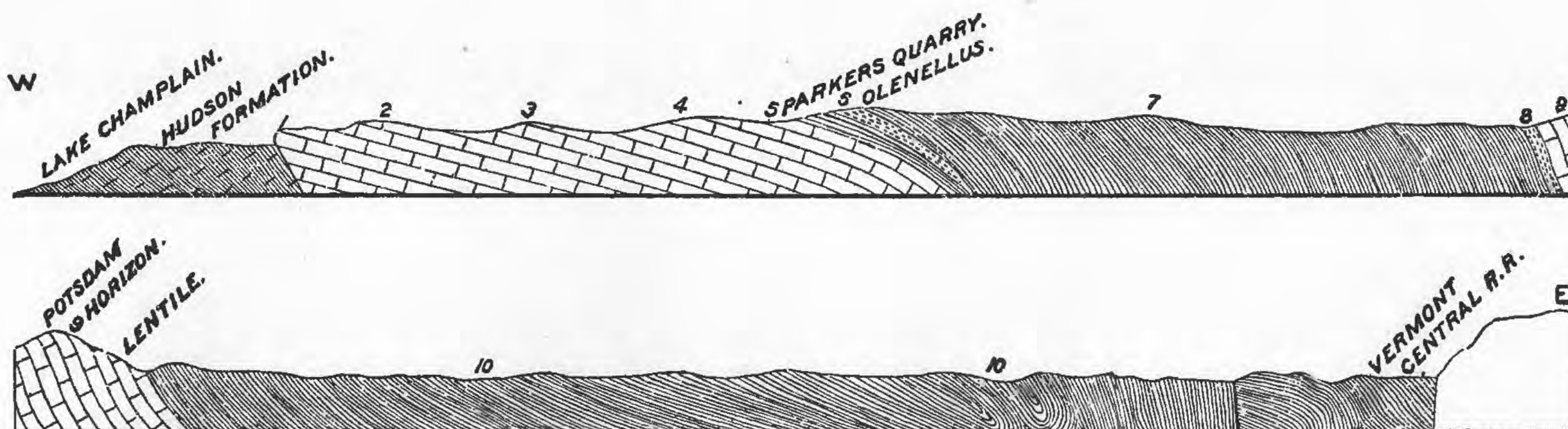

Fig. 50.—Section crossing from Lake Champlain east to the Vermont Central Railroad track, in the town of Georgia, Vt. At 1, an overthrust of the Lower Cambrian on the shales of the Hudson formation is shown. At 5 and 6 the Olenellus fauna is largely developed, and at 9 a few species occur which may belong to the Middle or the Upper Cambrian fauna.

High up in the section an interbedded limestone occurs that contains a fauna that may prove to be a portion of the Middle or it may be the Upper Cambrian fauna. In the St. Lawrence and Hudson valleys there is but one area known where the Lower Cambrian strata rest on the Algonkian and Archean rocks; this is in southern Vermont and western Massachusetts. Here the Olenellus zone is represented by a quartzite that was a sandy sea beach upon which the remains of a species of Olenellus were scattered and buried in the sand by the action of the waves. On the western or Adirondack side of

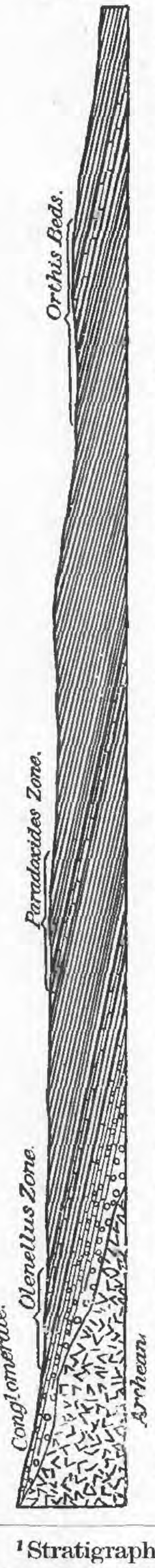

Fig. 51.—Section on Manuel's Brook, Newfoundland. The strata of the Lower Cambrian rest unconformably upon the Archean. Above the conglomerate the shales and sandstone, etc., dip at an angle of 12°, and are conformable through the Olenellus and Paradoxides zones and into the Orthis beds where the section is cut off by the sea.

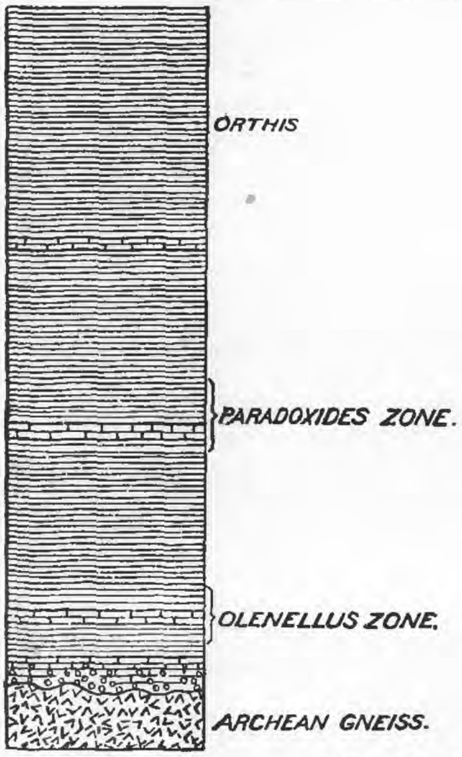

Fig. 52.—Restoration of the section represented by Fig. 51, to show a direct superposition of the Paradoxides zone upon the strata of the Olenellus zone.

the Cambrian Strait the Upper Cambrian sandstone rests unconformably upon the strata of the Algonkian; and the Lower Cambrian appears a few miles to the eastward, where it is brought up to view by a profound displacement of the strata.

Newfoundland section.—In Newfoundland a section is found, on Manuel's Brook, Conception Bay, that exhibits very clearly the stratigraphic relation of the Olenellus and Paradoxides faunas[1] (Figs. 51 and 52). At the base of the section a bed of conglomerate outlines the coast line of early

[1] Stratigraphic position of the Olenellus fauna in North America and Europe. Am. Jour. Sci., 3d ser., vol. 37, 1889, p. 380.

Cambrian time. The passage from coarse to fine sediment, in the upper beds of the conglomerate, indicates a gradual depression of the sea bed and the presence of deeper and more quiet waters, where the animal life of the time flourished, died, and became embedded in the soft mud that is now found transformed into clay shale and arenaceous limestone. Of the fossils found in these beds twenty-two species have been identified, all of which belong to the Olenellus fauna. Passing above the red and greenish shale of the Olenellus zone, and searching the layers of greenish shale above, we find, 270 feet above the bedof conglomerate, numerous traces of the Middle Cambrian or Paradoxides fauna; and in the immediately superjacent black argillaceous shales the latter fauna is very abundant in genera, species, and numbers of individual specimens. This is the only section known to me on the American continent where the two faunas are typically developed and occur in an unbroken, continuous, conformable geologic section.

The Manuel's Brook section is typical of the sections of the Atlantic Province of the Lower Cambrian. In Sweden strata containing the Olenellus fauna rest unconformably upon the Algonkian or Archean rocks, and the Paradoxides zone is higher up in the section. In Britain the Lower Cambrian strata rest unconformably upon the Algonkian rocks, and nowhere in the Atlantic Basin area is there any considerable thickness of strata known between the Olenellus zone and the unconformably subjacent pre-Cambrian rocks except it be on St. Mary's and Placentia Bays, Newfoundland.

Cambrian and pre-Cambrian.—The line of demarkation between the Cambrian and pre-Cambrian rocks may be considered as:

First. At the base of the Olenellus zone, in the continuous sections like those of Nevada and Utah.

Second. At the line of unconformable contact between any member of the Cambrian group and the subjacent Algonkian and Archean rocks in the interior area, or over the pre-Potsdam or Keweenawan continent.

Third. At the line of unconformable contact and the base of the Olenellus zone, in the Atlantic Basin, as shown by the sections of Newfoundland and Wales.

The Olenellus zone is so small a factor in the discussion of the geologic features of Europe that the observations thereon, properly belonging under this head, are united with those under "Geographic Distribution," Section VIII.

VI. THE NORTH AMERICAN CONTINENT DURING CAMBRIAN TIME.

The study of the known geographic distribution of the strata of the Olenellus zone and their relations to the subjacent and superjacent rocks has led to conclusions respecting the condition and growth of the continent during Cambrian and late Algonkian time that are worthy of greater consideration than can now be given to them, and I shall only touch upon the points that bear more directly upon the history of the Olenellus zone and fauna.

HABITAT OF THE OLENELLUS FAUNA.

One of the most important conclusions is that the fauna lived on the eastern and western shores of a continent that, in its general configuration, rudely outlines the North American continent of today. Strictly speaking the fauna did not live upon the outer shore facing the ocean, but on the shores of interior seas, straits, or lagoons that occupied the intervals between the several ridges that rose from the continental platform east and west of the main continental land surface of the time. On the eastern side, the first ridge east of the main portion of the continent, was the range extending from Alabama to the northeast along the line of the present Appalachian range and its extension to the north, as the Green Mountains, as far as the St. Lawrence. Whether or not the fauna existed in the Connecticut basin of the New England States to the eastward of the Green Mountains is unknown. That it occurs on the eastern side of the next ridge to the east is shown by its presence in eastern Massachusetts and northwestern Newfoundland; its presence in a still more easterly basin is proved by its occurrence on the peninsula of Avalon, to the eastward of the Archean ridges crossing central Newfoundland.

The occurrence of these basins between the Archean ridges of the pre-Cambrian continental platform has been shown by Dana and Crosby, and the presence of similar basins upon the western side have been pointed out by Dana. In one of the latter, between the Wasatch and Sierra Nevada ranges, the Olenellus fauna flourished, and it also extended to the northward, cutting across a break in the eastern range so as to occupy the eastern shore of the eastern range of mountains in British Columbia.

It is not my intention to discuss the evidence upon which the presence of these various outlying basins is asserted. This has lately been presented by Dana.[1] What I wish to call attention to now is that the Olenellus fauna lived upon the eastern and western sides of

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[1] Areas of continental progress in North America, and the influence of the conditions of these areas on the work carried forward within them. Bull. Geol. Soc. America, vol. 1, 1889, pp. 36-48. Archean axes of eastern North America; Am. Jour. Sci., 3d ser., vol. 39, 1890, pp. 378-383.

the mainland of the North American continental area that existed during late Algonkian and early Cambrian time. This view is sustained by the following observations: (1) The strata containing the Olenellus fauna are known only in the eastern and western portions of the continent; (2) as far as known the Lower Cambrian strata are absent in the interior of the continent; (3) the Upper Cambrian strata are unconformably superjacent to the Algonkian and Archean rocks, over the areas where the Middle and Lower Cambrian formations are absent; (4) the strata of the Middle and Lower Cambrian are conformably beneath the Upper Cambrian on the eastern and western sides of the present continent in all sections where the three divisions are present.

In order to present graphically the data for the preceding statements, I have prepared an outline map of the continent, upon which are arranged typical geologic sections of the Cambrian and, when known, the immediately subjacent Algonkian or Archean rocks (Plate XLIV). On this map each section represents the strata of a geographic province or area of greater or less extent. Thus the most western section, B, that of the Eureka district, Nevada, is typical of the Cambrian rocks in the Great Basin area, with the exception of the western slope of the Wasatch Mountains. The section H is considered typical of the Cambrian rocks of the upper Mississippi Valley, etc., etc.

DESCRIPTION OF MAP AND SECTION, PLATE XLIV.

PLATE XLIV. Outline map of the North American Continent, with diagrammatic sections so arranged as to illustrate the comparative thickness of the Cambrian rocks over the interior of the continent and on the eastern and western margins. The star at the base of each section indicates the geographic location of the section.

1. Western slope of the Wasatch Mountains. In this section the Cambrian rocks are conformably superjacent to the Algonkian. (See Fig. 46, p. 552.)
2. Eureka district of central Nevada. In this section the Algonkian and Lower Cambrian strata are conformable to each other. (See Fig. 45, p. 551.)
3. Mount Stephen section of British Columbia. The relations of the strata in this section are the same as in the Eureka section. (See Fig. 47, p, 552.)
4. Section on the Gallatin River, near Gallatin City, Mont. This is essentially the same as the Mount Stephen section, in having the Cambrian conformably superjacent to the Algonkian.
5. Grand Cañon of the Colorado, northern Arizona. In this section the Cambrian strata are unconformably superjacent to the inclined strata of the Algonkian. (See Fig. 48, p. 553.)
6. Llano County, Texas. This section is similar to that of the Grand Cañon, in having an unconformity between the Algonkian and the Cambrian.[1] (See Fig. 49, p. 554.)

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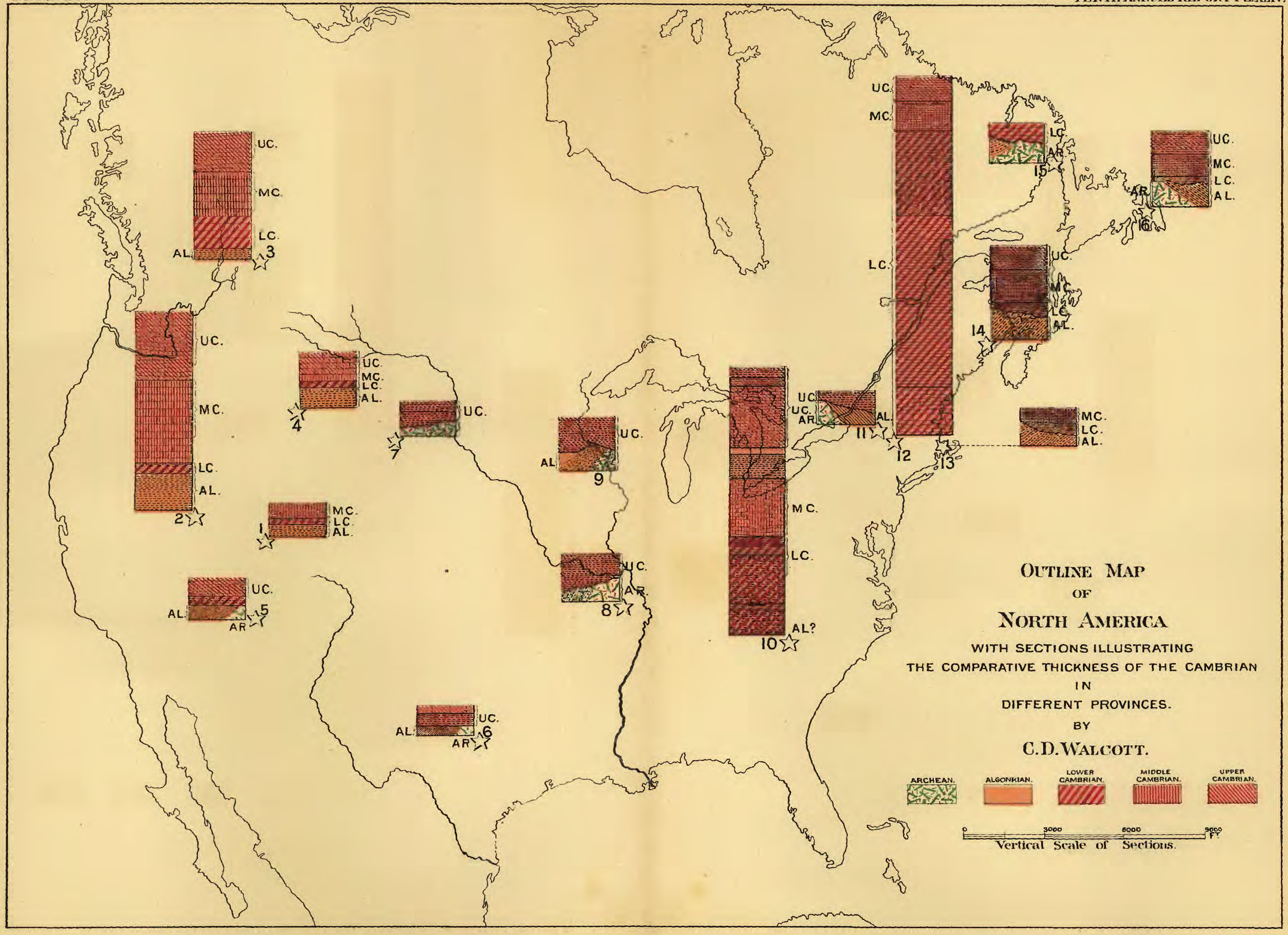
[1] Prof. T. B. Comstock has recently stated that Archean rocks also occur in the Texas area, subjacent to the Cambrian. (First Ann. Rep. Geol. Survey Texas, 1890, pp. 254-282.)

7. Black Hills of Dakota. The Upper Cambrian rests unconformably upon the Archean. (See Figs. 53 and 54, p. 561.)
8. Ozark Mountains, southeastern Missouri. The relations of the Cambrian to the Archean are the same as those in the Black Hills section.
9. Wisconsin and Minnesota. This is a generalized section to show the unconformity between the Upper Cambrian sandstone and the subjacent Archean and Algonkian rocks. (See Pl. XLV, Fig. 55, p. 561.)
10. Eastern Tennessee section. The Middle Cambrian zone is put in mainly on data from the northern Alabama section. The limits of the Lower Cambrian are not yet defined, but it is supposed to rest conformably upon the Algonkian rocks.
11. Eastern and northern slope of the Adirondack Mountains of New York. In this section the Potsdam sandstone of the Upper Cambrian rests unconformably upon and against the rocks of the Archean and Algonkian.
12. Trough between the Adirondack and Green Mountains, eastern New York and western Vermont. The base of this section is a massive limestone. Its contact with the subjacent rocks is unknown. Further details will undoubtedly change this section more or less. It has a great thickness, but the relations of the masses of limestone and shales, in the central portion of it, have not yet been fully worked out. (See Fig. 50, p. 555.)
13. North Attleborough and Braintree. In this section I have combined the Lower Cambrian of North Attleborough and the Middle Cambrian of Braintree in one generalized section to show their unconformity to the subjacent Archean.
14. Vicinity of St. John, New Brunswick. This section illustrates the unconformity between the Archean and the Cambrian and the shaly character of the Cambrian strata.
15. L'Anse au Loup, on the north side of the Straits of Belle Isle, Labrador. This section, like 13 and 14, represents the unconformity between the Cambrian and Archean.
16. Conception Bay, Avalon Peninsula, Newfoundland. The Cambrian rocks of the Avalon Peninsula rest unconformably upon strata of Archean and Algonkian age, as represented in the section. (See Fig. 51, p. 556.)

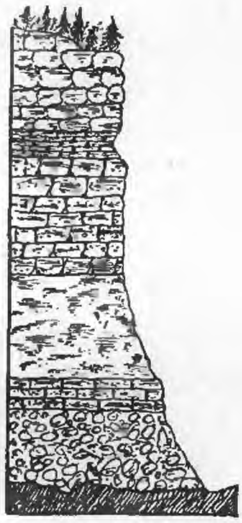
The theoretic section crosses the North American continent north of the 39th parallel in such manner as to traverse the Cambrian, Algonkian, and Archean at the close of the deposition of the sediments now forming the Upper Cambrian. The surface of the ancient continent is outlined by the line beneath the Cambrian deposit. The Upper Cambrian is represented as extending entirely across the continent, while the Middle and Lower are fully developed only on the margins. In Wisconsin and east of the Adirondack Mountains the Algonkian rocks are unconformably subjacent to the Cambrian strata, while in Utah, Nevada, and British Columbia they are conformably beneath the Lower Cambrian.

To more fully understand the actual relations of the Cambrian strata to the subjacent rocks, the reader is requested to examine the sections represented by Fig. 45, p. 551, Fig. 46, p. 552, Fig. 47, p. 552, where there is entire conformity between the Cambrian and pre-Cambrian strata; Fig. 48, p. 553 and Fig. 49, p. 554, that illustrate the unconformity between the Upper Cambrian and what I consider to be the youngest of the unconformable Algonkian rocks; Fig. 51, p. 556, which illustrates the unconformity between the two groups in the



THEORETIC SECTION AT CLOSE OF CAMBRIAN TIME.

Atlantic Coast Province. Over the interior of the continent their relations are shown by Figs. 53 and 54, where the Upper Cambrian



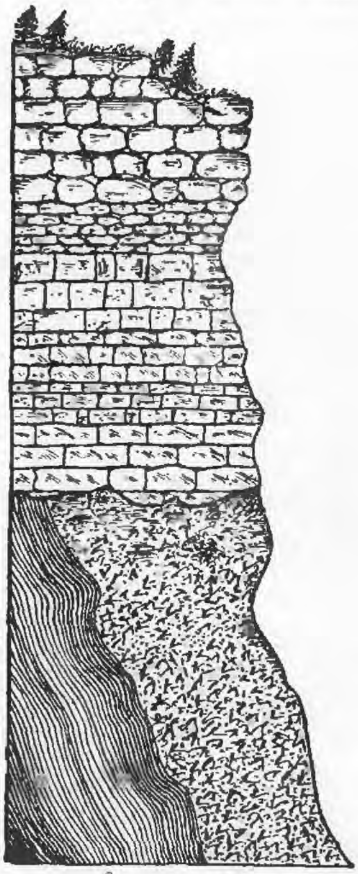


FIG. 53.—Section of the Upper Cambrian sandstone on Lower Rapid Creek, showing the conglomerate at the base and its unconformity with the subjacent Archean schists. 1. Massive gray limestone. 2. Thin-bedded impure limestone. 3. Reddish sandstone. 4. Concealed. 5. Coarse reddish sandstone. 6. Loose bowlders. 7. Schists. Numbers 1 and 2, Carboniferous; 3, 4, 5, and 6 Upper Cambrian.

FIG. 54.—Section of Upper Cambrian sandstone on Lower French Creek, showing the unconformity between it and the subjacent Archean rocks. (After Newton, Rep. Geol. and Resources Black Hills of Dakota, 1880, p. 90, Fig. 12.)

sandstones rest unconformably upon the upturned strata of the Algonkian or Archean, in the Black Hills of Dakota (7, of map, Pl. XLIV). In the Upper Mississippi Valley they are shown by Figs. 55–57, and Pls. XLV and XLVI. In Fig. 55 the Huronian quartzites

FIG. 55.—North and south sections through the Baraboo Ranges looking east. The section shows the horizontal Potsdam sandstone lying upon a deeply denuded surface of Huronian quartzite and quartz porphyry. (After Irving, Seventh Ann. Rep. U. S. Geological Survey, p. 405, Fig. 78.)

are seen to project up through the Potsdam sandstone. This is further illustrated by Prof. Chamberlin's theoretic restoration of the land surface in central Wisconsin, during the deposition of the Potsdam sandstone. In this section (Pl. XLV, *a*) the strata of the Archean, Huronian and Keweenaw series are shown to have formed the land surface from which the sediments forming the Potsdam sandstone were derived. The other sections show the unconformity between the Potsdam sandstone and the subjacent rocks. Figs. 56 and 57

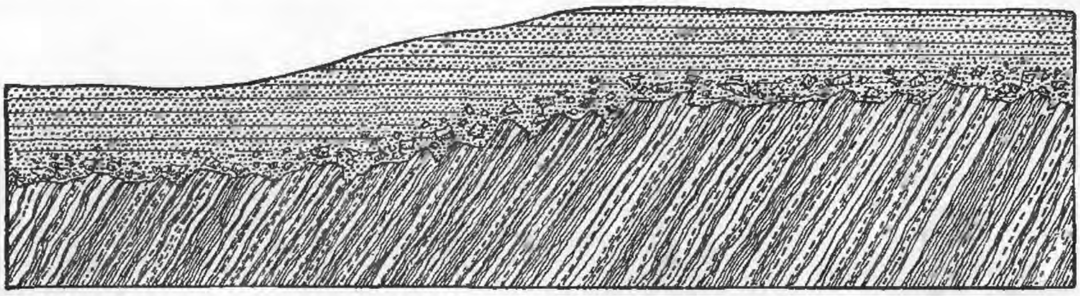


Fig. 56.—Section near Norway, Mich., showing the Potsdam sandstone overlying the ferruginous schists and ore of the Huronian or iron bearing series. (After Irving, Seventh Ann. Rep. U. S. Geological Survey, p. 410, Fig. 85.)

further illustrate the origin of the material forming the Potsdam sandstone, and Fig. 55 and Pl. XLV. fig. 1, prove that as the sea advanced upon the land the higher points of the Keweenawan continent continued to project above it as islands, and on the north as

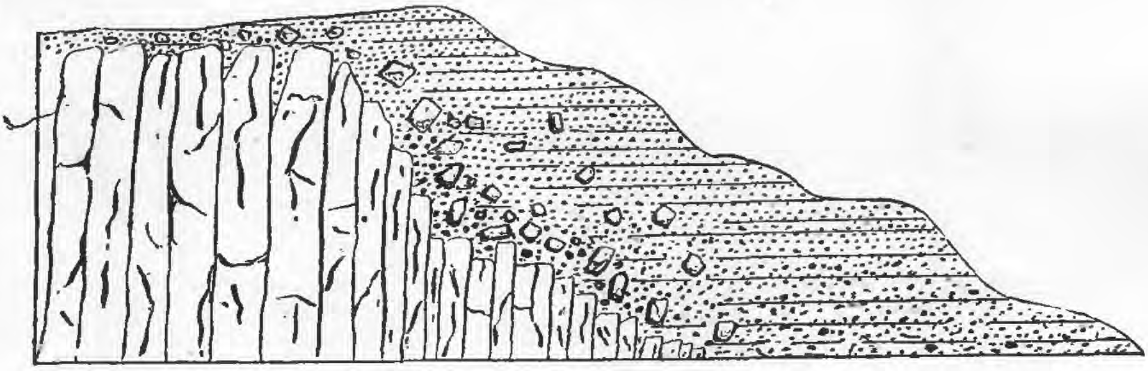


Fig. 57. Contact of the Huronian quartzite and Potsdam sandstone. South end of cliff on the east side of the upper Narrows of the Baraboo River near Ableman, Wis. Scale 50 feet to the inch. (After Irving, Seventh Ann. Rep. U. S. Geological Survey, p. 404, Fig. 76.

the great Archean nucleus of the continent during Upper Cambrian time. Around the islands, large and small, and along the shores of the northern continental mass, the sands, clays, etc., accumulated that now form the widely distributed sandstones and shales of the Upper Cambrian.

Description of Plate XLV.

1, Vertical section across northern central Wisconsin during the deposition of the Upper Cambrian (Potsdam) sandstone. (After Chamberlin, Geology of Wisconsin, vol. 1, 1883, Pl. 5, section.)

2, Section displayed to view on the east side of the gorge at the upper Narrows of the Baraboo River, showing the unconformity between the Potsdam sandstone and the subjacent Huronian quartzite. (After Irving, Seventh Ann. Rep. U. S. Geological Survey, p. 407, Fig. 80.)

3, Section on Black River in the vicinity of Black River Falls, Wis., showing the Potsdam sandstone resting on an eroded surface composed of granite and steeply inclined layers of gneiss and ferruginous schists. Scale 2 miles to the inch. (After Irving, Seventh Ann. Rep. U. S. Geological Survey, p. 403, Fig. 75.)

4, Section from southeast to northwest in the St. Croix River region of northwestern Wisconsin, through the Keweenaw series and Potsdam sandstone. (After Irving, Seventh Ann. Rep. U. S. Geological Survey, p. 413, Fig. 88.)

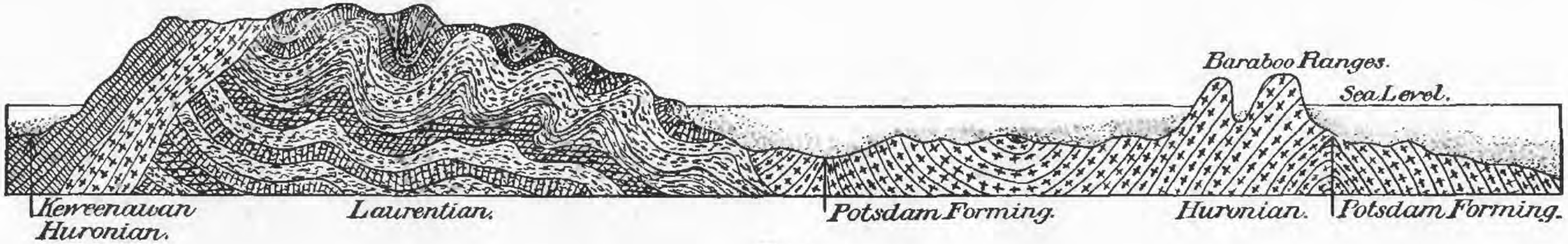


Fig. 1.

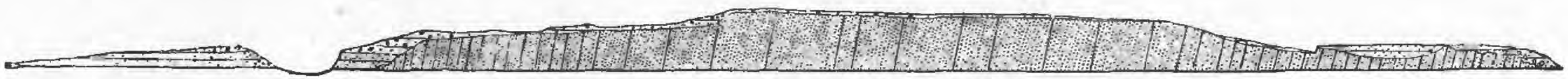


Fig. 2.

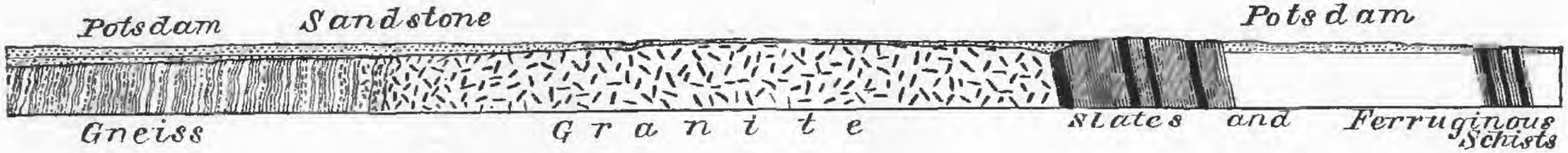


Fig. 3.

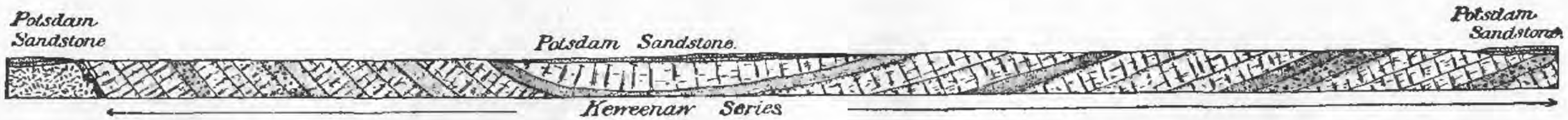


Fig. 4.

SECTIONS SHOWING DEPOSITION OF POTSDAM SANDSTONE IN WISCONSIN.

The study and correlations of the sections represented on the map have led to the construction of the theoretic section beneath it (Pl. XLIV). In this the lower portion of the great thickness of strata west of the Rocky Mountains is referred to the Algonkian system and the remaining portions to the three divisions of the Cambrian. From the Rocky Mountains to the Black Hills the Upper Cambrian is alone recognized, and from the Black Hills to the Upper Mississippi or Wisconsin area the Upper Cambrian, and from Wisconsin to the Adirondack Mountains of New York there is only the record of the presence of Upper Cambrian strata. East of the Adirondack Mountains, in the deep trough between them and the Green Mountains, a great thickness of Cambrian sediment accumulated. East of the Green Mountains the Lower and Middle Cambrian are known on the Atlantic coast; and it is assumed that the Upper Cambrian has been removed by erosion. Little attention has been given to the relative proportion of the vertical and horizontal scale; both are distorted in the section.

The study of the data given on Pl. XLIV and in the accompanying section leads to the conclusion that during the period of erosion of the Algonkian and Archean rocks of the interior of the continent prior to the deposition of the Upper Cambrian strata over them, the continent stood at a relatively high elevation above the sea into which the sediments were being washed. This is proved by the accumulation of more than 10,000 feet[1] of detrital sediment on the western shore during the latter part of Algonkian time; also by the great thickness of Lower and Middle Cambrian strata on both the eastern and western sides of the continent and the absence of these rocks from over the interior of the continent. It is readily inferred that the sediments washed from it on the eastern and western sides subsequently formed the Middle and Lower Cambrian rocks, the conformable pre-Cambrian rocks of the Wasatch Mountains and similar sections of strata to the north and south. The absence of strata of Upper Cambrian age in the Wasatch section (Fig. 46, p. 552) establishes the fact that the downward movement of the continent was not entirely uniform; and it is very probable that the accumulation of data from more extended observations will show other irregularities in the continental movement. As a whole, however, the elevation and depression of the continent appears to have been very uniform all across the central portion. That the Upper Cambrian sea was transcontinental is shown by the presence of the same species of Upper Cambrian fossils in similar stratigraphic relations to strata containing the Ordovician fauna in the valleys of the St. Lawrence and Lake Champlain and on the slopes of the Adirondacks of New York; in the southern Appalachian region of Tennessee and Alabama; in the Upper Mississippi Valley; in Wisconsin and Minne-

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[1] Wasatch and Nevada sections.

sota; in the sandstones and limestones of Texas and the Black Hills of Dakota, and in the limestones of Nevada and Montana. It is not possible to demonstrate that the faunas in these widely separated localities were contemporaneous. We know that they have the same general stratigraphic relations to the superjacent faunas and to the subjacent faunas when the latter are present. The study of the Olenellus fauna also proves that it contains a similar assemblage of forms on the opposite sides of the continent, and that it is subjacent to a definitely marked Middle Cambrian fauna in Nevada, Utah, British Columbia, and New York, and that the Paradoxides fauna is *superjacent to it in Newfoundland and Scandinavia.*

It is exceedingly difficult to restore the topography of the North American continent at any comparatively recent geologic period, and it is doubly so for the ancient pre-Cambrian continent, as the sum total of what is not known so far exceeds that which is known. The new lines of thought and investigation opened up by such a study are often valuable in leading to results not anticipated, and often a strong working hypothesis or even a theory may result from the direct investigation. Such is, I think, the result of the present study of the condition of the continent in Cambrian time. This presentation of results is more or less tentative and incomplete, suggestive rather than decisive, but it will lead to the study of phenomena bearing upon the subject in a new light, and thus prepare the way for a fuller consideration of it in the future.

VII.—THE CONTINENT OF EUROPE DURING THE DEPOSITION OF THE SEDIMENT NOW FORMING THE OLENELLUS ZONE.

An outline map of Europe, showing the comparative thickness and depth of the deposition of the Cambrian and Lower Silurian rocks in different areas, prepared and published by Dr. Henry Hicks,[1] exhibits very clearly the view expressed by him that the sediments of the Cambrian and Silurian were largely deposited on the western side of the continent. In Spain and Wales the sediments accumulated to a great thickness. To the eastward, in Sardinia, Bohemia, and Scandinavia, the sections show less than one-half the thickness, and in central Russia they are still further reduced. East of the White Sea, on the Arctic coast, and in the Ural Mountains the deposits are very thin, including only some members of the Silurian that rest unconformably upon the Archean. That I may not misinterpret Dr. Hicks's views to the reader, a copy of his map is here introduced (Pl. XLVIII.) On the plate the Lower Cambrian occurs at the base of section B in Wales; also at the base of section E in Scandinavia and section F in Russia. The Middle Cambrian zone is known to occur in sections A, C, and D, as well as in sections B and

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[1] Quart. Jour. Geol. Soc., vol. 31, 1875, pl. 27.

UNCONFORMITY BETWEEN POTSDAM SANDSTONE AND FERRUGINOUS SCHISTS.

E, and it is quite probable that the Lower Cambrian fauna is present in section A. To further illustrate the unconformity between the Archean and the Cambrian, illustrations of a section in Wales and one in Norway are introduced. (Figs. 58 and 59.)

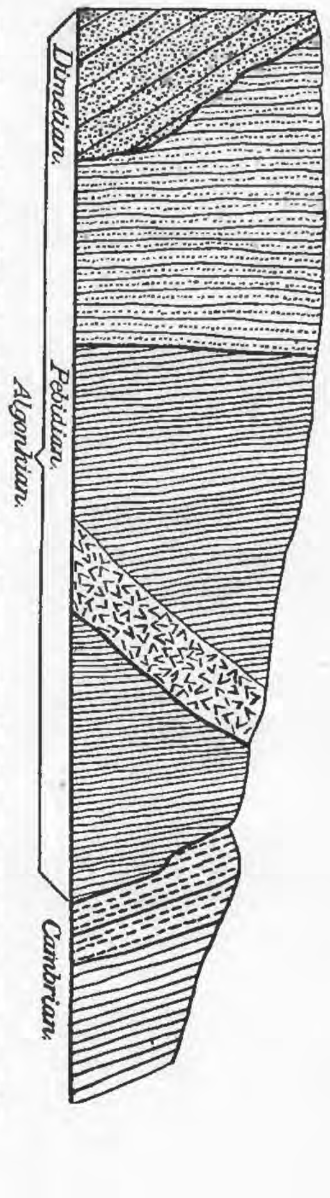

FIG. 58.—Section at Nun's-well Bay, St. David's, Wales. The Cambrian rocks are unconformably superjacent to the Pebidian strata of the Algonkian. (After Hicks, Quart. Jour. Geol. Soc., vol. 33, p. 236.)

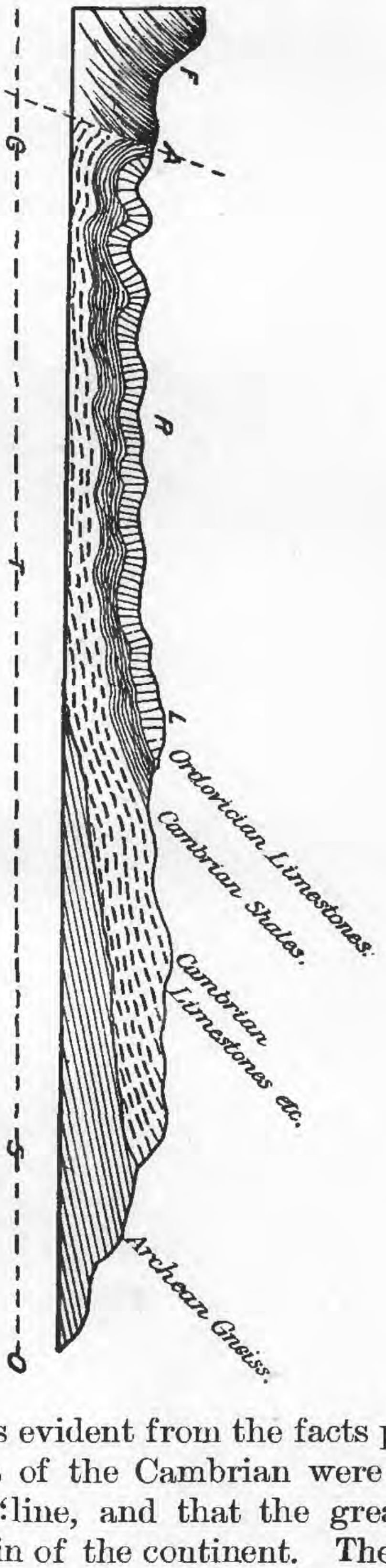

FIG. 59.—North and south section through the Dokka Valley, Torpen and Land, etc. Central Norway. (After Kjerulf.)

It is evident from the facts presented in Dr. Hicks's map that the strata of the Cambrian were deposited upon a gradually sinking coast line, and that the greatest depression was on the western margin of the continent. The study of the sections containing the Olenellus or Lower Cambrian fauna indicates that the central portions of the continent, Bohemia, etc., were not depressed to the sea-level until after the deposition of the Lower Cambrian. This leads to the conclusion that the movement which depressed the North American continent during Cambrian and Ordovician time also affected the western side of the European continent with a gradually diminishing force, from the Atlantic coast to the Ural Mountains.

VIII.—GEOGRAPHIC DISTRIBUTION.

The geographic distribution of the strata containing the Olenellus fauna has already been outlined in section V, p. 549. For convenience of reference the American localities of occurrence may be grouped in three principal provinces or areas: First, the Atlantic Coast Province; second, the eastern border or Champlain-Hudson Province; third, the western border or Rocky Mountain Province.

THE ATLANTIC COAST PROVINCE.

The most northern area included in this province is that of the coast of Labrador on the Straits of Belle Isle. It extends along the coast for several miles and the section includes 231 feet of arenaceous beds resting on the Archean and subjacent to 143 feet of gray, reddish, and greenish limestones, in which abundant remains of fossils occur. The species known are: *Spirocyathus atlanticus, Coscinocyathus billingsi, Archæocyathus profundus, Planolites virgatus, Helminthoidichnites marinus, Scolithus linearis, Iphidea bella, Kutorgina cingulata, K. labradorica, Obolella chromatica, Orthisina, ?* sp. undet., *Orthisina* sp. *?, Stenotheca ? elongata, S. ? rugosa, Hyolithes billingsi, Salterella pulchella, S. rugosa, Olenellus thompsoni ?, Ptychoparia miser, Protypus senectus, Solenopleura nana ?.*

Sir William E. Logan mentions the occurrence of the Olenellus fauna at Bonne Bay, on the northwestern coast of Newfoundland,[1] citing several species identical with those found on the coast of Labrador. Owing to the collector having included Lower Ordovician fossils in the same lot with the Olenellus, etc., a doubt remains as to the stratigraphic position of the beds from which the latter came. On the Atlantic side of Newfoundland fragments of a species of Olenellus were found in White Bay, according to Logan, but it was not until the writer studied the sections about Conception Bay that the fauna was well recognized. At Topsail Head a band of compact, gray and pinkish colored limestone is subjacent to about 100 feet of greenish argillaceous shales. The fauna in the limestone includes: *Kutorgina labradorica, Obolella atlantica, Scenella reticulata, Hyolithes impar, H. princeps, Hyolithellus micans, H. micans,* var. *rugosa, Microdiscus bellimarginatus, Olenellus (Mesonacis) bröggeri, Avalonia manuelensis, Agraulos strenuus, Solenopleura bombifrons.* On the opposite side of the bay, at Brigus Head, a

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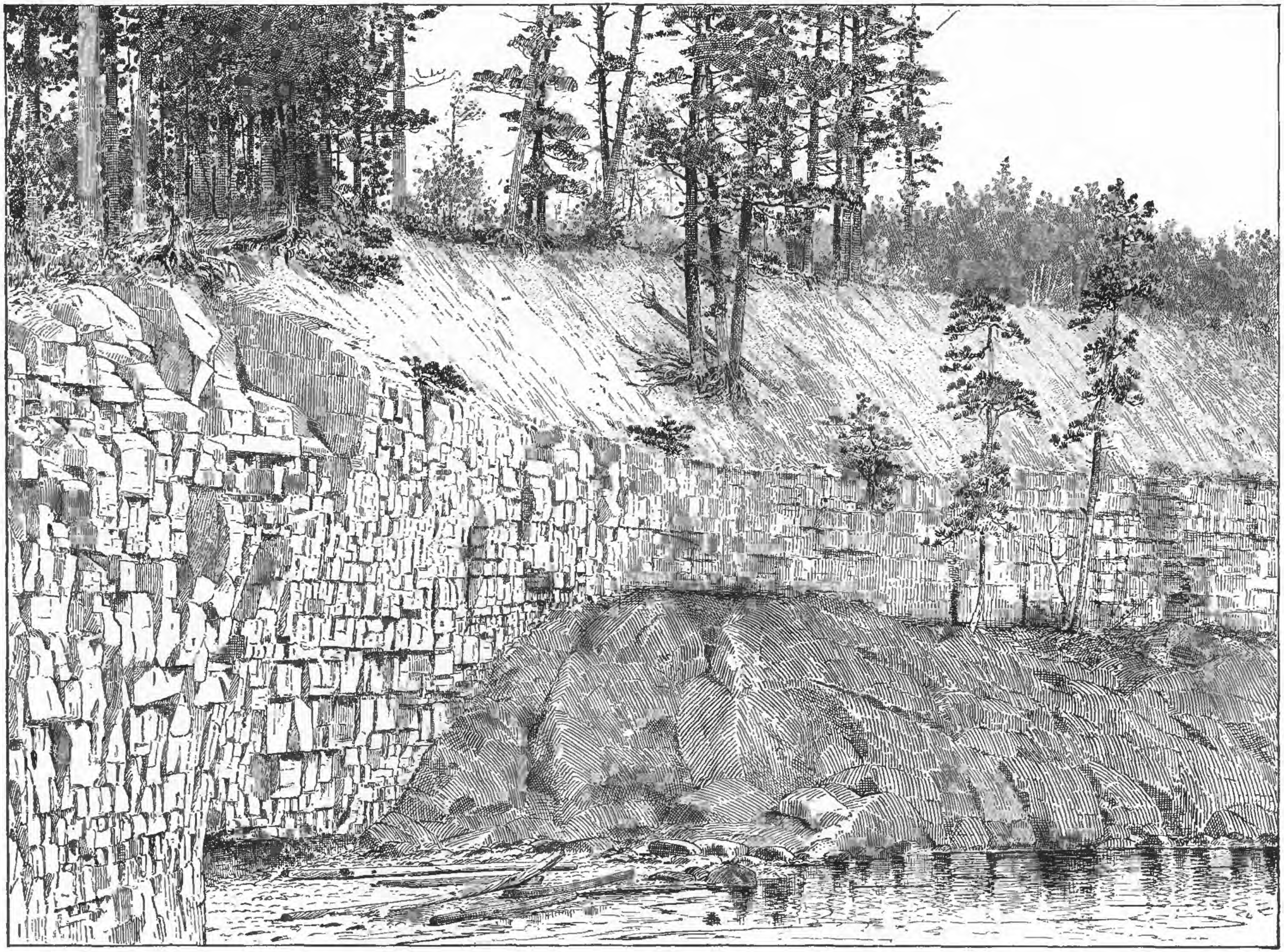
[1] Geol. Survey, Canada; Rep. Prog. from its commencement to 1863, pp. 865, 867.



UNCONFORMITY BETWEEN POTSDAM SANDSTONE AND ARCHEAN GRANITE.

bed of sandstone occurs beneath a limestone carrying *Olenellus* (*M.*) *bröggeri*, and the limestone is divided into three bands, by beds of shale, and the red and green shales extend several hundred feet upward in the section above the limestone. The strata of this portion of the province, however, are best seen in the Manuel's Brook section, west of Topsail Head (Fig. 51, p. 556), where a coarse, basal conglomerate rests conformably upon the Archean and is conformably subjacent to a series of red and green argillaceous shales that, in turn, are subjacent to dark argillaceous shales carrying the Paradoxides fauna. The fossils are most abundant in an impure arenaceous limestone which rests on the conglomerate, although quite abundant in the associated reddish shales. In the limestone and shales the following species were found: *Obolella atlantica*, *Helenia bella*, *Scenella reticulata*, *Stenotheca ? rugosa*, *S. ? rugosa*, var. *acutacosta*, *S. ? rugosa* var. *erecta*, *S. ? rugosa* var. *levis*, *S. ? rugosa* var. *paupera*, *Platyceras primævum*, *Hyolithes impar*, *H. princeps*, *H. quadricostatus*, *H. similis*, *H. terranovicus*, *Hyolithellus micans*, *Coleoloides typicalis Microdiscus helena*, *M. bellimarginatus*, *Olenellus* (*Mesonacis*) *bröggeri*, *Avalonia manuelensis*, *Ptychoparia ? attleboroughensis*, *Agraulos* (*S.*) *strenuus*, *A.* (*S.*) *strenuus* var. *nasutus*, *Solenopleura bombifrons*, *S. harveyi*, *S. howleyi*. Mr. E. Billings described *Straparollina remota* and *Hyolithes excellens* from a red limestone at Smith's Sound, Trinity Bay, that Mr. Murray correlated with the Brigus Head limestone. *H. excellens* appears to be identical with *H. princeps*.

The presence of the Lower Cambrian or Olenellus fauna in New Brunswick is claimed by Mr. Matthew. The evidence for this is presented in his latest paper on "Cambrian organisms in Acadia."[1] The section of the strata referred to the Basal series or pre-Paradoxides zone at the typical locality at Hanford Brook, St. Martin's, is as as follows:

		Thickness in feet.
"1.—*a*.	Coarse purplish red conglomerate resting on an amygdaloidal greenstone (toadstone) of the Coldbrook group	60
b.	Gray and purplish flags and sandstones with worm-casts, sea-weeds (Palæochorda and Buthotrephis), and numerous spicules of sponges.	70
c.	Purplish red sandstones, with greenish layers; remains of sea-weeds (Phycoidella), animal tracks (Psammichnites and Helminthites), worm-burrows (Arenicolites), etc	240
"2.—*a*.	Purplish red conglomerate, more friable than 1, *a*	35
b.	Soft purplish red shales, with green glauconite grains, the upper part firmer and more sandy, greenish gray layers interspersed especially towards the base. Platysolenites, Obolus, Volborthella, etc	175
c.	Purplish sandy shales, with a few bands of greenish shale; worm-casts (Scolites)	300
	Measures concealed, probably of this series.	320
		1,200

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[1] Trans. Roy. Soc. Canada, vol. 7, 1890, sec. 4, pp. 135-162.

"In this series of one thousand or more feet of beds, the very oldest layers which are fine enough to preserve organic markings, have trails and casts of marine worms, and also contain sea-weeds, one a Palæochorda or allied genus, the other a weed with a flat frond similar to Buthotrephis. That these beds are marine is clearly shown by the great numbers of spicules or hexactinellid sponges which they contain.

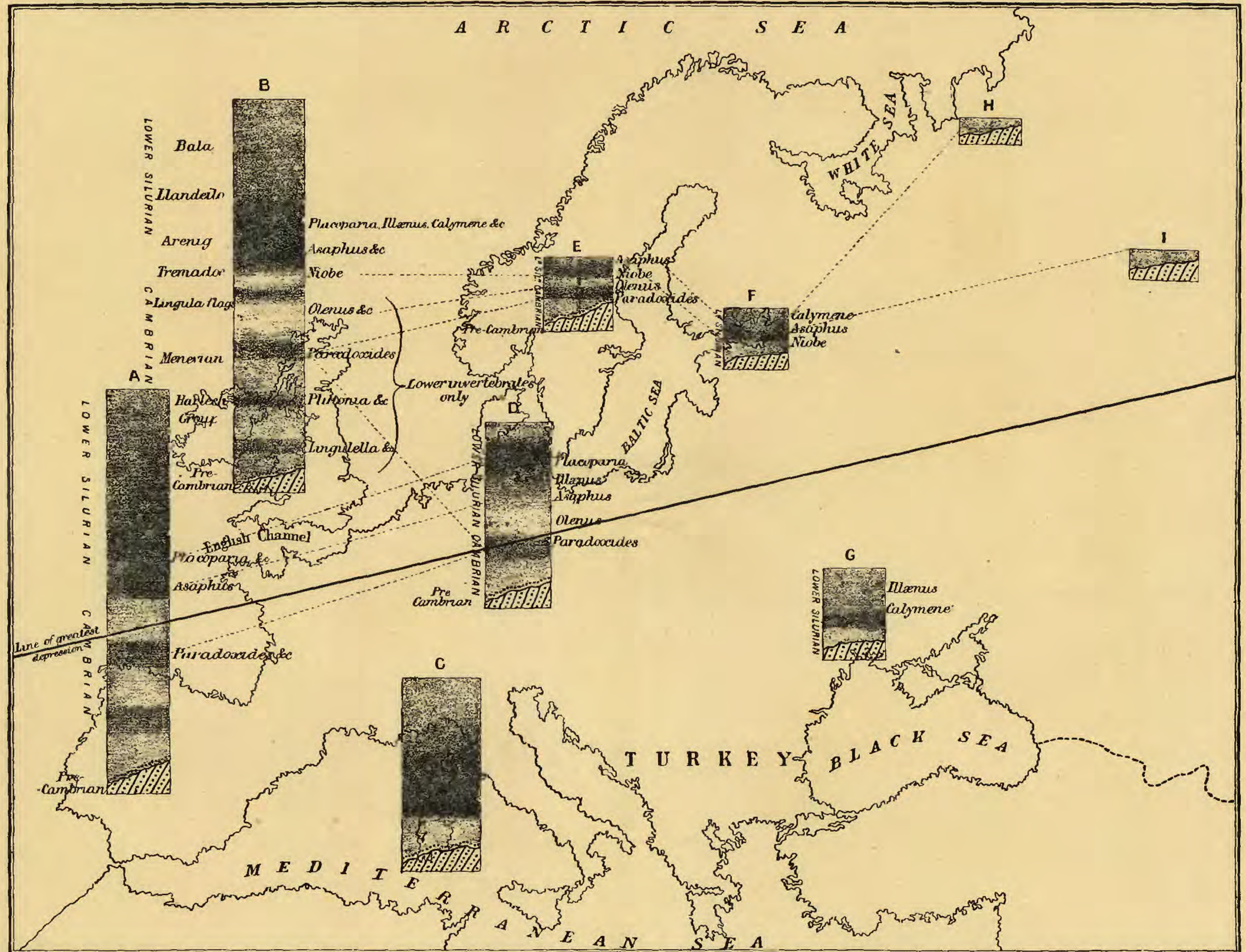
"About three hundred and fifty feet above the base, where the measures are flaggy, tracks of annelids are again abundant. Besides the smaller trails and burrows, there are frequent tracks of a marine animal, possibly a worm, similar to the markings on the Fucoidal sandstone of Sweden, which, by Prof. O. Torrell, have been referred to the genus psammichnites. A very similar track, with corresponding casts, occurs on the surfaces of the purple-streaked sandstones (Assise 3) of Band *b* in Division 1 of the St. John group, and a similar trail occurs as high up as the lower Band of Division 2 of that group. Above this point, such markings have not been found, though the kind of rock—flags and slates—is favorable to their occurrence. The flags of the middle of Division 2 of the St. John group seem to be the horizon of *Cruziana semiplicata* (Salter) and *C. similis* (Billings); but I have not found them here.

"About one hundred feet or more above the horizon where Psammichnites appears, separated from it by a conglomerate, indications of the Olenellus fauna show themselves. These consist of Volborthella (a chambered cell resembling Orthoceras), the cystidean genus Platysolenites, Pander, and a large Obolus, allied to *Michwitzia* (formerly *Obolus ?* or *Lingula ?*) *mon lifera* Linrs., of the Eophyton sandstone of Sweden and the upper part of the "Blue Clay" of Russia. Some of the layers in this part of the series abound in soft green grains similar to the glauconite grains of the Cambrian rocks in Russia. The paste enveloping them is red.

"A number of beds between this point and the top of the Basal series contain worm-casts and burrows, and some have remains of small strap-like sea-weeds." (Loc. cit., p. 138.)

"In summing up the facts bearing on the comparative age of this part of the Cambrian rocks in Acadia we get no aid from the typical genera of this horizon, Olenellus and Mesonacis, but the Acadian rocks contain other genera of this fauna which serve to fix their age with a certain degree of accuracy. Some of these genera, however, are such as may have a wider range of existence in time than the trilobites, and therefore are not of the same homotaxial value. The trilobites that do occur are not so definitive as some others." (Loc. cit., p. 143.)

If Mr. Matthew's stratigraphy be correct, this series is beneath the St. John group, although the absolute contact of the two formations has not been observed where the characteristic fossils of each occur



Conglomerates, Sandstones and Grits (shallow water accumulations) — Flags and fine sandstone — Schists and slates (deep water accumulations)

A. Central regions of Spain (Guadarama, Montes de Toledo, province of Leon, Daroca &c)
B. Wales (North & South) For the most part this represents the succession also in France (Brittany &c)
C. Sardinia. The succession here has not yet been thoroughly worked out, but this order appears to represent generally, the conditions observed here, & also on the South Coast of the Mediterranean (Algiers &c)
D. Bohemia and Bavaria
E. Norway and Sweden (Neighbourhood of Christiania)
F. West coast of Russia (Finland and neighbourhood of St Petersburg)
G. Podolia H. Shore of the Arctic Sea (region of Petchora &c) I Ural Mountains

OUTLINE MAP OF EUROPE, SHOWING THE COMPARATIVE THICKNESS AND DEPTH OF DEPOSITION OF THE CAMBRIAN AND LOWER SILURIAN ROCKS IN DIFFERENT AREAS.

in the section. The Basal series rests unconformably upon the "Laurentian" rocks, and the relations of the portions of the sections to each other are well shown in the illustration of the sections on page 139. A portion of this section is also seen on Caton's Island, and this is described and illustrated by Mr. Matthew (loc. cit., pp. 140, 141). On page 142 these two sections are correlated with those of the St. John City and Ratcliffe's Mill stream.

In correlating the several beds of the Lower Cambrian Mr. Matthew has followed the lithological characters of the beds, as the faunas are not sufficiently characteristic for comparison. Owing to this I have only considered the fauna of No. 1 *b* of the section (St. John group) of Hanford and Caton's Island as belonging to the Lower Cambrian. If the stratigraphy be correct in the Hanford Brook and Caton's Island section I think there is little question that the Lower Cambrian fauna is represented in the New Brunswick section. A list of all the species is given in Section IV. (Ante p. 546.)

At the locality discovered by Prof. N. S. Shaler, near North Attleborough,[1] in eastern Massachusetts, the rocks consist of thin-bedded shaly layers which pass into moderately thick, fine grained, greenish and red slates. Intermingled with these, in several levels, layers of conglomerate occur which are evidently derived from a not far distant shore-line. Specimens of the reddish calcareo-arenaceous fossil-bearing rock, from this locality and from Newfoundland, are lithologically identical; and a number of species are common to the two deposits. The fauna includes: *Obolella atlantica, O. crassa, Fordilla troyensis*, Lamellibranch? (genus ? and species ?), *Scenella reticulata, Stenotheca ? curvirostra, S.? rugosa, S.? rugosa* var. *abrupta, S.? rugosa* var. *paupera, Pleurotomaria* (*Raphistoma*) *attleboroughensis, Hyolithes americanus, H. billingsi, H. communis* var. *emmonsi, H. princeps, H. quadricostatus, Hyolithellus micans, Salterella curvatus, Platyceras primævum, Microdiscus bellamarginatus, Olenellus walcotti, Ptychoparia ? attleboroughensis, Agraulos strenuus.*

Mr. Foerste found a species of Hyolithes at East Point, Nahant, Mass., which is identical with the species found near North Attleborough. He states that the Nahant limestones are represented by red slates near North Weymouth, and that it is probable that the red slates and included limestones underly the Middle Cambrian Paradoxides beds of Braintree.[2]

Mr. J. H. Sears, of the Peabody Academy of Science, at Salem, Mass., sent me a small collection of the fossils from East Point, Nahant, in May, 1890, and I identified *Hyolithes communis*, var. *emmonsi*, *Hyolithes princeps* Billings, and a finely corrugated tube

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[1] On the Geology of the Cambrian district of Bristol County, Mass. Bull. Mus. Comp. Zool., Harvard College, vol. 16, pp. 13-26.

[2] Bost. Soc. Nat. Hist. Proc., vol. 24, 1889, pp. 261-263.

such as would result from cutting obliquely across the shell like that of the slender varieties of *Stenotheca rugosa*.

If we extend our observations of the strata to the eastern side of the Atlantic basin, we find that the Lower Cambrian (Bangor and Cærfai) series consist largely of green and purple slate, formed from a sediment almost identical with that of the Newfoundland section; and, further, that the shales or slates of the Paradoxides zone are lithologically the same in Newfoundland and Wales. In both cases the sediments were accumulated not far from a gradually sinking coast line, and they overlap on the subjacent Algonkian and Archean rocks.

CHAMPLAIN-HUDSON PROVINCE.

The sediments of the Olenellus zone, in this province, are largely developed in the trough lying between the Adirondack and Green Mountains. To the north, in the valley of the St. Lawrence, the deposit appears to have been mostly limestone, judging from the occurrence of the Olenellus fauna in bowlders of limestone in the conglomerates of Lower Ordovician age. From Bic Harbor, Trois Pistoles, and St. Simon the following species have been found in the conglomerate limestone, as observed in the collection of the Canadian Geological Survey and the Peter Redpath Museum of McGill College: *Trachyum vetustum, Scolithus linearis, Lingulella cœlata, Iphidea bella, Kutorgina cingulata, Obolella crassa, O. circe, O. gemma, Orthis, salemensis,* O. 1 n. sp., *Platyceras primævum, P. dawsoni, Scenella retusa, Stenotheca? rugosa, Hyolithes americanus, H. communis, H. princeps, Hyolithellus micans, Salterella pulchella, Microdiscus lobatus, M. speciosus, Olenellus thompsoni, Olenoides marcoui, Zacanthoides levis, Ptychoparia adamsi, P. metisensis, P. teucer, Ptychoparia* sp. undet., *Agraulos strenuus, A. redpathi, Protypus senectus, P. senectus* var. *parvulus*.

On the Island of Orleans, Dr. Selwyn found in the conglomerate limestone: *Obolella crassa, Orthisina* sp. ?, *Camerella* sp. ?, *Hyolithes americanus, Hyolithellus micans, Olenellus thompsoni, Ptychoparia adamsi, P. vulcanus, Solenopleura* sp. ? *Protypus senectus ? Olenoides marcoui, Zacanthoides levis*.

The origin of the bowlders containing the Olenellus fauna is unknown. There is a marked lithologic and paleontologic similarity between them and the limestone of Topsail Head and Conception Bay, Newfoundland, that points to similar conditions of sedimentation and life, and I found the head of an Olenellus on the Island of Orleans that is of the type of *O. (M.) bröggeri* of Newfoundland. It is quite possible that the deposits from which the conglomerates were derived extended around the Newfoundland coast, to the west and north, and thence along the margin of the pre-Cambrian land, southwest, toward the Adirondack Mountains of New York, and that the disturbances toward the close of the Cambrian Period, in the St. Lawrence Valley, resulted in the uplifting of the Lower Cambrian strata and its denudation and breaking up during Upper Cambrian and Lower Ordovician time.

Sir William Dawson writes me that he considers that the conglomerates at Metis and St Simon are older than the Phyllograptus beds at Point Levis, and at Metis the associated shaly beds hold Retiolites, Linnarssonia, and Protospongia.

In northern Vermont a massive and more or less arenaceous dolomite occurs at the base of the Cambrian section, and the upper part of the Olenellus zone is formed of dark, arenaceo-argillaceous shales.[1] At the typical locality of Parker's quarry, in the township of Georgia, Franklin County, the following species have been found: *Leptomitus zitteli, Phyllograptus? cambrensis, Climacograptus?? emmonsi, Planolites congregatus, P. virgatus, Kutorgina cingulata, Orthisina festinata, O. orientalis, O.? transversa, Salterella pulchella, Protocaris marshi, Microdiscus parkeri, Olenellus thompsoni, O.* (*Mesonacis*) *vermontana, Olenoides? marcoui, Bathynotus holopyga, Ptychoparia adamsi, P. vulcanus, Protypus hitchcocki, P. senectus, P. senectus* var. *parvulus.* Near the boundary line between the United States and Canada, east of Highgate Springs, a number of species occur at the same relative horizon as at Parker's quarry,[2] all but two of which are found at the latter locality, viz: *Scenella? varians,* and *Ptychoparia teucer.* East of Swanton the fauna includes: *Kutorgina cingulata, K. labradorica* var. *swantonensis, Orthisina festinata, O. orientalis, Camerella? antiquata, Salterella pulchella, Olenellus thompsoni, Ptychoparia adamsi,* and *Protypus senectus.*

On the eastern side of the outcroppings of the strata of the Olenellus zone, in central and southern Vermont, the rock is a massive quartzite that was formed near the old pre-Cambrian shore-line. In this formation, near Bennington, Vt., *Scolithus linearis, Olenellus* sp. ? *Nothozoe vermontana,* and *Hyolithes communis* are found, and to the south, in Dutchess County, N. Y., at Stissing Mountain, *Olenellus* sp. ? and *Camerella? minor* occur in a similar sandstone.

In central Vermont the green and purple slates begin to appear in the Lower Cambrian, and in Washington County, N. Y., there are about 8,000 feet of green and purple slates that are identical in lithologic character with the slates of the Lower Cambrian in North Wales. Below the green and purple slates there is a great thickness of dark, argillaceous and, sometimes, arenaceous shales, in which the Olenellus fauna occurs. If lithologic characters could be relied upon, we might correlate the Lower Cambrian slates of Wales with the lower portion of the Cambrian section in Newfoundland and

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[1] Bull. U. S. Geol. Survey, No. 30, 1886, pp. 15, 16.

[2] Ibid., p, 18.

with the upper portion of the Olenellus zone in western Vermont and eastern New York. It is a striking coincidence that similar mechanical sediments should have been deposited in Wales, Newfoundland, eastern Massachusetts, eastern Vermont, and eastern New York, and also contain essentially the same fauna, with the exception of Wales, where the fauna is still almost unknown.

In Washington County, N. Y., the following named species have been found in the slates and interbedded limestones: *Protospongia* sp.?, *Archæocyathus* (*A*) *dwighti*, *Planolites annularius*, *Helminthoidichnites marinus*, *Lingulella cœlata*, *L. granvillensis*, *Lingulella* sp.?, *Linnarssonia sagittalis* var. *taconica*, *Orthis salemensis*, *Orthisina* sp.?, *Camerella?* sp.? *Fordilla troyensis*, *Modioloides prisca*, *Stenotheca? elongata*, *S.? rugosa*, *Hyolithes americanus*, *H. communis*, *H. impar*, *Hyolithellus micans*, *H. micans* var. *rugosa*, *Leperditia* (*I.*) *dermatoides*, *Aristozoe rotundata*, *A. troyensis*, *Agnostus desideratus*, *A.* sp.?, *Microdiscus connexus*. *M. lobatus*, *M. speciosus*, *Olenellus* (*Mesonacis*) *asaphoides*, *Olenoides fordi*, *Zacanthoides eatoni*, *Conocoryphe trilineata*, *C. reticulata*, *Ptychoparia? fitchi*, *Protypus? clavatus*, *Solenopleura ? tumida*, and *S. nana*. In the vicinity of Troy, N. Y., the conglomerate and bedded limestone have afforded: *Archæocyathus* (*A.*) *rarum*, *A.* (*A.*) *rensselaericum*, *Planolites virgatus*, *Lingulella cœlata*, *Obolella crassa*, *Obolella gemma*, *O. nitida*, *Orthisina* sp.?, *Fordilla troyensis*, *Scenella retusa*, *Stenotheca? rugosa*, *Platyceras primævum*, *Hyolithes americanus*, *H. communis*, *H. communis* var. *emmonsi*, *H. impar*, *Hyolithes* 2 sp. undet., *Hyolithellus micans*, *H micans* var. *rugosa*, *Aristozoe troyensis*, *A.* sp.?, *Agnostus? nobilis*, *Microdiscus meeki*, *M. lobatus*, *M. speciosus*, *Olenellus* (*Mesonacis*) *asaphoides*, *Ptychoparia* sp.?, *Conocoryphe trilineata*, *Solenopleura nana*. South of Troy, in the northwest corner of Columbia County, N. Y., twelve of the above mentioned species have been found[1] in the brecciated limestones, and farther south, near Stockport, *Lingulella cœlata* and *Olenellus* sp.? occur in a brecciated limestone, interbedded in silicious shales.

The next occurrence of the fauna south of New York is in the clay shales resting on the quartzitic Chilhowee sandstone of Chilhowee Mountain, in eastern Tennessee. This locality has recently been discovered, and is yet to be developed. The fossils found are, Annelid trails in profusion, *Scolithus linearis*, Hyolithes, like *H. americanus*, *Isoxys chilhoweana*, and an undetermined species of Olenellus.

ROCKY MOUNTAIN PROVINCE.

In this province there appears to have been a large accumulation of more or less coarse, arenaceous sediment, commingled with con-

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[1] Bull. U. S. Geol. Survey, No. 30, 1886, p. 27.

siderable argillaceous material, before the deposition of the sediments of the Olenellus zone. As far as known, the Olenellus fauna appeared at the time the character of the sediments was changing to finer sands and argillaceous clays, and then to calcareous clays. The sedimentation is unlike that of the sections on the eastern side of the continent. (See figures 45, p. 551, 46, and 47, p. 552.) The southern portion of the province is found in the Great Basin region of Utah and Nevada, between the Wasatch range and the Sierra Nevada range. In the eastern or Wasatch area *Linguella ella, Olenellus gilberti,* and *Cruziana* sp.? occur in a thin band of fine micaceous sandstone, about 200 feet from the summit of the Cambrian rocks, which are conformably subjacent to strata of Ordovician age. The Olenellus-bearing sandstones are covered with trails of annelids, etc., and are evidently a littoral or shore deposit.

In the Eureka district of central Nevada the fauna is confined to a narrow belt of arenaceous shales, with some intercalated limestone. The fauna consists of but seven species: *Girvanella ?* sp.? *Kutorgina prospectensis, Scenella conula, Olenellus gilberti, O. iddingsi, Olenoides quadriceps, Ptychoparia subcoronata,* and *Anomocare parvum.* Of these, two species, *Olenoides quadriceps* and *Scenella conula*, are found 500 feet higher up in the section.[1] In the Highland range section of Nevada the rocks are essentially of the same character as in the Eureka section; the two species, *Olenellus gilberti* and *O. iddingsi,* occur in an arenaceous shale associated with *Cruziana* sp.?.[2] In the Pioche section[3] more limestone is interbedded in the arenaceous shale and the fauna of the Olenellus zone is larger. It includes: *Eocystites?? Lingulella ella, Kutorgina pannula, Acrothele subsidua, Acrotreta gemma, Orthis highlandensis, Olenellus gilberti, Zacanthoides levis, Crepicephalus augusta, C. liliana,* and *Oryctocephalus primus.* Of these, *Kutorgina pannula, Acrothele subsidua, Acrotreta gemma,* and *Hyolithes billingsi* pass to the zone above that carrying Olenellus. In limestones of the Olenellus zone at Silver Peak, in western Nevada, the following species were collected by Mr. Clayton:[4] *Girvanella?* sp.?, *Spirocyathus atlanticus, Ethmophyllum meeki, E. whitneyi, Kutorgina cingulata?, Hyolithes princeps, Olenellus gilberti.*

In British Columbia the Lower Cambrian rocks occur on the eastern side of the Rocky Mountains. In the section of Mt. Stephen and Castle Mountain (fig. 47, p. 552), Mr. McConnell found the Olenellus fauna at the base of the Castle Mountain limestone; beneath it there are dark colored argillites and sandstones, estimated at over 10,000 feet in thickness.[5] They compare in position and character to the pre-

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[1] Bull. U. S. Geol. Survey, No. 30, 1886, p. 32.

[2] Op. cit., pp. 33, 34. [3] Op. cit., p. 35. [4] Op. cit., p. 38.

[5] Geol. and Nat. Hist. Survey, Canada, Ann. Rep., new ser., vol. 2, 1887; Report on Geological Structure of a Portion of the Rocky Mountains, p. 29 D.

Olenellus strata, of the Wasatch section, which are referred to the Algonkian period. In the collection made by Mr. McConnell, from the limestones of the Olenellus zone, there are *Olenellus* sp. ?, *Ptychoparia adamsi* and *Protypus senectus*.

The distribution of the genera and species is given in the following table, and, more or less, in discussing the relations of the Lower Cambrian fauna to that of the superjacent faunas. In the table the column under "Bic Harbor" also includes St. Simon, Trois Pistoles, Isle of Orleans, and any other associated localities in the St. Lawrence Valley. In the same manner the Pioche species are included under the Highland range column, and the Oquirrh Cañon, Utah, locality of *Olenellus gilberti* and *Lingulella ella* under the Wasatch Mountains column. The letters S. P., in the Highland range column, refer to the Silver Peak locality in western Nevada.

Table of the geographic distribution of the Lower Cambrian fauna in North America.

	Western Vermont.	Bic Harbor.	Labrador.	Newfoundland.	Eastern New York.	Eastern Massachusetts.	Eastern Tennessee.	Eureka, Nevada.	Highland Range.	Wasatch Mountains.	British Columbia.
SPONGIÆ.											
Leptomitus zitteli Walcott	×										
Trachyum vetustum Dawson		×									
Girvanella ? sp. ?								×	S.P. ×		
Protospongia sp. ?					×						
HYDROZOA.											
Phyllograptus ? cambrensis Walcott	×										
Climacograptus ?? emmonsi Walcott	×										
ACTINOZOA.											
Protopharetra sp. ?											
Spirocyathus atlanticus Billings			×						S.P.		
Coscinocyathus billingsi Walcott			×								
Archæocyathus profundus Billings			×								
dwighti Walcott					×						
rarum Ford					×						
rensselæricum Ford					×						
Ethmophyllum meeki Walcott									S.P.		
whitneyi Meek									S.P.		
ECHINODERMATA.											
Eocystites ? sp. ?									×		
TRAILS, BURROWS, AND TRACKS.											
Planolites annularius Walcott					×						
congregatus Billings	×										
virgatus Hall	×		×		×						
Helminthoidichnites marinus Emmons			×		×						
Scolithus linearis Hall (?)	×		×				×				
Cruziana sp. ?									×	×	

Table of the geographic distribution of the Lower Cambrian fauna in North America—Continued.

	Western Vermont.	Bic Harbor.	Labrador.	Newfoundland.	Eastern New York.	Eastern Massachusetts.	Eastern Tennessee.	Eureka, Nevada.	Highland Range.	Wasatch Mountains.	British Columbia.
BRACHIOPODA.											
Lingulella cælata Hall (sp.)		×			×						
ella H. & W.									×	×	
granvillensis Walcott					×						
sp. ?					×						
Acrotreta gemma Billings									×		
Acrothele subsidua White									×		
Iphidea bella Billings		×	×								
Kutorgina cingulata Billings	×	×	×						S.P.?		
labradorica Billings			×	×							
labradorica var. swantonensis Walcott	×										
pannula White (sp.)									×		
prospectensis Walcott								×			
sp. ?											
Linnarssonia sagittalis var. taconica Walcott					×						
Obolella atlantica Walcott				×		×					
chromatica Billings			×								
circe Billings		×									
crassa Hall (sp.)		×			×	×					
gemma Billings		×			×						
nitida Ford					×						
Orthis highlandensis Walcott									×		
salemensis Walcott		×			×						
Orthisina festinata Billings	×										
orientalis Whitfield	×										
? transversa Walcott	×										
? sp. undet.		×	×								
sp. ?			×								
sp. ?					×						
Camerella ? antiquata Billings	×										
? minor Walcott					×						
? sp. ?		×			×						
LAMELLIBRANCHIATA.											
Fordilla troyensis Barrande					×	×					
Modioloides prisca Walcott					×						
Lamellibranch ?, genus ?, species ?						×					
GASTEROPODA.											
Helenia bella Walcott				×							
Scenella conula Walcott								×			
reticulata Billings				×		×					
retusa Ford		×			×						
? varians Walcott	×										
sp. ?											
Stenotheca ? elongata Walcott			×		×			*×			
curvirostra S. & F.				×		×					

*100 feet above the Olenellus zone.

Table of the geographic distribution of the Lower Cambrian fauna in North America—Continued.

	Western Vermont.	Bic Harbor.	Labrador.	Newfoundland.	Eastern New York.	Eastern Massachusetts.	Eastern Tennessee.	Eureka, Nevada.	Highland Range.	Wasatch Mountains.	British Columbia.
Stenotheca ? rugosa Hall (sp.)		×	×	×	×	×					
rugosa var. abrupta S. & F.						×					
rugosa var. acuta-costa n. var.				×							
rugosa var. erecta n. var.				×							
rugosa var. levis n. var				×							
rugosa var. paupera Billings				×		×					
Platyceras primævum Billings		×		×	×	×					
dawsoni Walcott		×									
Straparollina remota Billings				×							
Pleurotomaria (Raphistoma) attleboroughensis S. & F.						×					
PTEROPODA.											
Coleoloides typicalis Walcott				×							
Hyolithes americanus Billings		×			×	×	×				
billingsi Walcott			×			×			*×		
communis Billings	×	×			×	×					
communis var. emmonsi Ford					×	×					
impar Ford				×	×						
princeps Billings		×		×		×			S.P.		
quadricostatus S. & F.				×		×		×			
similis Walcott				×							
terranovicus Walcott				×							
2 sp. (undetermined)					×						
Hyolithellus micans Billings		×		×	×	×					
micans var. rugosa Walcott				×	×						
Salterella curvatus S. & F						×					
pulchella Billings	×	×	×								
rugosa Billings			×								
CRUSTACEA.											
Isoxys chilhoweana Walcott							×				
Leperditia (I.) dermatoides Walcott					×						
sp. undet											
Aristozoe rotundata Walcott					×						
troyensis Ford					×						
sp. ?					×						
Nothozoe vermontana Whitfield	×										
Protocaris marshi Walcott	×										
TRILOBITA.											
Agnostus ? nobilis Ford					×						
desideratus Walcott					×						
sp. undet					×						
Microdiscus connexus Walcott					×						
helena Walcott				×							
meeki Ford					×						
bellimarginatus S. & F.				×		×					

*2,000 feet above the Olenellus zone.

Table of the geographic distribution of the Lower Cambrian fauna in North America—Continued.

	Western Vermont.	Bic Harbor.	Labrador.	Newfoundland.	Eastern New York.	Eastern Massachusetts.	Eastern Tennessee.	Eureka, Nevada.	Highland Range.	Wasatch Mountains.	British Columbia.
Microdiscus lobatus Hall		×			×						
speciosus Ford		×			×						
parkeri Walcott	×										
sp. ?											
Olenellus thompsoni Hall	×	×	?				?				
gilberti Meek								×	S.P.×	×	×?
iddingsi Walcott								×	×		
(Mesonacis) vermontana Hall (sp.)	×										
(Mesonacis) asaphoides Emmons (sp.)					×						
(Mesonacis) bröggeri Walcott				×							
walcotti S. & F.						×					
Olenoides fordi Walcott					×						
? marcoui Whitfield (sp.)	×	×									
quadriceps H. & W.								×			
Zacanthoides eatoni Walcott					×						
levis Walcott		×							×		
Bathynotus holopyga Hall	×										
Avalonia manuelensis Walcott				×							
Conocoryphe trilineata Emmons (sp.)		?			×						
reticulata Walcott					×						
Ptychoparia adamsi Billings	×	×									×
? attleboroughensis S. & F.				×		×					
? fitchi Walcott					×						
metisensis Walcott		×									
miser Billings (sp.)			×								
subcoronata H. & W.								×			
teucer Billings (sp.)	×	×									
vulcanus Billings (sp.)	×	×									
2 sp. ?		×			×						
Agraulos redpathi Walcott		×									
strenuus Billings		×		×		×					
(S.) strenuus var. nasutus Walcott				×							
Crepicephalus augusta Walcott									×		
liliana Walcott									×		
Oryctocephalus primus Walcott									×		
Anomocare parvum Walcott								×			
Protypus hitchcocki Whitfield (sp.)	×										
senectus Billings (sp.)	×	×	×								×
senectus var. parvulus Billings	×	×	×								
? clavatus Walcott					×						
Solenopleura bombifrons Matthew				×							
harveyi Walcott				×							
howleyi Walcott				×							
? tumida Walcott					×						
nana Ford			?		×						

In the following summary the total number of American genera and species are given under each class:

Résumé of American fauna.

	Number.		
	Genera.	Species.	Varieties.
Spongiæ	4	4	0
Hydrozoa	2	2	0
Actinozoa	5	9	0
Echinodermata	1	1	0
Trails, burrows, and tracks	4	6	0
Brachiopoda	10	29	2
Lamellibranchiata	3	3	0
Gasteropoda	6	13	5
Pteropoda	4	15	2
Crustacea	5	8	0
Trilobita	15	51	2
Total	59	141	11

The fauna referred to the Lower Cambrian by Mr. Matthew in New Brunswick has not been incorporated in the preceding tables, and it has not been illustrated, owing to the fact that the illustrations for this paper were completed before the publication of Mr. Matthew's memoir. He describes five new genera, Phycoidella, Microphycus, Monadites, Radiolarites, and Dichoplectella, and eighteen new species, *Phycoidella stichidifera, Palæochorda setacea, Hydrocytium ? silicula, Microphycus catenatus, Monadites globulosus, M. pyriformis, M. urceiformis, Radiolarites ovalis, Plocoscyphia ? perantiqua, Astrocladia ? elongata, A. ? elegans, A. ? virguloides, Dichoplectella irregularis, Hyalostella minima, Obolus ? major, Lingulella martinensis, Leperditia ventricosa*, and *L. steadi*; and illustrates five genera and five species—*Buthotrepis antiqua* Brongniart, *Platysolenites antiquissimus* Eichwald, *Volborthella tenuis* Schmidt, *Psammichnites gigas* Torrell, and *Arenicolites lyelli* Torrell var. *minor*—that he identifies with the Lower Cambrian fauna of Sweden, and proposes the genus *Holmia* for *Olenellus kjerulfi*.[1] He also mentions *Agraulos articephalus* and *Ellipsocephalus* sp. from 1*b* of the "St. John Group," p. 143, and *Obulus pulchea.*

If Mr. Matthew be correct in referring this fauna to the pre-Paradoxides zone we now have from America 67 genera, 165 species, and 12 varieties in the Lower Cambrian or pre-Paradoxides Cambrian fauna of North America.

It is yet uncertain how many identical species there may be

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[1] Trans. Roy. Soc. Canada, vol. 7, sec. iv., pp. 135–162, 1890.

between America and Europe. Mr. Matthew has identified five. Omitting these and also the list of Torell's genera and species, applied to trails and annelid borings, there remain about eight genera and thirty species to account for from pre-Paradoxides Cambrian rocks. Adding these to the American fauna the totals are 75 genera and 195 species.

EUROPE.

The distribution of the fauna in Europe is confined to Scandinavia, Russia and Britain, with the exception of a single species somewhat doubtfully referred to the fauna from Spain and probably a portion of the Cambrian fauna of the Island of Sardinia.

Scandinavia.—From the work of the Swedish and Norwegian geologists it appears that in Scandinavia the Archean is subjacent to a considerable thickness of sandstone with intercalated shale, in which *Olenellus* (*H.*) *kjerulfi* and other fossils occur. The Olenellus appears near the summit of the series and just beneath strata in which Paradoxides is found. According to Holm[1], who is the latest authority on the subject, the fauna of the Olenellus zone in Scandinavia, consists of: *Olenellus* (*H.*) *kjerulfi* Linnarsson, *Ellipsocephalus nordenskioldi*, *Arionellus primævus* Brögger, *Hyolithes* sp. undet., *Metoptoma* sp., *Lingulella ? nathorsti* Linnrs., *Obolus* sp., *Discina ?* sp. From the Eophyton sandstone, beneath the *Olenellus* (*H.*) *kjerulfi* zone, Linnarsson described[2] *Astylospongia radiata*, Linnars., *Bythrotrephis* sp. *Aglecrinites lindstromi* Linnars., *Lingula ? monolifera* Linnrs., *Hyolithes levigatus* Linnars., *Arenicolites spiralis* Torell, *Fraena tenella* Linnars., *Cruziana dispar* Linnars., *Scolithus mirabilis* Linnars., *Eophyton linnæanum* Torell, *E. torelli* Linnars. These last three species are probably based on inorganic markings. In addition to the preceding, Dr. Torell described and illustrated, in 1868, *Arenicolites gigas* Torell *Scolithus linearis* "Hall," *Cordiates? nilssoni*, *Eophyton linnæanum* Torell and an undetermined form; he also described *Lingula* sp., *Fucoides antiquus*, *F. concinnatus* and *Paleophycus tubularis* Hall.[3]

In a later memoir he mentions a number of trails and borings from the sandstones at Lugnas, placing them under various genera and species. They include: *Cruziana dispar* Lins., sp., *Cruziana ? orbicularis* n. sp., *Lithodictyon fistulosum* n. gen. n. sp., *Palæophycus tubularis* Hall, *Fucoides antiquus* Brongn., *Fucoides circinnatus* Brongn., *Archæorrhiza tuberosa* n. gen. n. sp., *Halopoa* n. gen., *Halopoa imbricata* n. sp., *Halopoa composita* n. sp., *Cordaites ?*

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[1] Aftryck vr. geol. Fören. Stockholm Förhandl., vol, 9, part 7, 1887, p. 22.

[2] Geog. och Pal. Iakttag. öfver Eophytonsandstenen i Vestergötland. Kongl. Svenska Vet. Akad. Handl., vol. 9, No. 7, 1871.

[3] Sparagmitetagens geognosi och paleontologi. Acta Univer. Lundensis, Lunds Univer. Års-Skrift, vol. 4, 1868, pp. 34-39, pls. 1-3.

nilssoni Tor., *Eophyton linnæanum* Tor., *E. torelli* Linnars., *Psammichnites* n. gen., *P. gigas* Tor., *P. gumœllii* n. sp., *P. impressus* n. sp., *P. filiformis* n. sp., *Protolyellia princeps* n. gen. n. sp., *Spatangopsis costata* n. gen. n. sp., *Micrapium erectum* n. gen. n. sp., *Spiroscolex* n. gen., *S. spiralis* n. sp., *S. crassus* n. sp., *Scolithus linearis* Hall, *S. errans* n. sp., *S. pusillu s* n. sp., *Monocraterion tentaculatum* n. gen. n. sp., *Diplocraterion* n. gen., *D. parallelum* n. sp., *D. lyelli* n. sp.[1] Without figures or specimens it is impossible to speak intelligently of these genera and species, as they are founded largely on trails, burrows, and casts of trails and markings on and in the sandstone.

In Sweden the strata of the Olenellus zone are everywhere conformably subjacent to the Paradoxides beds. They are almost exclusively sandstones except in the north of Sweden, where they contain considerable intercalated beds of schist. The zone is divided into Eophyton and Fucoid sandstones.[2] In Scania the series is divided into four zones, with a maximum thickness of 910 feet. The most interesting zone is that of the Lungas sandstone, from which the casts of the Medusæ, described by Nathorst,[3] were obtained.

The section, according to Dr. Lundgren,[4] is as follows:

(4) *Greywacke schists* (50 feet), containing nodules of phosphorite, but no recognizable fossils.

(3) *Hardeberga sandstone* (600 feet). A coarse grained, hard sandstone with quartzose matrix, passing into greywackes in the upper zones, containing fucoid-markings and burrows of Annelides.

(2) *Quartzite and quartzite conglomerate* (150 to 200 feet). A thick, hard rock, brittle, with conchoidal fracture.

(1) *Lugnas sandstone.* A coarse sandstone (60 feet), containing (crystals of) quartz, felspar, and mica; in other words, an *arkose.* According to Angelin himself, the lowest layers of this sandstone alternate with the bedded gneiss. According to Linnarsson, this relation is open to question.

According to Nathorst,[5] the section at Andrarum, in southwestern Sweden, is as follows, from below upward:

1. Sandstone with worm tracks; sandstone, pyritiferous.
2. Greywacke slate, with worm tracks and Lingula; greywacke, lime-bearing, with Lingula.
3. Drawing slate, with Lingula, Theca (rare).
4. Gray limestone, with fragments of fossils.

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[1] Petrificata Suecana Formationis Cambricæ. Acta. Univer. Lundensis. Lunds Univer. Års-Skrift., 1870, vol. 6, pp. 1-14.

[2] A comparison between the oldest fossiliferous rocks of northern Europe; G. Linnarsson. Geol. Mag., new ser., decade 2, vol. 3, 1876, p. 146.

[3] Om Aftryck af Medusor i Sveriges Kambriska lager. Kongl. Sv. Vetenskaps-Akad. Handl., vol. 19, 1881, No. 1.

[4] Lundgren, Bernhard, text to Angelin's Geol. Öfversigts-Karta öfver Skåne, 1878, pp. 12-18.

[5] Om lagerföljden inom Cambriska formationen vid Andrarum i Skåne: Öfvers. Kongl. Vetenskaps-Akad Förhandl., No. 1, 1869, pp. 61-65.

5. Drawing slate, with Lingula and horizontal worm tracks.
6. Alum slate and swinestone, with Paradoxides, Agnostus, Microdiscus, Conocoryphe, Theca, Lingula, Graptolites.
7. Andrarum limestone, with the fossils enumerated before, in another place.
8. Alum slates and swinestone, with fossils in the following order: Olenus, Agnostus, Orthis, Parabolina, Eurycare, Leptoplastus, Sphæropthalmus, Peltura, Acerocare.

In central and northern Norway Professor Kjerulf divides the lower portion of the section into: 1*b*, the Lower Paradoxides zone, with *Paradoxides kjerulfi*, etc.; and 1*a*, the Sparagmite formation, without fossils.[1] The base of the section rests unconformably upon the Archean; and 1*b* is succeeded by the *Paradoxides tessini* beds.

The sections on Lake Miösen[2] and through Fugelberg and Ulven show the succession of strata to be as follows, from above downward:

Dark clay slates, with graptolites, near Ulven	Stage 3
Gray limestone, with Orthoceras, at Ringsaker	Stage 3
Black alum shales, with stink-stone and *Agnostus pisiformis*, at Nyhus	Stage 2
In the lowest alum shales, of considerable thickness, Linnarsson recognized *Agnostus parvifrons* Linnarsson, which belongs to a lower Palæozoic horizon	Stage 1c
Green clay slates, with occasional calcareous sandstone beds and *Olenellus* (*Paradoxides*) *kjerulfi* Linnarsson, Arionellus, Obolus, Discina, at Tomten	Stage 1*b*
Quartz sandstone, reddish and white, at Tomten	Stage 1*a*

Russia.—In Russia the Olenellus zone, according to Schmidt, occurs in Estland.[3] The relation of the strata to the section in Norway and Sweden is shown in the following scheme:

Scheme.

East Baltic region.	Swedish.	Norwegian.
Dictyonema schist.	Dictyonema schist.	Dictyonema schist... 2*e*
Ungulite sand.		
	Olenus zone.	Olenus zone 2*d* 2*c* 2*b* 2*a*
	Paradoxides zone.	Paradoxides zone .. 1*d* 1*c*
	Olenellus zone.	
	Zone of O. Kjerulfi.	Zone of O. Kjerulfi...1*b*
Fucoidal sandstone.	Fucoidal sandstone.	Sparagmite étage .. 1*a*
Zone of O. Mickwitzi.	Eophyton sandstone.	
Blue clay.		
Lower sandstone.		

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[1] Die Geologie des südlichen und mittleren Norwegen, Bonn., 1880, p. 155.

[2] Op cit., pp. 132–133.

[3] Ueber eine neuentdeckte untercambrische Fauna in Estland, Mém. Acad. Imp. Sci., St. Pétersbourg, ser. VII, vol. 36, No. 2, 1888, pp. 12, 13.

The correlations made in the scheme are of great value, as by them the Fucoidal and Eophyton sandstones of Sweden are clearly included in the Olenellus zone, and with them their included faunas. The list of fossils given by Dr. Schmidt includes *Olenellus mickwitzi* Schmidt, *Scenella discinoides* Schmidt, *S. ? tuberculata* Schmidt, *Mickwitzia monilifera* Linnarsson (sp.), *Obolella ?* sp., *Discina ?* sp. *Volborthella tenuis* Schmidt, *Platysolenites antiquissimus* Eichwald (sp.), *Medusites lindstromi* Linnarsson, *Frœna tenella* Linnarsson, Cruziana sp., Primitia ? (sp.). The genus Mickwitzia was proposed to include the *Lingula ? monolifera* of Linnarsson. For the details of the fauna and sedimentation the reader is referred to Dr. Schmidt's admirable memoir.

Spain.—The only species recorded from the Spanish peninsula that can be classed with the Olenellus fauna is *Ethmophyllum marinus* Rœmer.[1]

On the Island of Sardinia a large Cambrian fauna has been discovered that includes the genera Archæocyathus, Coscinocyathus, Obolella, Kutorgina, Olenopsis, Metadoxides, etc. Until more complete data is published on the geological section and the range of the species, it is not safe to assign any one group of species to the Olenellus zone. Dr. Bornemann, however, is now working on this fauna, and he may soon determine the stratigraphic range of the various genera and species, and thus differentiate between the Olenellus and Paradoxides faunas, unless they are commingled in the same stratum of rock.

Britain.—The Lower Cambrian strata of Britain are largely found in North and South Wales, although a small area in Shropshire has afforded the only specimens of Olenellus found in Britain. According to Dr. Hicks, the Cambrian rocks of St. David's, in South Wales, consist at the base of the Cærfai group, which is unconformably superjacent to the crystalline Archean rocks, and conformably subjacent to the Solva group, in which the Paradoxides fauna occurs. The Cærfai group includes, at St. David's, 1,570 feet of strata: conglomerates, 520 feet; red shales and schists, with fossils, 50 feet, and pebble sandstone, 1,000 feet. In the table the Bangor and Llanberis Lower Cambrian rocks of North Wales are included.[2] The fossils found by Dr. Hicks in the Lower Cambrian rocks of South Wales are: *Lingulella primæva, L. ferrugineæ, Discina cærfaiensis, Leperditia ? cambriensis.*[3] These, with the species from North Wales, described by Dr. Henry Woodward[4] as *Conocoryphe viola,* do not

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[1] Lethæ a Geognostica, vol. 1, 1880.

[2] Classification of the Eozoic and Lower Palæozoic rocks of the British Isles. Pop. Sci. Rev., n. ser., vol. 5, 1881, pp. 289–308; one plate of sections.

[3] Quart. Jour. Geol. Soc., vol. 27, 1871, pp. 399–404.

[4] On the discovery of trilobites in the upper green (Cambrian) slates of Penrhyn, Bethesda, near Bangor, North Wales. Quart. Jour. Geol. Soc. London, vol. 44, 1888, pp. 74–78, pl. 4.

prove the presence of the Olenellus zone, but the weight of stratigraphic evidence is so strongly in favor of including them in its fauna that I shall do so. In the summer of 1888 I visited the locality of *Conocoryphe viola*, and found fragments of it associated with a species of Hyolithes. At the Cumley quarries, Little Caradoc, Shropshire, Professor Lapworth[1] discovered in some calcareous sandstone, interbedded in the Cumley sandstone, *Kutorgina* sp. ?, *Scenella* sp. ?, *Ptychoparia* sp. ?, *Obolella* sp. ?, *Hyolithellus* sp. ?, and *Olenellus* (*H.*)*callavei.*

France.—In a recent paper, M. A. Bigot[2] compares the Cambrian rocks of Wales with those of the northwest of France, in Bretagne and Normandie, and expresses the result in the following table.[3]

Wales.	Normandie.
Arenig.	Armorican sandstones.
Olenus.	Feldspathic sandstones.
Solva and Menevian.	Green schists and sandstones.
Cærfai.	Red schists and marbles.
Conglomerate.	Purple pudding-stone.
Pebidian.	Schists of Saint-Lô.

If the correlations in this table are correct it is not improbable that the Olenellus fauna will be found in the Red schists and marble, correlated with the Cærfai terrane.

As far as known the Olenellus fauna does not occur on the continents of Asia, Africa, Australia, or South America.

RELATIONS OF THE LOWER CAMBRIAN FAUNA TO THE SUPERJACENT FAUNAS.

The fauna succeeding the Olenellus fauna, in the stratigraphic succession, has usually been called the Paradoxides fauna, from the presence, in all the typical sections in the Atlantic Basin, of species of the genus Paradoxides. In the sections of Cambrian strata in the Rocky Mountain province and the Champlain-Hudson province, there is a Middle Cambrian fauna, more or less distinctly defined, that succeeds the Olenellus fauna, but it is not the typical Paradoxides fauna of the Atlantic province. On this account I will speak of the Middle Cambrian fauna, of the Atlantic Basin, as the Paradoxides fauna or Middle Cambrian fauna; and the term Middle Cambrian fauna will be applied equally to the Paradoxides fauna and to the fauna occupying the same stratigraphic position in the Champlain-Hudson and Rocky Mountain provinces.

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[1] On the discovery of the Olenellus fauna in the Lower Cambrian rocks of Britain. Nature, vol. 39, 1888, pp. 212, 213.

[2] Le Précambrien et le Cambrien dans le Pays de Galles et leurs equivalents dans le massif Breton. Bull. Soc. géol. France, 3d ser., vol. 17, 1889, pp. 161-183.

[3] Op cit., p. 181.

PHYSICAL OR STRATIGRAPHIC RELATIONS.

The section on Manuel's Brook (Fig. 51, p. 554) shows a continuous deposition of sediments, from the basal conglomerate, through the Lower Cambrian (Olenellus fauna) time, to and through Middle Cambrian (Paradoxides zone) time; a thickness of about 250 feet of shale having been deposited between the typical Olenellus zone and the Paradoxides zone. The same conditions of continuous and conformable sedimentation appear to have prevailed on the eastern side of the Atlantic Basin, in Wales, Norway, and Sweden. The great conformable sections of Cambrian strata, in the Rocky Mountain area (Figs. 45, p. 549; 46 and 47, p. 550), do not, as far as known, present evidence of interruption in the sedimentation between the Lower, Middle, and Upper Cambrian strata, except near the eastern shore-line, as in the Wasatch section of Utah (Fig. 46), where strata of Upper Cambrian age do not appear to have been deposited. In Russia, Spain, Sardinia, and on the western side of the Atlantic, in New Brunswick[1] and Massachusetts, the stratigraphic relations of the faunas are not exhibited; and, in the St. Lawrence and Champlain-Hudson areas of America, the data are wanting by which to identify the subfaunas of the Cambrian in any continuous stratigraphic section. As far as known to me, the stratigraphic or physical relations of the faunas, do not furnish sufficient evidence to account for the change from the Olenellus to the Middle Cambrian fauna; and there is no recognized unconformity indicative of a physical and consequent time interruption in the deposition of the sediments that compose the strata containing the Lower and Middle Cambrian faunas.

In the following table the order of succession of the Cambrian faunas is shown, in six typical areas in America:

	Cambrian group.		
	Upper Cambrian.	Middle Cambrian.	Lower Cambrian.
Newfoundland	Olenus zone.	Paradoxides zone.	Olenellus zone.
Massachusetts	Unknown.	Paradoxides zone.	Olenellus zone.
New York	Dicellocephalus zone.	Indicated by other genera than Paradoxides.	Olenellus zone.
Tennessee	Present in part.	Same as in Nevada and Utah.	Olenellus zone.
Nevada and Utah	Dicellocephalus zone.	Represented by other genera than Paradoxides.	Olenellus zone.
Upper Mississippi Valley.	Dicellocephalus zone.	Unknown.	Unknown.

The correlations in the table follow the Newfoundland section. In New York the Paradoxides zone has not been recognized, unless we

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[1] Mr. Matthew's later observations indicate that in New Brunswick the representatives of the two faunas occur in several sections.

consider the representative species, *Linnarssonia sagittalis* var. *taconica, Agnostus desideratus,* Agnostus, of the type of *A. pisiformis, Microdiscus connexus* and *Zacanthoides eatoni,* as representing it. This I am at present inclined to do. In Newfoundland the genus Olenus is represented, but in New York, Nevada, Wisconsin, etc., the genus Dicellocephalus is taken as the representative genus of the Upper Cambrian. In the southern Appalachian area, Tennessee, Alabama, etc., the Upper Cambrian fauna is well developed, and the Middle Cambrian fauna is indicated by *Olenoides curticei* n. sp., *Ptychoparia antiquata,* Salter, Agnostus, 2. sp., etc. The Lower Cambrian fauna has been recently discovered and contains Hyolithes, like *H. americanus, Isoxys chilhoweana, Olenellus, sp.?*

The succession of the Cambrian faunas in Europe is, as shown in the following table, essentially the same as on the Atlantic coast of North America.

Table showing the order of succession of the Cambrian faunas in Europe, where the Olenellus zone has been recognized.[1]

[The local sections are given in Dr. Lapworth's paper.]

	Cambrian system.		
	Upper Cambrian or Olenus zones.	Middle Cambrian or Paradoxides zones.	Lower Cambrian or Olenellus zones.
Scandinavia	Dictyonema and Olenus zones.	Paradoxides zones.	Olenellus.
Russia	Dictyonema.	Unknown.	Olenellus.
Britain	Dictyonema and Olenus zones.	Paradoxides zones.	Olenellus.
Sardinia			Types of the Olenellus fauna, but not Olenellus.

ZOOLOGICAL RELATIONS.

Under this head will be mentioned (1) the species that range from the Lower Cambrian into the Middle Cambrian, in each typical province of the Olenellus fauna; (2) the relation of the genera and species, irrespective of geographic distribution and vertical range; (3) the comparison of the faunas as a whole.

New York and Vermont.—The Olenellus fauna has a great vertical range in Washington and Rensselaer counties, N. Y. I have called it 14,000 feet,[2] but this may be modified by a more detailed study of the sections. About 2,000 feet below the summit of the strata assigned to the Cambrian, the fauna contains *Olenellus asaphoides,* but with it occur the species *Lingulella granvillensis,*

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[1] Nature, vol. 39, 1888, p. 213.

[2] Am. Jour Sci., 3d ser., vol. 35, 1888, p. 242.

Linnarssonia sagittalis var. *taconica*, *Agnostus desideratus*, *Agnostus*, of the type of *A. pisiformis*, *Microdiscus connexus*, and *Zacanthoides eatoni*, all of which are representative although not identical species of the Paradoxides fauna of the Atlantic province.

Farther south, in the valley of the Hudson in Dutchess County, Prof. William B. Dwight discovered strata that he considers to be above the quartzite, carrying Olenellus. In it he found several species that may be referred to the Middle Cambrian fauna. They are: *Olenoides stissingensis*, *Leperditia ebinina*, and *Kutorgina stissingensis*. None of these species occurs in the Olenellus fauna, and the Olenoides belongs to the type of the genus occurring in the Middle Cambrian rocks of the Rocky Mountain province. *Kutorgina stissingensis* is the representative of *Kutorgina labradorica*, and *Leperditia ebinina* belongs to a division of that genus that includes an almost identical species from a stratum of rock, referred to the Middle Cambrian, in the Tonto sandstone of the Grand Cañon section of Northern Arizona.[1] As far as these few species can, they indicate that the Middle Cambrian fauna of eastern New York has the same general facies as that of the southern Appalachian region in the State of Georgia and in the Rocky Mountain province.

In the Georgia section of northern Vermont the Olenellus zone has a thickness of about 1200 feet.[2] With the possible exception of *Ptychoparia adamsi* none of the species are known to range upward in the section.

Rocky Mountain province.—In the Rocky Mountain province, the Eureka district and Highland Range sections[3] show the relations of the Lower, Middle, and Upper Cambrian faunas. In each section the Olenellus fauna is confined to a comparatively narrow zone,

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[1] The Tonto section at the head of Nun-ko-weap valley is as follows, from top downward:

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

The base rests unconformably upon the Chuar shales, etc. Nos. 4 and 5 are referred to the Middle Cambrian, and the strata above to the Upper Cambrian. In the Texas Cambrian section the *Ptychoparia minor* fauna is known from the upper portion of the basal sandstone (see fig. 49, p. 552), and it is not improbable that the Middle Cambrian fauna will be found in the lower portion of the sandstone series.

[2] Bull. U. S. Geol. Survey, No. 30, 1886, pp. 15–20; also p. 552, note 3.

[3] Bull. U. S. Geol. Survey, No. 30, 1886. Introduction.

just above the non-fossiliferous quartzite. In the Eureka district the fauna consists of only six species: *Kutorgina prospectensis, Scenella conula, Olenoides quadriceps, Olenellus gilberti, O. iddingsi* and *Anomocare parvum*. Of these, two species, *Olenoides quadriceps* and *Scenella conula* are found 500 feet higher in the section.[1] The Olenellus fauna, in the Highland Range section, includes only *Cruziana sp. ?, Olenellus gilberti* and *O. iddingsi*.[2] One hundred feet higher in the section *Hyolithes billingsi* is found, and in the Eureka section *Stenotheca elongata* occurs 2,000 feet above the Olenellus zone, although a Lower Cambrian species in the Atlantic province. In the Pioche section[3] the fauna of the Olenellus zone is larger. It includes *Eocystites sp. ?, Lingulella ella, Kutorgina pannula, Acrothele subsidua, Acrotreta gemma, Orthis highlandensis, Olenellus gilberti, Zacanthoides levis, Crepicephalus augusta,* and *C. liliana*. Of these *Eocystites sp. ?* is very doubtfully identified by single plates; *Kutorgina pannula, Acrothele subsidua, Acrotreta gemma,* and *Hyolithes billingsi* pass to the zone above that carrying Olenellus.

In the Wasatch section of Utah *Olenellus gilberti* occurs in a narrow band of arenaceous shale that is subjacent to silico-argillaceous shales, containing a number of species that I formerly referred to the Olenellus fauna. Restricting the fauna to only those species occurring in association with Olenellus or a grouping of species characteristic of the Olenellus zone, where Olenellus is present, all the species, with the exception of *Olenellus gilberti* and *Cruziana sp. ?*, are referred to the Middle Cambrian fauna.

In the section of Mount Stephen and Castle Mountain, in British Columbia, Mr. McConnell[4] found the Olenellus fauna at the base of the Castle Mountain limestone; beneath it there are dark colored argillites and sandstones, estimated at over 10,000 feet in thickness, which correspond in position and character to the pre-Olenellus strata of the Wasatch section, which are referred to the Algonkian period. In the collection made by Mr. McConnell from the Olenellus zone there are *Olenellus* sp. ?, *Ptychoparia adamsi* and *Protypus senectus*. The fauna of the Middle Cambrian zone is 2,000 feet higher up in the section, and includes, in the collection made by Dr. C. Rominger, Sponge ?, *Lingulella macconnelli* Walcott, *Crania ? columbiana* Walcott, *Linnarssonia*, like *L. sagitallis* Salter, *Acrotreta gemma* var. *depressa* Walcott, *Kutorgina pannula* White, *Kutorgina*, like *K. whitfieldi*, *Orthis ?* sp., *Orthisina alberta* Walcott, *Scenella conula ?* Walcott, *Platyceras romingeri* Walcott, *Hyolithellus*, like *H. micans* Billings, *Agnostus interstrictus* White, *Karlia stephenensis*

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[1] Op. cit., p. 32.

[2] Op. cit., pp. 33, 34.

[3] Op. cit., p. 35.

[4] Geol. and Nat. Hist. Survey Canada, Ann. Rept., new ser., vol. 2, 1887; Rept. Geol. Structure of a portion of the Rocky Mountains, p. 29 D.

Walcott, *Olenoides nevadensis* Meek, *Zacanthoides spinosus* Walcott, *Bathyuriscus howelli* Walcott, *B.* (*Kootenia*) *dawsoni* Walcott, *Ogygopsis klotzi* Rominger (sp.), *Ptychoparia cordilleræ* Rominger (sp.).

As known at present six species only pass from the Olenellus zone to the superjacent strata, in the Rocky Mountain province. They are: *Kutorgina pannula*, *Acrothele subsidua*, *Acrotreta gemma*, *Scenella conula*, *Hyolithes billingsi*, and *Olenoides quadriceps*. Of these *Acrotreta gemma* extends up to the Upper Cambrian zone, in Montana.

Newfoundland.—The fauna of the Olenellus zone contains but one species that ranges up into the Paradoxides zone—*Hyolithes princeps*. *Agraulos strenuus* is closely allied to *Agraulos socialis* of the Paradoxides fauna, and *Platyceras primævum* is very like *P. minutissimum* of the Upper Cambrian.

The review of the sections shows but little specific relationship between the two faunas, as only nine species are now known to range from zone to zone. A review of the genera shows a large percentage common to the two zones. Of the sixty-eight genera of the Olenellus zone forty-seven pass up into the Middle Cambrian.

The genera confined to the Lower Cambrian, in America, are:

Leptomitus.
Protopharetra.
Spirocyathus.
Coscinocyathus.
Ethmophyllum.
Modioloides.
Fordilla.
Helenia.
Coleoloides.
Hyolithellus.
Isoxys.
Protocaris.
Olenellus.
Bathynotus.
Avalonia.
Oryctocephalus.
Protypus.

Of the European genera, the following five are referred only to the Lower Cambrian:

Mickwitzia.
Volborthella.
Platysolenites.
Medusites.
Fræna.

RELATIONS OF THE GENERA AND SPECIES.

The comparison between the two subfaunas will be made by considering the genera and species of each class of the Lower Cambrian and comparing it with the same class of the Middle Cambrian fauna.

No traces of land vegetation have been discovered in the rocks of the Cambrian Period.

Algæ.—As far as known to me there are no true Algæ in the rocks of the Lower Cambrian. That such forms existed there can scarcely be any doubt, but after a study of all the reported species, I think that they can be referred to trails of worms or mollusks with much more propriety than to the Algæ. Specimens of Cruziana collected in

Newfoundland lead me to think that it is a trail or burrow and not an Alga.[1]

Spongiæ.—The sponges of the Lower Cambrian are limited to four genera, of which one, Protospongia, is found in the upper beds of the Olenellus zone of the Atlantic province, and also in the Middle Cambrian in Nevada, New Brunswick, Newfoundland, Wales, and Sweden. Leptomitus is confined to the Lower Cambrian.

Hydrozoa.—It is to the researches of Dr. A. G. Nathorst that we owe a knowledge of the occurrence of Medusæ in the Lower Cambrian rocks of Sweden. By a series of comparisons between the casts found in the rocks at Lugnas and the casts made by the impressions of recent Medusæ, more especially of *Aurelia aurita* and *Cyrena capilata*, he has shown that it is extremely probable, if not certain, that the delicately constructed Medusæ lived during the Lower Cambrian epoch and left traces of their existence in the clays and sands of the sea-shore. Dr. Nathorst[2] figures and describes *Medusites lindstromi* Linnrs., *M. favosus* Nathorst and *M. radiata* Linnrs., and states that he thinks the species of Eophyton are the casts of trails made by the Medusæ in moving along the sea-bed. The form described as *Dactyloidites asteroides* may be referred provisionally to the Medusæ and thus give an American species from the Lower Cambrian. There are in the collections of the U. S. Geological Survey a group of forms from the middle part of the Cambrian in Alabama, that appear to be generically related to *Medusites lindstromi*. They will be described in an account of the Middle and Upper Cambrian fauna. In ascending the geological scale, it is not until the lithographic slate of the Upper Jura, at Solenhofen, etc., is reached, that traces of the Medusæ are again met with.

The Graptolitidæ is represented by two species that are provisionally referred to the genera Phyllograptus and Climacograptus. These generic types are not met with again until the base of the Silurian is reached, where they are largely developed. Mr. Matthew has described two species of Graptolites from the Middle Cambrian of New Brunswick, which he refers to Dendrograptus and Protograptus.

Actinozoa.—It has been an open question for some years whether the forms referred to the genus Archæocyathus were corals or sponges. Dr. G. J. Hinde has recently reviewed the genera and species, and

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[1] Since the preceding was written Mr. Matthew's paper has appeared, in which he describes *Buthotrephis antiqua, Phycoidella stichidifera, Palæochorda setacea, Hydrocytium ? silicula,* and *Microphycus catenatus* as Algæ. He also describes under the Monera Radiolaria ?, *Monadites globulosus, M. pyriformis, M. urceiformis,* and *Radiolites ovalis.*—(On Cambrian Organisms in Acadia, Trans. Roy. Soc. Canada, vol. 7, sec. iv, 1890, pp. 144–148.)

[2] Kongl. Svenska Vetenskaps-Akademiens Handlingar, Bandet 19, N. 1, 1881. Om Aftryck af Medusor i Sveriges Kambriska Lager.

concluded that they form a special family of the *Zoantharia sclerodermata,* in some features allied to the group of perforated corals. A restudy of all the species and a personal examination of Dr. Hinde's specimens leads me to agree with him that they should be referred to the Actinozoa. With the exception of the single doubtful species of Archæocyathus described by Mr. Matthew, from the Paradoxides zone of St. John, New Brunswick, *A. ? pavonoides,* there are no representatives of this family (Archæocyathinæ) in the later Cambrian. The first true corals met with in the ascending series occur near the base of the Silurian fauna.

Echinodermata.—The Echinodermata are represented by a few scattered plates of a species of Cystid, which is referred provisionally to the genus Eocystites. It is impossible to make any comparison between it and the Cystids of the Middle Cambrian.

Annelida, etc.—The trails, burrows, and tracks of animals that occur in the Lower Cambrian are nearly all duplicated in the Upper Cambrian. This is true of the genera Planolites, Helminthoidichnites, Scolithus, and Cruziana, of the American rocks. As far as determined by traces left by their passage the same type of animals existed throughout Cambrian time.

Brachiopoda.—The Brachiopoda, with 10 genera and 29 species, affords a much broader opportunity for comparison, but even here the specific connection is very slight between the two zones. Of the genera, Lingulella is represented in the Paradoxides zone by a group of forms that have received the names *L. linguloïdes and L. dawsoni* in New Brunswick; *Lingulella sp.,* in Linnarsson's Brachiopoda of the Paradoxides beds of Sweden (Plate 3, Figs. 24–28), and *L. granvillensis* in the Olenellus zone of New York. The species of the genus Acrotreta, of the Paradoxides zone of Sweden and New Brunswick, and the Middle Cambrian zone of the Rocky Mountain province, are so closely allied to the species from the Olenellus zone in Nevada that we consider that one species, *A. gemma,* ranges from the base of the Cambrian through to the Upper Cambrian. *Acrothele subsidua* also ranges from the Lower Cambrian to the Middle Cambrian, in the Rocky Mountains; and *A. matthewi,* of the Paradoxides zone of New Brunswick, is a closely allied if not identical species. The genus Iphidea has a vertical range from the Olenellus zone in Labrador to the Middle Cambrian in Sweden, where it is found in the Paradoxides beds. A very closely allied species also occurs in the lower portion of the Cambrian section in the Grand Cañon of the Colorado of Arizona, a horizon that will probably be referred to the Middle Cambrian. The genus Kutorgina has one species, *K. labradorica,* that has a wide geographic range, and a closely allied, representative species, *K. stissingensis,* occurs in the Middle Cambrian zone of New York. *K. pannula* ranges from the Olenellus zone to the Middle Cambrian in Nevada, and is found in the upper portion of the Olenellus zone in New York.

Linnarssonia sagittalis var. *taconica* is scarcely to be considered a typical Olenellus zone species, as it occurs so high in the Lower Cambrian section. Still, as it is associated with Olenellus we may consider it as forming a part of the fauna, and compare it directly with the same species as found in the Paradoxides zone of New Brunswick and Sweden. Of the six species of the genus Obolella none are known to occur in the Middle Cambrian, and it is not until we reach the Upper Cambrian that we find representatives of the genus. The genus Orthis, as represented by *O. salemensis* and *O. highlandensis* (the broad and narrow hinge types), is not known to occur in the Middle Cambrian zone, although both forms of the genus are represented in the Silurian. Among the species referred to Orthisina, we find that *O. orientalis* is very closely related to *O. pepina*, of the Upper Cambrian; also that *O. festinata* is of the type of *O. exporecta* of the Paradoxides zone of Sweden, and *Orthis billingsi* of the New Brunswick Middle Cambrian. *Camerella antiquata* and *C. minor* have no known representatives in the Middle or Upper Cambrian.

As a whole, the Brachiopoda are strongly represented in the Lower Cambrian and do not exhibit any special evidence of embryonic character when compared with the fauna of the Middle and Upper Cambrian. If, however, the comparison is extended to the Upper and Lower Silurian faunas, etc., the predominance of the inarticulate shells of the families Obolellidæ, Siphonotretidæ, and Lingulidæ over the articulate shells of the Orthidæ and Rhynchonellidæ, in the Cambrian indicates that the general law of progressive evolution in this class finds expression in the small number of articulate brachiopods in the Cambrian as compared with the later faunas and the predominance of the inferior inarticulate species.

Lamellibranchiata.—The genus Fordilla and the form described as *Modioloides prisca* appear to be the representatives of the Lamellibranchiata in the Olenellus zone. The presence of these two shells is of unusual interest, as none of the same class are met with in the geologic succession before the abrupt appearance of the group of species in the Arenig (Lower Silurian) strata of South Wales.

Gasteropoda.—Among the Gasteropoda, the genus Scenella is represented in the Upper Cambrian by simple Patelloid shells. It has not been found in the Paradoxides fauna of the Atlantic Basin, but in the Middle Cambrian strata of the Mt. Stephen section in the Rocky Mountains a representative species was found by Dr. Rominger. The forms referred to the genus Stenotheca are very closely allied if not identical in the Lower and Middle Cambrian zones. *S. rugosa*, of the Lower Cambrian, and *S. acadica* of the Paradoxides zone are examples of this intimate specific relationship. The little

Platyceras of the Lower Cambrian has a representative, *P. romingeri*, in the form described from the Mt. Stephen Middle Cambrian fauna of British Columbia. A single species in the Upper Cambrian connects this genus with the Ordovician fauna. *Pleurotomaria attleboroughensis* does not appear to have a representative before reaching the Lower Ordovician fauna, and *Straparollina remota* has no connection through the known Middle Cambrian fauna with the fauna of the Lower Silurian.

Pteropoda.—The four genera and fifteen species of this class are very strongly related to those of the Middle Cambrian fauna. *Hyolithes princeps* is a large form that is very abundant in the Olenellus zone, and it has a great geographic range. It is found in western Nevada, eastern Massachusetts, and eastern Newfoundland. A closely allied if not identical species occurs in the Paradoxides zone in Newfoundland. *H. maximus* of the Paradoxides zone of Bohemia is of this same specific type, although differing considerably in detail of form. *H. americanus* is very closely related in form to *H. acadica* of the Paradoxides zone in New Brunswick, and the same type is abundant in the Upper Cambrian of the Mississippi Valley, under the name of *H. primordialis*. *H. billingsi* is known to range from the Lower to the Middle Cambrian, and has been found in Labrador, New York, and Nevada. *H. communis*, *H. impar*, *H. quadricostatus*, and *H. terranovicus* are species which do not appear to have representatives in the Middle Cambrian fauna. *H. similis* is very much like *H. primus* of the Paradoxides zone of Bohemia. The genera Hyolithellus and Coleoloides do not appear to be represented by well authenticated species in the Middle Cambrian. Salterella is not met with again until the Ordovician fauna is reached and there very doubtfully.

Crustacea.—Of the true crustaceans, *Leperditia dermatoides* has a close specific relationship with an undescribed species from the Middle Cambrian of the Grand Cañon section of Arizona; and a representative species, *L. stissingensis*, occurs in the New York Middle Cambrian. The newly described type *Isoxys chilhoweana* is, as far as known to me, distinct from more recent genera.

The genus Aristozoe, although abundantly represented in the Silurian fauna of Europe, is not known from the Middle Cambrian. *Protocaris marshi* still remains the oldest known Phyllopod crustacean. The Upper Cambrian Phyllopod, *Hymenocaris vermicauda*, is the next met with, unless some of the forms referred to Stenotheca, in the Paradoxides zone, are portions of the carapace of some species whose generic relations are undetermined.

Trilobita.—The sixteen genera and fifty-three species of trilobites constitute less than one-third of the entire fauna. The range of variation among the genera and species includes forms with and without eyes, and with and without facial sutures. One of the surprising facts is that the genus Agnostus, which has been theoretically considered the ancestral form of the trilobite, does not appear to exist in the lower portion of the Olenellus fauna, but, as shown by Brögger, in Sweden it is more typical of the Middle Cambrian than of the Olenellus zone. The undoubted species of the genus known from the Olenellus zone are found in the upper portion, in association with types of the Middle Cambrian fauna. The reference of *Agnostus nobilis* Ford, from the lower part, to Agnostus is very doubtful, as the form is probably a Microdiscus. The type which, by a priori reasoning, should succeed Agnostus is Microdiscus, with its three and four segments and eyeless cephalic shield. As known, however, it occurs at the base of the Olenellus zone, and its specific variations indicate prolonged existence in a period of which the record has not yet been discovered. Reaching its known maximum development, in species and size, in the Olenellus zone, the genus diminishes in the Paradoxides zone in about the same ratio that Agnostus increases in importance. In the Upper Cambrian Microdiscus is represented only by *Pemphigaspis bullata* Hall. Agnostus continues on into the Ordovician fauna. *Microdiscus connexus*, of the upper portion of the Olenellus zone, in New York, is the Paradoxides zone type of the genus, i. e., *M. punctatus*, while *M. sculptus*, of the Lower Paradoxides zone of South Wales, is the Olenellus zone type, i. e., *M. speciosus*.

The genus Olenellus has been found wherever the Lower Cambrian fauna is known, except in New Brunswick. It presents great variation in specific characters, and I have included several of the species in the subgenus Mesonacis, and Mr. Matthew has proposed the genus Holmia to include *O. kjerulfi*. The marked difference between this genus and Paradoxides is the absence of true facial sutures and in the general configuration of the central portion of the head, more notably in the form of the eye. Among the species of Paradoxides the eyes of *P. rugulosus* Corda and the group of species from the St. John terrane, of New Brunswick, approach most nearly to those of Olenellus. In the type, *O. thompsoni*, the distinction between it and Paradoxides is very striking. The absence of facial sutures and the long spine-like telson finds no counterpart in the latter. *O.* (*Mesonacis*) *vermontana* has the typical Paradoxides form of pygidium; also a peculiar posterior series of thoracic segments that are related to those of Paradoxides. This species appears as a link between the type *O. thompsoni* and the remaining species referred to the genus, all of which have a pygidium like that of Paradoxides, and none of the pleuræ of the thoracic segments are prolonged, as in the type of the genus and in the young of some species of Paradoxides.

I call attention here to the fact that while no true facial sutures exist in Olenellus, there is. on the underside of the test of the head, a line-like depression that corresponds in position to the suture in Paradoxides. It may be well to note that Olenellus resembles the living Limulus in having well developed eyes, without the presence of facial sutures. The external resemblance to Limulus is further enhanced by the telson-like pygidium of *O. thompsoni.* The structure of the cephalic appendages of the trilobite also relate it to Limulus.[1] If we consider the head of Limulus as belonging to a more highly organized form than the head of Paradoxides, the fact that the head of Olenellus is without facial sutures does not make it rank below Paradoxides. In fact *Olenellus* (H.) *bröggeri*, of Newfoundland, impresses me as being as highly, if not more highly, organized than any of the species of Paradoxides. *Olenellus thompsoni* and *O. gilberti* might be considered the progenitors of Paradoxides, inasmuch as they have a strong development of the pleura of one of the thoracic segments, a feature that is present in the young of *P. bohemicus,* but does not continue to the adult.

American paleontologists have considered the genus Olenellus as the descendent of Paradoxides, but the fact of occurrence proves such a theory to be incorrect. The argument advanced by Mr. Ford[2] that the young of *Olenellus asaphoides* passed through the Paradoxides stage, in its embryonic development, may be explained in another way, by assuming that the species of Olenellus, having the pleuræ of the third segment prolonged (macropleural) originated earlier than those with the pleuræ of uniform length (brachypleural), and hence the prolonged pleuræ are shown only in the embryonic phases of growth in the brachypleural species. As pointed out by Ford, the genus Paradoxides, like Olenellus, has brachypleural and macropleural species, but it is significant that it is in the young of Paradoxides that the macropleural features of *O. thompsoni* are developed, while in the adult it is reduced to a very insignificant character. That a genetic relationship exists between Olenellus and Paradoxides there is considerable probability. Olenellus exhibits greater specific variation and is more diversified by spines on the head and thorax, but in the essential elements of structure it is related to Paradoxides, except in the absence of true facial sutures. Just what weight to give this character is not fully decided, although I am inclined to refer the two genera to distinct families. With the exception of *O.* (*Mesonacis*) *vermontana,* there are no known connecting species between the typical forms of the two genera.

The genus Olenoides is largely developed in the Middle Cambrian of the interior of the continent. One species only, *O. marcoui,* is found in the lower portion of the Olenellus zone. Two other species, *O. fordi* and *O. quadriceps,* are in the upper portion, near the passage between the Lower and Middle Cambrian. As far as the

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[1] Bull. Mus. Comp. Zool., Harvard College, vol. 8, No. 10, 1881, pp. 208-211.

[2] Am. Jour. Sci., 3d ser., vol. 22. 1881. pp. 250-259.

specimens of *O. marcoui* of the Lower Cambrian will permit of comparison it is closely related to *O. nevadensis* of the Middle Cambrian. The two species of Zacanthoides, *Z. eatoni* and *Z. levis*, are representative species of the genus, and serve to unite the fauna with that of the Middle Cambrian, as *Z. typicalis* and several species occur in the Middle Cambrian of the interior of the continent. The genera Bathynotus, Avalonia, Oryctocephalus, and Protypus are peculiar to the fauna, and do not appear to be represented in the Middle or Upper Cambrian faunas.

Conocoryphe trilineata and *C. reticulata* are two of the best marked types in the New York Lower Cambrian; they are closely related to *C. elegans* and *C. coronata*, of the Paradoxides zone, in having the same general form and in the absence of eyes. The genus Ptychoparia is represented by nine species, all of which are more or less closely related to forms in the Middle and Upper Cambrian. *Agraulos strenuus* is represented in the Upper Cambrian by *A. socialis*. *Ellipsocephalus nordenskioldi*, of Sweden, is represented by *E. hoffi* of the Paradoxides zone of Bohemia. *Crepicephalus augusta* and *C. liliana* are types that are more or less abundant in the Upper Cambrian fauna of the interior of the continent. They are not represented, to my knowledge, in the Middle Cambrian fauna. The small head that I have referred to *Anomocare parvum* may be compared to *A. limbatum* of the Paradoxides beds of Sweden. The genus Solenopleura, with its five species, is also well developed in the Middle Cambrian fauna. *S. howleyi*, from the base of the Olenellus zone of Newfoundland, is very closely related to the type of the genus *S. holometopa* of the Paradoxides zone of Sweden.

COMPARISON OF THE FAUNAS AS A WHOLE.

The first thing that strikes one in comparing the fauna of the Olenellus zone with that of the Middle Cambrian is that the latter is not wholly known, or, in other words, there existed somewhere a Middle Cambrian fauna, which has not yet been discovered. We are now obtaining evidence of a considerable fauna that existed during Middle Cambrian time on the western slope of the Appalachian shore, and on the west coast of what then existed as the North American Continent. Of this fauna there is scarcely any representation known in the Middle Cambrian or Paradoxides fauna of the Atlantic province. This adds to the fauna, but there is still a notable absence of certain forms in the Middle Cambrian fauna which are present in the Lower Cambrian. The first noticeable exception is the absence of representatives of the peculiar group of corals that occur in the Olenellus zone. With a single possible exception, the Archæocyathinæ are not represented in the Middle Cambrian. Among the Brachiopoda the genus Obolella has a large development in the Lower Cambrian and is present in the Upper Cambrian, but is scarcely represented in the Middle Cambrian; and the Brachiopoda, as a whole, are more largely developed in species and number of individuals than in the Middle Cambrian. Lamellibranchs are represented in the Lower Cambrian, but not in the Middle Cambrian. Among the Gasteropods, Pleurotomaria and Straparollina are yet to be discovered in the Middle Cambrian. The same is true of the Phyllopod crustacean *Protocaris marshi*.

Viewing the Olenellus fauna as a whole and comparing it with the known Middle Cambrian fauna of the Atlantic basin, or the Paradoxides fauna, the impression made is that the former is more highly differentiated, and, zoologically considered, should be the successor of the Paradoxides fauna. If, in our comparison, we include the Middle Cambrian fauna of the interior of the continent, this conclusion will be changed, owing to the presence of a group of trilobites, from the Middle Cambrian of Nevada, Utah, and British Columbia, that includes the genera Olenoides, Asaphiscus, Bathyuriscus, Karlia, and Ogygopsis. These genera suggest the trilobites of the second or Ordovician fauna, and serve to connect the Middle Cambrian fauna so closely with the second fauna that the idea of its preceding the Olenellus fauna can not be entertained.

It was owing to the comparison made between the two faunas in the Atlantic basin that led me to so long retain the view that the Olenellus fauna succeeded the Paradoxides fauna in time, and to think that the Paradoxides fauna would be found, if at all, beneath the Olenellus zone, in the interior of the continent. Now that we know that the Olenellus fauna occurs beneath the Paradoxides zone in America, and that there is a representative Middle Cambrian fauna in the Valley of the Hudson, that serves in a measure to connect the Paradoxides fauna of the Atlantic basin and the Middle Cambrian fauna of the interior of the continent, there is no hesitation in referring the group of species, forming the fauna between the Olenellus and the Upper Cambrian zone, in the Appalachian and Rocky Mountain provinces, to the Middle Cambrian, and in correlating its stratigraphic position with that of the Paradoxides fauna of the Atlantic province.

The cause of the abrupt change from the Olenellus to the Paradoxides faunas is not yet fully recognized. While a considerable portion of the genera pass up, very few of the species are known to do so, and in none of the sections has there been found a commingling of the characteristic species of the Lower and Middle faunas. I shall advert to this question again, in preparing the review of the Middle Cambrian fauna which is now in hand.

ORIGIN OF FAUNA.

If we attempt to classify the Olenellus fauna by its genesis, an almost impenetrable wall confronts us. That the life in the pre-

Olenellus seas was large and varied there can be little, if any, doubt. The few traces known of it prove little of its character,[1] but they prove that life existed in a period far preceding Lower Cambrian time, and they foster the hope that it is only a question of search and favorable conditions to discover it. As far as known to me, the most promising area in which to search for the pre-Olenellus fauna is on the western side of the Rocky Mountains in the United States and on their eastern slopes in British Columbia. There the great thickness of conformable pre-Olenellus zone strata presents a most tempting field for the student collector. Another of the known possible areas is that of New York and Vermont, but the prospect is not as favorable as in the West. Other and better fields may exist in Asia and Africa, but as yet they are unknown, with the exception of the areas described by Baron Richthofen in China,[2] where a great thickness of conformable sedimentary beds exists beneath a horizon that is comparable with the Middle Cambrian of western North America.

COMPARISON AND CORRELATION.

If a comparison is made between the fauna of the Olenellus zone and that of the Silurian group the superiority of the latter in number of species, genera, and families is at once apparent. If the comparison is extended to class characters the disparity between the two is very much reduced and it is made evident that the evolution of life between the epoch of the Olenellus fauna and the epoch of the Ordovician fauna has been in the direction of differentiating the class types that existed in the earlier fauna, with one or two exceptions, the most notable of which is the Cephalopoda. The classes represented by non-testaceous species may or may not have existed. The study of the Olenellus fauna adds a little more to our knowledge of the rate of convergence backward in geologic time of the lines representing the evolution of animal life, and at the same time proves that an immense time interval elapsed between the beginnings of life and the epoch represented by the Olenellus fauna.

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[1] See ante, p. 552. In 1874, (Palæozoic Fossils, vol. 2, part 1, 1874, pp. 76, 77), Mr. Billings described some fossils from the "Huronian rocks" of Newfoundland. They were *Aspidella terranovica*, a fossil resembling in some respects a small Chiton, or Patella flattened by pressure, but whose true zoological relations are unknown. Associated with it are numerous specimens of what appear to be *Arenicolites spiralis*. As far as known these are the only fossils found in the Algonkian rocks beneath the Cambrian of Newfoundland.

From the red quartzite at Pipestone, Minnesota, Prof. N. H. Winchell describes *Lingula calumet* and *Paradoxides barberi*. The latter, I think, was founded on a concretion, but the *Lingula calumet* has in many respects a strong resemblance to a crushed form of Obolella. It may be for the present considered as one of the doubtful fossils of the Algonkian rocks. Geol. Nat. Hist. Survey of Minnesota, 13th Ann. Rep., 1885, pp. 65–68.

[2] China, vol. 2, pp. 94, 100, 101.

Correlation.—It is not desirable in this place to enter into a discussion of the principles or criteria of correlation employed in this paper except very briefly. In the broadest sense three principles are made use of:

1. Superposition, or stratigraphic position of the strata.
2. The occurrence of similar groupings of organic remains.
3. The occurrence of similar lithologic characters.

In correlating the Lower Cambrian strata of one geologic province with what are considered to be equivalent strata in other provinces, the order of superposition is considered where the relations to the subjacent and superjacent rocks are known.

The presence of the Olenellus fauna is, however, regarded as the strongest test and it is chiefly used in determining the presence of the Lower Cambrian zone in any geologic section. It is assumed that the presence of this fauna indicates the same relative geologic horizon. It is not implied that the formations characterized by the Olenellus fauna are strictly contemporaneous wherever found. On the contrary, its presence in such widely separated localities as England, Newfoundland, Tennessee, Nevada, and British Columbia, is *prima facie* evidence that the deposits are not strictly contemporaneous. This is supported by the known laws of geographic distribution of animal life. That they were contemporaneous in a geologic sense, or that they occupy the same relative position in the geologic sequence of formations, is accepted throughout this paper.

The use of lithologic characters is of much less importance than either stratigraphic position or similarity of organic remains, and is used only within a district, area, or province.

If the reader wishes an analysis of the elements of correlation used in each instance it may be obtained by comparing the data given in each separate area, district, or province, with that of the area, district, or province with which it is correlated either directly or by implication. He will thus determine the amount and character of the evidence upon which the correlations between the several districts, areas, or provinces have been based.

As an element of weakness in paleontologic correlation, we may cite the character of the Middle Cambrian or Paradoxides fauna of the Atlantic province as compared with the essentially different Middle Cambrian fauna of the Rocky Mountain province. The position of the latter in the geologic series would not be inferred from its zoologic characters. It is only its occurrence at a horizon between the Lower and Upper Cambrian faunas that gives any strong reason for correlating it with the Paradoxides fauna. The latter retains all the essential characters of the Primordial fauna, whereas the former partakes in its trilobites largely of the characters that are more typical of the Ordovician fauna. It appears from what we now know of the two, that the Middle Cambrian fauna of the Rocky

Mountain province had advanced further in development toward the Ordovician fauna than had the Paradoxides fauna of the Atlantic province. It is an interesting fact in this connection that the Upper Cambrian fauna of the Rocky Mountain province and the Atlantic province appears to be essentially of the same grade or phase of development. What became of the descendants of the Middle Cambrian fauna of the Rocky Mountain province during Upper Cambrian time is one of the unsolved problems.

X. NOTES ON THE GENERA AND SPECIES.

Many of the genera and species have already been described at length in Bulletin 30 of the U. S. Geological Survey, and the student is referred by the citation given under such genera and species to the place of description. In the case of new genera and species, original observations on described genera and species, or descriptions that have not appeared in publications of the Geological Survey, most of the descriptions are published at length.

Following each species a reference is given to the location of the type specimens, or, if the specimens are in the collections of the U. S. National Museum a reference is made to the number under which they are entered in the Museum catalogue.

SPONGIÆ.

Genus LEPTOMITUS Walcott, 1886.

Bull. U. S. Geol. Survey, No. 30, p. 89.

LEPTOMITUS ZITTELI Walcott, 1886.

(Pl. XLIX, figs. 1, 1*a*.)

Bull. U. S. Geol. Survey, No. 30, p. 89.

A sponge related to the glass-rope sponge, Hyalonema.

Nat. Mus. Cat. Invert. Foss., 15308.

Genus PROTOSPONGIA Salter.

Bull. U. S. Geol. Survey, No. 30, p. 90.

PROTOSPONGIA sp. ?.

(Pl. XLIX, fig. 2.)

Numerous spiculæ, similar to those of *P. fenestrata* Salter, occur in the upper portion of the Olenellus zone in Washington County, N. Y. As far as can be determined they are identical with the Middle Cambrian form, which is figured in Bulletin 30, U. S. Geological Survey. Pl. VI, Figs. 2, 2*a*–*b*.

Nat. Mus. Cat. Invert. Foss., 17438.

GIRVANELLA Nich. and Eth., jun.

Mon. Sil. Foss., Girvan Dist. 1, 1878, p. 23. Mentioned as Strephochetus, Seely. See Bull. U. S. Geol. Survey, 1886, p. 91.

(Pl. LX, fig. 4.)

That the forms found at Prospect and Silver Peaks, Nevada, are generically identical with Girvanella is extremely uncertain. Nothing is known of the minute structure. They are apparently organic and resemble *Girvanella ocellatus* Seely in external appearance. Whether the form is a Sponge or a Rhizopod is also uncertain.

Nat. Mus. Cat. Invert. Foss., 15311.

TRACHYUM BILLINGS, 1865.

TRACHYUM VETUSTUM Dawson.

Trachyum vetustum Dawson, 1890. Received in MSS. from Sir William Dawson, accompanied by figure and description.

Small rounded and irregular bodies, 6^{mm} and less in diameter, calcareous, and imbedded in a finely granular limestone, partly oolitic and with rounded siliceous grains. Occurring in groups on the weathered surface as if possibly attached to each other below.

The best specimens show on the weathered surface a circular outline, with a thick wall and central canal, cup, or osculum, usually small in comparison with the thickness of the wall. The weathered surface appears finely granular, with obscure, radiating grooves and ridges.

A transparent slice shows a badly preserved reticulated structure, which may in a general way be compared with that of Protopharetra from the Cambrian of Sardinia, or with the basal portion of some species of Archæocyathus, though of finer texture. The pores traversing this structure would seem, though irregular, to have been on the whole arranged in an obliquely radiating manner, and to have terminated in rows of openings at least on the inner surface. The structure, however, is very imperfect and masked by a general finely granular crystallization.

The specimens occur in the bowlders in the Quebec group conglomerate of Metis, along with the Lower Cambrian trilobite (*Ptychoparia metisensis*), described by Mr. C. D. Walcott, and are therefore of the same age; and if sponges, among the oldest known, and probably referable to the calcareous group of Pharetrones of Zittel. In texture these fossils bear a close resemblance to the genus Trachyum of Billings, represented by two species from the Quebec group of Cape Norman, Newfoundland.[1]

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[1] Palæozoic Fossils, vol. 1, p. 211.

The weathered specimens are, indeed, except by their smaller size and less open cup or osculum and different state of preservation, scarcely distinguishable from one of Billings's species. For this reason they may, for the present, be referred to the above genus.

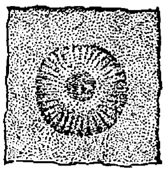
FIG. 60.—*Trachyum vetustum.* Weathered cross-section. x2.

A slice of one of the specimens shows imbedded in the wall what seems to be a section of a microscopic spiral shell without septa.

ACTINOZOA.

For a number of years it has been an open question whether the forms included under the genus Archæocyathus of Billings were allied to the corals or sponges. The first reference to them is by Captain Bayfield,[1] who mentioned finding a Cyathophyllum in Labrador, in 1845. Since Mr. Billings's paper in 1861 authors have varied in their opinions.[2] Quite recently Dr. G. J. Hinde has reviewed the genera and species, and concludes that "the Archæocyathinæ form a special family of the Zoantharia sclerodermata, in some features allied to the group of perforate corals."

Although previously inclined to consider the forms under notice sponges, I am now of the opinion that Dr. Hinde is more nearly correct in referring them to the corals.

PROTOPHARETRA Bornemann.

Geol. Zeitschr., 1883, p. 274.

PROTOPHARETRA sp.?

(Pl. LI, figs. 1, 1*a*.)

This is a form related to *P. polymorpha* Bornemann.[3] It varies in form of growth from round stems to flattened fronds, in which the structure is very irregular. It is an open question if *Spirocyathus atlanticus* is not generically identical with Protopharetra.

Formation and locality.—Lower Cambrian; Silver Peak, Nevada.

Nat. Mus. Cat. Invert. Foss., 15303.

SPIROCYATHUS Hinde.

Quart. Jour. Geol. Soc. London, 1889, vol. 45, p. 136.

This genus is proposed to include the original type of the genus Archæocyathus. As the change to another type was made by Mr. Billings and no good result can now come from urging the use of

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[1] On the junction of the transition and primary rocks of Canada and Labrador; H. W. Bayfield. Quart. Jour. Geol. Soc. London, vol. 1, 1845, pp. 450–459.

[2] See Bull. U. S. Geol. Survey, No. 30, 1886, pp. 78–80.

[3] Nova. Acta. Leop.—Carol. Deutsche Akad. Naturforscher., vol. 51, pt. 1, 1886.

the name Archæocyathus to include the species *S. atlanticus*, it appears best to accept Dr. Hinde's generic name.

SPIROCYATHUS ATLANTICUS, Billings (sp.).

(Pl. L, figs. 1, 1*a*-*f*. 2, 2*a*.)

See Bull. U. S. Geol. Survey, No. 30, p. 73.

There is quite a variation between the specimens representing this species, as shown by Figs. 1*b*, 1*c*, 1*e*, 2, 2*a*. They are not considered of specific importance.

Formation and locality.—Lower Cambrian; on the Straits of Belle Isle, Labrador, and Silver Peak, Nevada. Longitude 117° 20′ W., latitude 38° N.

Nat. Mus. Cat. Invert. Foss., 15301.

COSCINOCYATHUS Bornemann.

Zeitschr. Deutsch. geol. Gesell., 1884, p. 704.

COSCINOCYATHUS BILLINGSI Walcott.

(Pl. LI, figs. 2, 2*a*, *b*.)

Archæocyathus billingsi Walcott. See Bull. U. S. Geol. Survey, No. 30, p. 74.

By the subdivision of the genus Archæocyathus this species is referred to Coscinocyathus.

Nat. Mus. Cat. Invert. Foss., 15302.

ARCHÆOCYATHUS Billings.

ARCHÆOCYATHUS PROFUNDUS Billings (sp.)

(Pl. LII, figs. 1, 1*a*-*c*; Pl. LIII, figs. 1, 1*a*-*b*; Pl. LIV, fig. 3.)

Ethmophyllum profundum Walcott. See Bull. U. S. Geol, Survey, No. 30, p. 84.

The recent studies of Dr. Hinde[1] resulted in his retaining the genus Ethmophyllum and Archæocyathus and proposing the new generic name Spirocyathus for the original type species of Archæocyathus. This appears to be the best way out of the difficulty caused by Mr. Billings defining his genus from one species and citing another as its type.

Formation and locality.—Lower Cambrian; L'Anse au Loup, Straits of Belle Isle, Labrador.

Nat. Mus. Cat. Invert. Foss., 15304.

Subgenus ARCHÆOCYATHELLUS Ford.

ARCHÆOCYATHUS (A.) RENSSELAERICUS Ford.

(Pl. LIV, figs. 1, 1*a*-*e*.)

Archæocyathus rensselaericus Ford. See Bull. U. S. Geol. Survey, No. 30, p. 85.

This species differs from the typical form of Archæocyathus in having a poriferous outer wall. In this respect it is identical with

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[1] Quart. Jour. Geol. Soc. London, vol. 45, 1889, pp. 125-148.

Ethmophyllum, but it does not have the peculiar set of canals attached to the inner wall. It is an intermediate type between the two genera, and may be referred to Archæocyathellus, the latter being considered a subgenus.

Formation and locality.—Lower Cambrian; Conglomerate limestone on the ridge east of the city of Troy, N. Y.

Nat. Mus. Cat. Invert. Foss., 15305.

ARCHÆOCYATHUS (A.) DWIGHTI Walcott.

(Pl. LIV, figs. 4, 4*a*.)

Archæocyathus (*A.*) *dwighti* Walcott, 1889, U.S. Nat. Mus., Proc., vol. 12, p. 34.

This species differs from *A.* (*A.*) *rensselaericus* in having, in the outer wall, a double row of pores and then a raised space upon which no pores have been detected. Interior structure unknown.

Formation and locality.—Lower Cambrian ; Troy, N. Y., and near School House No. 8, Greenwich, Washington County, N. Y.

Nat. Mus. Cat. Invert. Foss., 18352.

ARCHÆOCYATHUS (A.) RARUS Ford.

(Pl. LIV, figs. 2, 2*a*–*b*.)

See Bull. U. S. Geol. Survey, No. 30, p, 87.

Formation and locality.—Lower Cambrian ; Conglomerate limestone, on the ridge east of the city of Troy, N. Y.

Nat. Mus. Cat. Invert. Foss., 15306.

ETHMOPHYLLUM Meek.

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 75.

ETHMOPHYLLUM WHITNEYI Meek.

(Pl. LV, figs. 1, 1*a*–*e*.)

See Bull. U. S. Geol. Survey, No. 30, p. 81.

In addition to this species a second has been discovered in the material from Silver Peak; and the *Archæocyathus marianus* Roemer[1] proves to belong to the same genus.

Formation and locality.—Lower Cambrian ; Silver Peak, Western Nevada. The species occurs in a limestone and calcareous shale, associated with *Spirocyathus atlanticus*, *Hyolithes princeps*, *Olenellus gilberti*, etc.

Nat. Mus. Cat. Invert. Foss., 15307.

ETHMOPHYLLUM MEEKI Walcott.

(Pl. LV, figs. 2, 2*a*–*c*.)

Ethmophyllum meeki, Walcott, 1889, U. S. Nat. Mus., Proc., vol. 12, p. 34.

This form differs from *E. whitneyi*, with which it is associated,

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[1] Lethæa geonostica, vol. 1, 1880, p. 301.

in having stronger radiating septa, numerous dissepiments, and large pores in the outer wall.

Formation and locality.—Lower Cambrian; Silver Peak, Nevada.
Nat. Mus. Cat. Invert. Foss., 18358.

TRAILS, BURROWS, AND TRACKS OF ANIMALS.

As far as known to me, there are no true Algæ found in the rocks of the Lower Cambrian, except possibly in New Brunswick. That such forms existed there can scarcely be any doubt, but, after a careful study of all the reported species, I think they can be referred to trails of worms or mollusks with much more propriety than to the Algæ.

The trails, burrows, and tracks are referred to the following genera and species:

PLANOLITES Nicholson.

Planolites Nicholson, 1873. Proc. Roy. Soc. London, p. 289.

PLANOLITES ANNULARIUS Walcott.

(Pl. LX, fig. 5.)

Planolites annularius, Walcott, 1889, U. S. Nat. Mus., Proc., vol. 12, p. 34.

The cast of a burrowing worm that shows numerous annulations.

Formation and locality.—Lower Cambrian. At the Reynolds Inn locality of *Olenellus* (*M.*) *asaphoides*, one mile west of North Greenwich, Washington County, N. Y.
Nat. Mus. Cat. Invert. Foss., 18360.

PLANOLITES CONGREGATUS Billings.

(Pl. LXI, fig. 1.)

Palæophycus congregatus Billings, 1861. Bull. Geol. Survey Canada, p. 2.

This and the following species were referred to the Algæ by Mr. Billings. The reference may be correct, but these forms impress me as being the casts of worm-borings; and there is nothing in the specimens to indicate their vegetable origin. This form of cast is found in sandy argillaceous deposits, all through the sedimentary rocks.

PLANOLITES VIRGATUS Hall (sp).

(Pl. LXI, fig. 5.)

Palæophycus virgatus Hall, 1847, Pal., N. Y., vol. 1, p. 263, pl. 70, fig. 1.
Palæophycus incipiens Billings, 1861. Bull. Geol. Survey Canada, p. 2.

This character of worm-boring is common in the sandy shales near Swanton, and at Parker's quarry, Georgia, Vermont, where it is associated with *Olenellus* (*M.*) *asaphoides*. The type specimens described by Professor Hall are from the same geologic horizon as those to which Mr. Billings gave the name *P. incipiens*, and I think there is no good reason for separating them as two species.

HELMINTHOIDICHNITES Fitch.

Helminthoidichnites Fitch, 1850. Trans. N. Y. State Agric. Soc. for 1849, p. 868.
Compare *Nemertites* Nicholson, 1873. Proc. Roy. Soc. London, p. 289.

HELMINTHOIDICHNITES MARINUS Emmons (sp.).

(Pl. LX, fig. 1.)

Gordia marina Emmons, 1844. Taconic System, p. 67, pl. 1, fig. 2. Idem, 1846. Agric, N. Y., vol. i, p. 68, Pl. xiv, fig. 2. Idem, Hall, 1847, Pal. N. Y., vol. 1, p. 264, pl. 71, figs. 1, 2.
Palæophycus rectus Fitch, 1850. Trans. N. Y. State Agric. Soc. for 1849, p. 862.
Compare *Fucoides flexuosa* Emmons, 1844. Taconic System. pl. 5, fig. 3.
Helminthoidichnites tenuis Fitch, 1850. Trans. N. Y. State Agric. Soc. for 1849, p. 866, figure in text.

Dr. Fitch proposed the genus Helminthoidichnites for "*tracks resembling those of worms*," and figured this species as a very narrow trail on an arenaceous shale. I have seen fragments of a similar trail in the arenaceous slates of the Olenellus zone and also in the Upper Cambrian shales of the Grand Cañon of the Colorado, Arizona. Those from the latter afford the best illustration, and a figure is given of a small portion of the surface of the arenaceous shale showing the trail upon it.

This type of borings or trails is very abundant in the purple, green, and dark slates and the arenaceous shales of the Olenellus zone. Similar trails may have been made by many different species during all the geologic epochs, down to the present day.

Fig. 4, Pl. LXII, illustrates a rather broad trail or boring; Fig. 3 a narrow form where a portion is stained with oxide of iron; Fig. 1 numerous trails crossing each other at various angles; Fig. 2 a cluster of narrow trails separated by numerous breaks in their course.

The specimens figured by Emmons and Hall show the curvings and crossings much more completely than any in the collections accessible to me.

SCOLITHUS Haldeman.

Scolithus Haldeman, 1840. Suppl. to No. 1 of Monog. of the Limniades, etc., p. 3.

SCOLITHUS LINEARIS Haldeman.

(Pl. LXIII, figs. 1, 1*a–c*.)

Scolithus linearis Haldeman, 1840. Suppl. to No. 1 of Monog. of the Limniades. etc., p. 3.
Scolithus linearis Hall, 1847. Pal. N. Y., vol. i, p. 2, Pl. I, Figs. 1*a–c*. Billings, 1861. Bull. Geol. Survey Canada, p. 2. Idem, 1862. Geol. Vermont, vol. 2, p. 943. Idem, 1865. Pal. Foss., vol. i, p. 2.

This form appears to range through the Cambrian. Exactly similar holes are found in the sandstones of the Potsdam sandstone. It is not probable that the same species of animal made them in the two epochs, but we have nothing to guide us in separating them.

Formation and locality.—Lower Cambrian. L'Anse au Loup, Straits of Belle Isle, Labrador.

CRUZIANA d'Orbigny.

Bilobites DeKay, 1823. Ann. Lyc. Nat. Hist., New York, vol. 1, pp. 45-49. Not *Bilobites* Linn., 1775.
Cruziana d'Orbigny, 1842. Voyage d'Amérique merid. III.
Rusophycus Hall, 1852. Pal. N. Y., vol. ii, p. 23.

CRUZIANA sp.?

(Pl. LXIV, figs. 1, 1*a*–*c*; Pl. LXV, figs. 1, 1*a*, 2; Pl. LXVI, figs. 1, 1*a*, *b*.)

A careful examination of a large series of specimens of the trails and burrows referred to Cruziana, from a single layer of sandstone, leads me to consider that they are all of animal origin, and that many of the so-called species were formed by one species of animal. Also that specific differences in the animals making them would not generally be shown in the casts of the burrows and trails.

Fig. 1, on Pl. LXIV, shows the form and surface markings of a cast of the under surface of the animal when it was at rest. Fig. 1, Pl. LXV, shows a succession of similar casts made by the forward movement of the animal. Fig. 2, Pl. LXV, preserves the form of several successive casts of the animal, and at the same time the form of trail made when it was in more rapid motion than when the cast represented by Fig. 1, Pl. LXV, was formed. From Fig. 1, Pl. LXV, it is but a step to the form represented by Fig. 2 of the same plate and the narrow form, Fig. 1*b*, Pl. LXIV, Fig. 1, Pl. LXVI. The latter approach very closely to the genus Arthrophycus of Hall.

In a paper on the genus Cruziana and allied forms, I hope to give my reasons for considering them as burrows and trails of animals and not the casts of fucoids.

HYDROZOA.

PHYLLOGRAPTUS Hall.

PHYLLOGRAPTUS?? CAMBRENSIS, n. sp.

(Pl. LIX, figs. 3, 3*a*.)

Diplograptus secalinus Emmons, 1856. Am. Geol., vol. 1, part 2, pl. 1., fig. 11.
Diplograptus simplex Walcott, 1886. Bull. U. S. Geol. Surv., No. 30, p. 92, pl. 11, figs. 4, 4*a*.
Phyllograptus ? simplex, Walcott, 1889. Am. Jour. Sci., 3d ser., vol. 37, p. 388.

A note on this species in Bulletin 30 contains the following statement: "Dr. Emmons originally applied the name *Fucoides simplex*

(Taconic System, 1844, Pl. V, fig. 1; Agric. Rept., N. Y., pt. 5, 1846, Pl. XVII, fig. 1), to a species previously named by Prof. Amos Eaton (see Twentieth Rept., N. Y. State Mus. Nat. Hist., 1868, p. 268), as *Fucoides secalinus*. Subsequently he referred the species named by him to Eaton's *F. secalinus*, calling it *Diplograptus secalinus*, gave a description as above, and at the same time figured another species which we have found in the fine argillaceous shales of Parker's ledge. For this I have decided to use Emmons's name *simplex*, the name *D. secalinus* being restricted to the species from the Hudson River group, as described by Prof. Hall (Pal. of N. Y., vol. 1, 1847, p. 267)." (Pp. 92, 93.)

A revision of the synonymy leads me to the conclusion that as the name *simplex* was applied to the species *Fucoides simplex* by Emmons, which is a synonym of *Fucoides secalinus* of Eaton, that the name *simplex* can not longer be used for the second species, and I therefore propose the name *cambrensis*. The generic reference is without value, owing to the imperfection of the material for study.

Formation and locality.—Lower Cambrian, Georgia formation; Parker's quarry, Georgia, Franklin County, Vermont.

Nat. Mus. Cat. Invert. Foss., 15314.

CLIMACOGRAPTUS Hall.

CLIMACOGRAPTUS?? EMMONSI Walcott.

(Pl. LIX, fig. 4.)

See Bull. U. S. Geol. Survey, No, 30, 1886, pp. 93, 94.

Type in collection of E. Hurlbert, Esq., Utica, N. Y.

DACTYLOIDITES Hall.

DACTYLOIDITES ASTEROIDES Fitch.

(Pl. LVII. Pl. LVIII, figs. 1, 1*a*.)

Buthotrephis ? asteroides Fitch, 1850. Trans. New York State Agric. Soc., vol. 9, for 1849, p. 863.

Dactyloidites bulbosus Hall, 1886. Thirty-ninth Ann. Rep., Reg. State Mus. Nat. Hist., New York, for 1885, p. 160; Pl. 11, Figs. 1, 2.

The original description and figure illustrating this species are imperfect, but to any one acquainted with the form as shown on the slabs of slate, there is little doubt of the identity of the species described by Dr. Fitch and that described by Prof. Hall. The type specimen had five divisions or rays, and the one described by Prof. Hall has six. On a large slab now in the State Museum, at Albany, both five and six rayed specimens occur. Some of the specimens show the structure figured by Dr. Fitch, and others that seen on the plate published by Prof. Hall. Dr. Fitch classed the species with plants, indicating by the generic name a fucoid. Prof. Hall compares it with the graptolites, but thinks the form is referable to the sponges or marine algæ. Neither author gives its correct stratigraphic position.

A comparison with figures given by Nathorst of Medusites, suggests that the problematical forms under consideration are compressed impressions of the mouth and gastric cavity of a species of Medusa. The scope of the present paper does not permit of a full discussion of the evidence favoring this view. It may be presented in the future.

I found *Olenellus (M.) asaphoides, Microdiscus speciosus* and other species of Lower Cambrian fossils in a thin bed of limestone interbedded in the slate at the quarry from which the slabs containing the impressions of this species were obtained.

Formation and locality.—Lower Cambrian; Middle Granville, Washington County, New York.

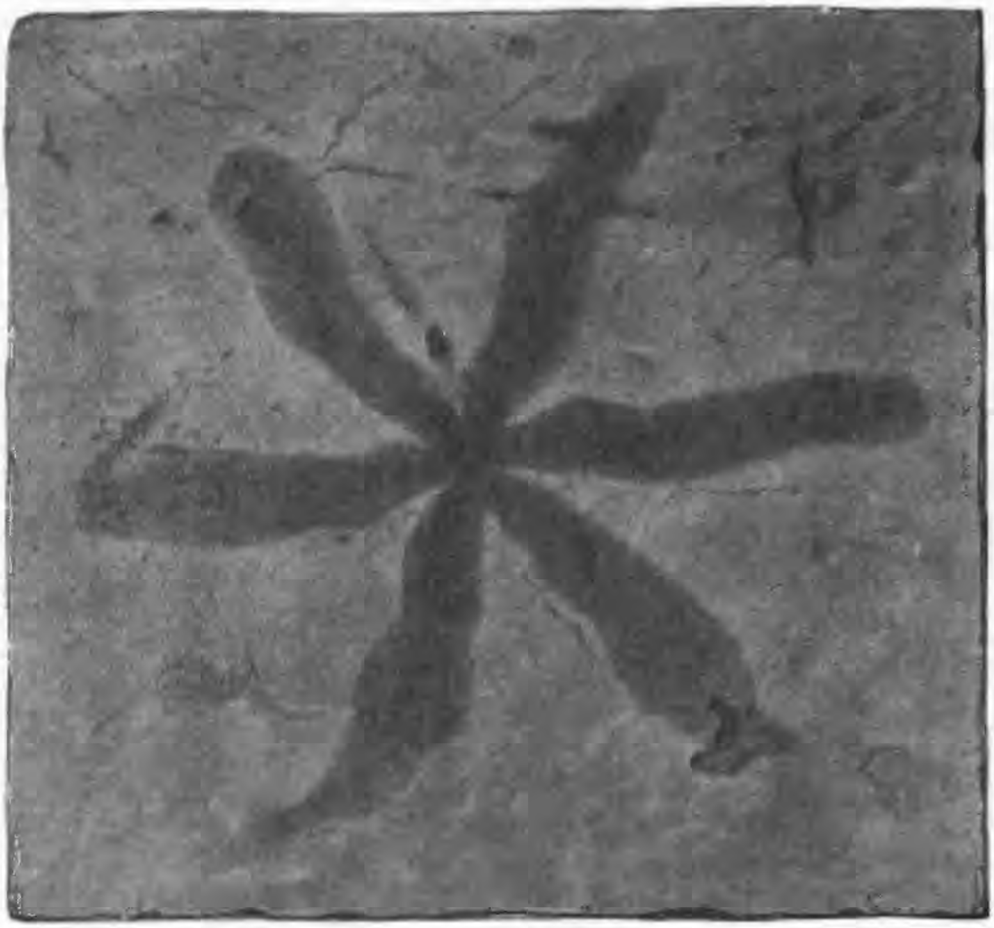

FIG. 61.—*Dactyloidites asteroides.* Specimen on a slab of slate from Middle Granville, N. Y. The six rays are narrow, as in the type figured by Dr. Fitch.

ECHINODERMATA.

EOCYSTITES Billings.

(Pl. LX, fig. 3.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 94.

A few plates of a cystidian character are all that are known of the Echinodermata in the Lower Cambrian. The generic reference is provisional.

Formation and locality.—Lower Cambrian; Georgia, Vermont, and Pioche, Nevada.

Nat. Mus. Cat. Invert. Foss., 15317.

BRACHIOPODA.

LINGULELLA Salter.

LINGULELLA CÆLATA Hall (sp.)

(Pl. LXVII, figs. 1, 1*a–e*.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 95.

Formation and locality.—Lower Cambrian; conglomerate limestone on the ridge east of the city of Troy, N. Y.; also, one mile south of Schodack Landing, in Columbia County, New York.

Nat. Mus. Cat. Invert. Foss., 15325.

LINGULELLA ELLA H. & W.

(Pl. LXVII, figs. 2, 2*a–e*.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 97.

This species occurs in the Lower and Middle Cambrian zones, in Nevada. The illustrations are taken from the specimens found in the Middle Cambrian zone, as they are there more numerous and better preserved.

Formation and locality.—Lower and Middle Cambrian; near Pioche, Nevada.

Nat. Mus. Cat. Invert. Foss., 15319.

LINGULELLA GRANVILLENSIS Walcott.

(Pl. LXVII, figs. 4, 4*a–d*.)

Lingulella granvillensis Walcott, 1887. Am. Jour. Sci., 3d ser., vol. 34, pp. 188, 189, Pl. i, Figs. 15–15c.

Shell small, elongate ovate, margins subparallel for a short distance at the widest portion about midway of the shell, broadly rounded in front, ventral valve attenuate toward the beak; dorsal valve ovate and rounded at the beak. General surface depressed convex. Surface marked by fine concentric lines and more rarely, fine radiating lines.

The cast of the interior of the ventral valve shows four narrow elongate scars, radiating from the beak toward the front margin.

A cast of the interior of a dorsal valve shows fine vascular markings and a well marked median groove, also faint impressions of the anterior adductor muscular scars and also what may have been the adjustor muscular scars.

This species occurs abundantly in the upper portion of the Olenellus zone of Washington County, N. Y. It is the representative in the Lower Cambrian of *Lingulella dawsoni* (Bull. 10, U. S. Geol. Survey, 1884, p. 15), of the Middle Cambrian. It may also be compared with *Lingulella ferruginea*, which ranges from the Harlech beds through the Menevian and probably into the period of the Lingula flags (Brit. Foss. Brach., vol iii, p. 337). Dr. G. Linnarsson figures a closely related species from the Paradoxides beds of Sweden (Brach. Par. Beds of Sweden, Pl. III, Figs. 24–28).

Formation and localities.—Lower Cambrian. Limestones interbedded in the shaly slates, 2 miles south of North Granville; by the roadside a little west of the bridge crossing the Poultney River at Low Hampton; and on the roadside north of school-house No. 4, in the northeast part of Whitehall, Washington County, N. Y.

Nat. Mus. Cat. Invert. Foss., 17440.

ACROTRETA Kutorga.

ACROTRETA GEMMA Billings.

(Pl. LXVII, figs. 5, 5*a–e*.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 98.

The specimens of this species, associated with *Olenellus gilberti*, at Pioche, Nev., are larger and usually more depressed than those from the Upper Cambrian strata of Montana. The range of variation among the latter includes the Lower Cambrian form.

Nat. Mus. Cat. Invert. Foss., 15343.

IPHIDEA Billings.

IPHIDEA BELLA.

(Pl. LXVII, fig. 6.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 100.

ACROTHELE Linnarsson.

ACROTHELE SUBSIDUA White.

(Pl. LXX, figs. 1, 1*a–c*.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 108.

This species is abundant in association with *Olenellus gilberti*, near

Pioche, Nev., and it also occurs at Antelope Springs in association with the Middle Cambrian fauna.

Fragments of a closely related form occur in the higher Olenellus horizon of Washington County, N. Y.; and the *Acrothele matthewi* Hartt, of the Middle Cambrian, New Brunswick, is a closely allied, if not identical, species.

Nat. Mus. Cat. Invert. Foss., 15347.

KUTORGINA Billings.

KUTORGINA CINGULATA Billings.

(Pl. LXIX, figs. 1, 1*a*–*h*.)

See Bull. U. S Geol. Survey, No. 30, 1886, p. 102.

Nat. Mus. Cat. Invert. Foss., 15337.

KUTORGINA LABRADORICA Billings.

(Pl. LXIX, figs. 3, 3*a*–*b*.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 104.

In addition to the localities mentioned in Bulletin 30, there is to be added Topsail Head limestone, Conception Bay, S. E. Newfoundland, and the Vermont localities are to be dropped as the shells from them are referred to the variety *swantonensis.*

Nat. Mus. Cat. Invert. Foss., 18309.

KUTORGINA LABRADORICA var. SWANTONENSIS Walcott.

(Pl. LXIX, fig. 2, 2*a*–*b*.)

Kutorgina labradorica, var. *swantonensis,* Walcott, 1889. U. S. Nat. Mus. Proc., vol. 12, p. 36.

A comparison of a series of specimens of *K. labradorica,* from Newfoundland, with a series from near Swanton, Vt., show constant differences. The striæ on the Swanton shells are finer and more regular, and the valves are less transverse in proportion to the length, and the beak of the ventral valve is less elevated.

Formation and locality.—Lower Cambrian. East of Swanton and Highgate Springs, Vt.

Nat. Mus. Cat. Invert. Foss., 15329.

KUTORGINA PANNULA White. (sp.)

(Pl. LXIX, figs. 5, 5*a*–*f*.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 105.

This species ranges from the Olenellus zone to the Middle Cambrian in Nevada. A form that appears to be specifically identical, occurs in the upper part of the Olenellus zone, in Washington County,

N. Y., and also in the Sillery conglomerate on the south shore of the Island of Orleans.

Nat. Mus. Cat. Invert. Foss., 15332.

KUTORGINA PROSPECTENSIS Walcott.

(Pl. LXIX, figs. 4, 4*a*.)

See Bull. U. S. Geol. Survey, No. 30, p. 106.
Nat. Mus. Cat. Invert. Foss., 15335.

LINNARSSONIA Walcott.

Am. Jour. Sci., 3d ser., vol. 29, 1885, p. 114.

LINNARSSONIA SAGITTALIS var. TACONICA Walcott.

(Pl. LXVIII, figs. 1, 1*a*—*d*.)

Linnarssonia taconica Walcott, 1887. Am. Jour. Sci., 3d series, vol. 34, pp. 189, 190, Pl. i, figs. 18–18*d*.

Shell small, rarely exceeding 3^{mm} in length or breadth, usually circular or transversely broad oval. Ventral valve moderately convex; apex excentric; dorsal valve depressed convex; beak obtusely pointed, marginal; surface of the valves marked by fine lines of growth.

In the interior of the ventral valve, near the posterior margin, oblique scars occur, one on each side of the raised rim surrounding the foraminal opening in allied species. From a point of the foraminal rim a narrow depression extends obliquely outward and forward on each side, so as to inclose a Λ-shaped elevation, that is strongly marked in casts of the interior valve. The interior of the dorsal valve shows two large oval scars near the posterior margin, separated by a low ridge that extends over three-fourths of the distance to the front margin.

This species is related to both *L. transversa* and *L. sagittalis.*[1] It differs chiefly in the characters of the interior of the dorsal valves. As yet none of the specimens have shown the ventral valve to be perforate; this is owing probably to the minute size of the opening and the imperfection of the specimens which have been examined.

This is the first instance known to me of the occurrence of this genus in association with the Lower Cambrian faunas, as it is essentially a Middle Cambrian type both in New Brunswick, Newfoundland, Sweden and Wales.

This variety occurs in the upper part of the Olenellus zone, in Washington County, N. Y., and, with the exception of the variation in size, it is essentially identical with *L. sagittalis* Salter, *L. transversa* Hartt, and *L. misera* Billings, of the Paradoxides zone.

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[1] Am. Jour. Sci., 3d series, vol. 9, pp. 114–117.

Formation and localities.—Lower Cambrian; limestones interbedded in the shaly slates at Rock Hill school-house (No. 8), near North Greenwich; 1½ miles west of North Greenwich; lowest fossiliferous horizon on D. W. Reid's farm, 1½ miles west of North Greenwich; west summit of Bald Mountain, in the town of Greenwich; 2 miles south of North Granville; on the roadside just west of Low Hampton crossing of the Poultney River; and 1 mile south of Shushan, all in Washington County, N. Y.

Nat. Mus. Cat. Invert. Foss., 17441.

OBOLELLA Billings.

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 109.

OBOLELLA ATLANTICA Walcott.

(Pl. LXXI, figs. 1, 1*a*–*c*.)

Obolella atlantica Walcott, 1889, U. S. Nat. Mus. Proc., vol. 12, p. 36.

This is a small species of Obolella that occurs in great abundance in Newfoundland and also less frequently at North Attleborough, Mass.[1] It is of the type of *Obolella crassa,* but differs in the details of the interior surfaces and the average smaller size.

Formation and locality.—Lower Cambrian; Manuel's Brook, Topsail and Brigus Heads, Conception Bay, Newfoundland.

Nat. Mus. Cat. Invert. Foss., 18322.

OBOLELLA CIRCE Billings.

(Pl. LXXI, figs. 3, 3*a*.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 118.

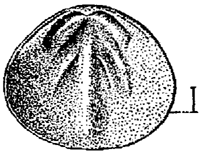

FIG. 62.—*Obolella circe?*. Interior of a dorsal valve from St. Simon. This shell is doubtfully referred to the species.

Nat. Mus. Cat. Invert. Foss., 14892.

OBOLELLA CHROMATICA Billings.

(Pl. LXXI, figs. 2, 2*a*, *b*.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 112.

Nat. Mus. Cat. Invert. Foss., 14891.

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[1] Bull. Mus. Comp. Zool., Harvard College, vol. 16, 1888; Prelim. Descp. North Attleborough Fossils, p. 27.

OBOLELLA CRASSA Hall (sp.).

(Pl. LXXI, figs. 4, 4*a*-*f*.)

See Bull. U. S. Geol. Survey, 1886, p. 114.

In addition to the localities mentioned in Bulletin 30, the species is now known to occur near North Attleborough, Mass.[1]

Nat. Mus. Cat. Invert. Foss., 15347.

OBOLELLA GEMMA Billings.

(Pl. LXXI, figs. 5, 5*a*—*c*. Pl. LXXII, figs. 2, 2*a*.)

See Bull. U. S. Geol. Survey, p. 116.

Nat. Mus. Cat. Invert. Foss., 14889.

OBOLELLA NITIDA Ford.

(Pl. LXXII, fig. 1.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 118.

This species has been found at several localities in Washington County, N. Y., but the specimens have not added to our knowledge of the species.

Nat. Mus. Cat. Invert. Foss., 15353.

ORTHIS Dalman.

ORTHIS HIGHLANDENSIS Walcott.

(Pl. LXXII, figs. 5, 5*a*, *b*.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 119.

Nat. Mus. Cat. Invert. Foss., 15355.

ORTHIS SALEMENSIS Walcott.

(Pl. LXXII, figs. 6, 6*a*.)

Orthis salemensis Walcott, 1887. Am. Jour. Sci., 3d series, vol. 34, pp. 190, 191, Pl. i, figs. 17, 17*a*.

Shell about the average size of the Cambrian species of the genus. Transversely subquadrilateral; front broadly rounded and slightly sinuate midway; hinge line as long as the greatest width of the shell

Ventral valve convex, most elevated about one-fourth the distance from the beak to the anterior margin; beak small and incurved to the margin of the medium sized area; the surface of the area and the foramen have not been observed; mesial sinus broad and shallow, it

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[1] Bull. Mus. Comp. Zool., Harvard College, vol 16, 1888.: Prelim. Descp. North Attleborough Fossils, p. 27.

is marked by a low median rib and laterally by two costæ on each side, a third appearing just outside the sinus.

The dorsal valve, associated in the same hand specimen of limestone, is slightly more convex; frontal margin with a rather deep sinuosity to receive the projection of the ventral valve; median fold broad and but slightly elevated, marked by two or three low costæ; the beak appears in the broken specimen in the collection to be scarcely elevated above the surface of the shell, and to terminate at the cardinal margin; area unknown.

The surface of both valves is marked by fine concentric lines of growth, and low, rounded costæ, varying in number from six to seven, as in the specimens figured, to twelve or fourteen in other specimens.

In the broad costæ and the general aspect of the shell this species is unlike any known to me from the Cambrian.

Formation and localities.—Lower Cambrian; limestones interbedded in the shaly slates one and one-half miles south of Salem; one mile south of Shushan, and near Rock Hill school-house (No. 8), Greenwich, Washington County, N. Y. It is also present in limestone bowlders of the Cambrian conglomerate at Metis, on the St. Lawrence, below Quebec. *Olenellus* sp. *Hyolithellus micans*, etc., occur in association with it.

Nat. Mus. Cat. Invert. Foss., 17443.

ORTHISINA d'Orbigny.

ORTHISINA FESTINATA Billings.

(Pl. LXXII, figs. 7, 7*a*, *b*.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 120.
Nat. Mus. Cat. Invert. Foss., 15359.

ORTHISINA ORIENTALIS Whitfield.

(Pl. LXXII, fig. 8.)

See Bull. U. S. Geol. Survey, No. 30. 1886, p. 120.
Nat. Mus. Cat. Invert. Foss., 15360.

ORTHISINA TRANSVERSA Walcott.

(Pl. LXXII, figs. 9, 9*a*.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 121.
Nat. Mus. Cat. Invert. Foss., 15361.

CAMARELLA Billings.

CAMARELLA ANTIQUATA Billings.

(Pl. LXXII, fig. 3.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 122.
Nat. Mus. Cat. Invert. Foss., 15363.

CAMARELLA ? MINOR Walcott.

(Pl. LXXII, figs. 4, 4*a–d*.)

Camarella minor Walcott, 1889, U. S. Nat. Mus. Proc., vol. 12, p. 36.

Shell small, moderately convex; valves about equal in depth. Ventral valve convex on the umbo, with the beak slightly incurved; cardinal slopes nearly straight from the beak to the rounded sides; the posterior or umbonal third of the valve is usually more or less tumid, a ridge of growth separating it from the anterior portion of the shell. Dorsal valve shorter than the ventral valve; transversely oval, most prominent at the umbo; beak very small and terminating at the cardinal margin.

The casts of the surface show only concentric lines of growth. Usually an elevated line or ridge separates the tumid umbonal portion of the shell from the anterior part.

The casts of the interior of the ventral valve have a small pit just in front of the termination of the beak, from which two narrow depressions extend forward and separate off a short, narrow, central ridge and two lateral pointed projections, which extend forward to the line of the base of the central ridge and are defined, laterally, by sharp, narrow depressions. This form indicates that two lamellæ or plates extended out from the beak on each side of a narrow central depression and then curved outward toward the margin, somewhat as in Pentamerus. In one cast two slight ridges extend from the base of the lateral projections a short distance anteriorly. In the interior of the dorsal valve a transverse depression, just in front of the beak, corresponds to a transverse ridge on the interior of the valve.

Owing to the imperfect casts of the interior the generic reference to Camarella is tentative.

In company with Prof. William B. Dwight I found this species associated with heads and fragments of a trilobite that is referred to *Olenellus asaphoides*.

Formation and locality.—Lower Cambrian; in the quartzitic sandstones of Stissing Mountain, near Stissingville, Dutchess County, New York.

LAMELLIBRANCHIATA.

The presence of two shells that can be referred to this class is of unusual interest, as none are met with above until the base of the Lower Silurian (Ordovician) is reached. There is some doubt about the reference of *Fordilla troyensis*, as it may possibly be founded on the valves of a small crustacean. *M. prisca* appears to be a true lamellibranchiate shell.

FORDILLA Barrande.

FORDILLA TROYENSIS Barrande.

(Pl. LXXIII, figs. 1?, 2, 2*a–c*.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 125.

The cast of a shell closely allied to this was found near North Attleborough, Mass., by Prof. N. S. Shaler.[1]

Nat. Mus. Cat. Invert. Foss., 15372.

MODIOLOIDES Walcott.

MODIOLOIDES PRISCA Walcott.

(Pl. LXXIII, fig. 3.)

Modiolopsis ?? prisca Walcott, 1887. Am. Jour. Sci., 3d series, vol. 34, pp. 191, 192, Pl. i, Fig. 19.

The only specimen of the species known to me is the cast of a right (?) valve, 2^{mm} in length. It is transversely oval in outline and rather strongly convex; the beak is subcentral and curves toward the hinge line, but does not reach it; an oval muscular scar is situated just within the pallial line, at the supposed anterior end; pallial line simple, continuous as far as observed.

The minute size and the fact that we have only the cast of the interior of the valve, render it very difficult to determine the correct generic relations of the shell. The nearly central position of the beak distinguishes it from all known species of Modiolopsis; while the muscular scar and pallial line, with the oval form, relates it to *Modiolopsis curta* of the Hudson River formation. The discovery of the character of the hinge line may place it in a genus of the Arcadæ; but at present I do not wish to state more than that I think it is undoubtedly a lamellibranchiate shell. With the possible exception of *Fordilla troyensis,* which possibly may be the shell of some Estheria-like crustacean, I know of no other true lamellibranchiate shell in the Cambrian system of America, as defined in 1886. (Am. Jour. Sci., 3d series, vol 32, p. 147.)

Formation and locality.—Lower Cambrian; limestone interbedded in shaly slate, on the roadside north of school-house No. 4, in the northeast part of Whitehall, Washington County, N. Y.

Nat. Mus. Cat. Invert. Foss., 17445.

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[1] Bull. Mus. Comp. Zool., Harvard College, vol. 16, 1888, p. 28.

GASTEROPODA.

HELENIA Walcott.

Helenia Walcott, 1889, U. S. Nat. Mus. Proc., vol. 12, p. 39.

Shell an elongate, narrow, flattened, curved tube; transverse section and aperture elliptical. Surface marked by transverse, concentric, imbricating lines of growth.

HELENIA BELLA Walcott.

(Pl. LXXVIII, figs. 4, 4*a*–*b*.)

Helenia bella Walcott, 1889, U. S. Nat. Mus. Proc., vol. 12, p. 39.

Shell an elongate, narrow, flattened, curved tube. The plane of the flattened surfaces is slightly twisted, so as to throw the lateral margins about one quarter of a turn around and to incline the upper and lower faces nearly 45° at one extremity as compared with the other. The curvature is nearly semicircular. The cross section is an elongated ellipse. The form of the aperture of the larger extremity, as indicated by the striæ of growth, has the peristome arching forward on one of the flattened sides and curving slightly backward on the opposite side. As far as I am able to determine, the shell was open at the smaller end, as in Dentalium, or the extremity was decollated in all the specimens collected. I am inclined to think that it was open at both ends, and hence should be referred to the Dentalidæ.

Surface marked by irregular, transverse or concentric, imbricating lines of growth that vary in number and size on the same specimen and in different specimens.

Helenia bella is provisionally referred to the Dentalidæ on account of its form and the apparent opening at both extremities.

Formation and locality.—In a pinkish colored limestone of Lower Cambrian age, in association with *Hyolithes princeps, Olenellus* (*H.*) *bröggeri,* etc., in railway cut north of Manuel's Brook, Conception Bay, Newfoundland.

Nat. Mus. Cat. Invert. Foss., 18324.

SCENELLA Billings.

SCENELLA ? CONULA Walcott.

(Pl. LXXIII, figs. 4, 4*a*.)

See Bull. U. S. Geol. Survey, No. 30, 1886; p. 127.

Nat. Mus. Cat. Invert. Foss., 15367.

SCENELLA RETICULATA Billings.

(Pl. LXXIII, figs. 9, 9*a*–*d*.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 125.

This species was found in great abundance in association with *Olenellus* (*H.*) *bröggeri,* near Manuel's Brook, Conception Bay, Newfoundland. It varies very much in form and size of the aperture, owing probably to accidents of growth. It has also been found near North Attleborough, Mass., by Prof. N. S. Shaler.[1]

Nat. Mus. Cat. Invert. Foss., 18321.

SCENELLA RETUSA Ford.

(Pl. LXXIII, figs. 6, 6*a*.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 126.

Type in collection of S. W. Ford.

SCENELLA? VARIANS Walcott.

(Pl. LXXIII, figs. 5, 5*a*.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 127.

Nat. Mus. Cat. Invert. Foss., 15370.

SCENELLA sp.?

A depressed conical shell occurs in the form of casts in the reddish brown sandstones, east of Lansingburgh, N. Y., that differs from all described species from the Cambrian. It is most nearly related to *S. varians*, but owing to the imperfection of the material it is not thought best to give it a specific name.

STENOTHECA Salter.

STENOTHECA ? ELONGATA Walcott.

(Pl. LXXIV, figs. 9, 9*a*-*b*.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 129.

Nat. Mus. Cat. Invert. Foss., 15364.

STENOTHECA ? RUGOSA Hall.

(Pl. LXXIV, figs. 1, 1*a*-*i*.)

See Bull. U. S. Geol. Survey, No. 30, p. 128.

This species varies considerably in form and surface characters. Several of the more srongly marked varieties are given names as follows:

Var. abrupta, S. & F., Figs. 6, 6*a*.
Var. acuta-costa, n. var., Figs 2, 2*a*, *b*.
Var. erecta, n. var., Fig. 4.
Var. levis, n. var., Figs. 5, 5*a*.
Var. paupera, Billings, Figs. 3, 7.

The varieties *abrupta* and *paupera* also occur near North Attleborough, Mass.[2]

Nat. Mus. Cat. Invert. Foss., 15365, 18310, 18311, 18312, 18313.

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[1] Bull. Mus. Comp. Zool., Harvard College, vol. 16, 1883, p. 29.

[2] Bull. Mus. Comp. Zool. Harvard College, vol. 16, p. 29.

STENOTHECA CURVIROSTRA S. & F.

(Pl. LXXIV, fig. 10.)

Stenotheca curvirostra Shaler & Foerste, 1888. Bull. Mus. Comp. Zool., vol. 16, p. 30, Pl. i, Fig. 8.

"Shell small, rather elongate; the lower part gently curved, the curvature more marked, especially at the beak; the beak always considerably elevated above the aperture of the shell. The transverse ribs are narrow and sharp; from ten to eighteen are found on a single shell; the interspaces are broad and flat. The longitudinal striæ are fine and closely set. Diameter of the aperture of the shell in the largest specimen found, 4^{mm}; height of the shell, 5^{mm}.

"*Locality and position.*—Station No. 2, North Attleborough, Mass.; Cambrian; 5 specimens."

Type in collection of Prof. N. S. Shaler.

PLATYCERAS Conrad.

PLATYCERAS PRIMÆVUM Billings.

(Pl. LXXIV, figs. 11, 11*a*.)

See Bull. U. S. Geol. Survey, No. 30, p. 130.

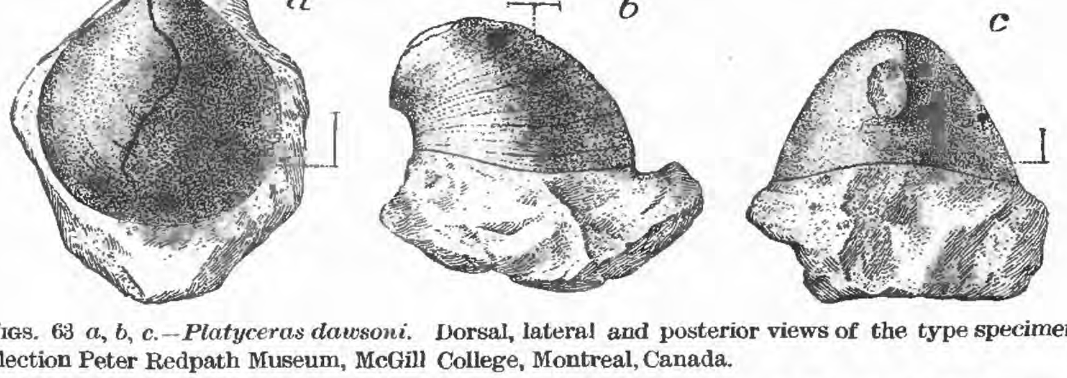
This little shell appears to have a wide geographic distribution and a great vertical range, as a form, apparently identical with it, occurs in the Upper Cambrian limestones of New York. Since Bulletin 30 was written it has been found at North Attleborough, Mass.,[1] and at Conception Bay, Newfoundland.

Nat. Mus. Cat. Invert. Foss., 15371.

PLATYCERAS DAWSONI, n. sp.

Shell small, ventricose; apex unknown. Body expanding rapidly from the base of the apex to the nearly circular aperture; peristome broadly sinuate at the posterior margin. Surface marked by a few concentric lines of growth.

This little shell is a strongly marked form. It is referred to Platyceras on account of the incurving toward the apex and the sinuosity of the posterior margin.



FIGS. 63 *a*, *b*, *c*.—*Platyceras dawsoni*. Dorsal, lateral and posterior views of the type specimen. Collection Peter Redpath Museum, McGill College, Montreal, Canada.

[1]Bull. Mus. Comp. Zool., Harvard College, Mass., vol. 16, p. 30.

Formation and locality.—Lower Cambrian; associated with Olenellus at St. Simon, province of Quebec, Canada.

STRAPAROLLINA REMOTA Billings.

(Pl. LXXIV, figs. 13, 13*a*.)

See Geol. Survey, Canada; Pal. Foss., vol. 2, pt. 1, 1874, p. 70, Fig. 38.

Prof. J. F. Whiteaves, paleontologist to the Geological Survey of Canada, informs me that the type specimen of this species can not be found. He kindly sent a fragment showing the outer whorl. On this longitudinal lines and concentric striæ are shown, in addition to the characters given the species by Mr. Billings.

PLEUROTOMARIA De France.

PLEUROTOMARIA (RAPHISTOMA) ATTLEBORENSIS S. & F.

(Pl. LXXIV, figs. 12, 12*a*.)

Pleurotomaria (*Raphistoma*) *attleborensis* Shaler & Foerste. Bull. Mus. Comp. Zool., Harvard College, vol. 16, pp. 30, 31, Pl. 2, Fig. 11.

"Shell small, flattened, composed of three whorls. The first whorl is very small; the succeeding ones increase rapidly in size. The surface in general slopes at a low angle from the apex of the shell to the sides. In the last whorl of the cast the outside margin of the coil thickens a little, forming an indistinct border along the margin of the shell, which becomes more evident as it approaches the orifice. The edge of the whorl is compressed and rather narrowly rounded. The surface of the shell is marked by fine, transverse, closely set striæ, which apparently are directed backward toward the earlier formed parts of the shell, but in reality indicate various stages of growth of the shell. The internal cast does not show these fine striæ, but broader and more widely separated elevations, having the same direction as the striæ. The diameter of the shell is 3.2^{mm}; the height is a little less than 1^{mm}. Owing to the shape of the shell it is difficult to measure its height accurately.

"*Locality and position.*—Station No. 1, North Attleborough, Mass.; Cambrian; one specimen. The discovery of another coiled gasteropod in this division of the Cambrian of America is of interest, and makes the sudden influx of coiled genera in the Upper Cambrian less inexplicable."

This is one of the most interesting forms found at the locality, discovered by Prof. N. S. Shaler, near North Attleborough, Mass. It appears to be a true representative of the Pleurotomaridæ in the Lower Cambrian.

Type in the collection of Prof. N. S. Shaler.

PTEROPODA.

HYOLITHES Eichwald.

HYOLITHES AMERICANUS Billings.

(Pl. LXXV, figs. 2, 2*a–f*.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 132.

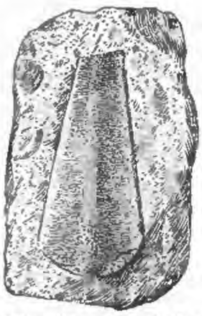


Fig. 64.—*Hyolithes americanus.* Dorsal surface. Natural size.

On the dorsal surface of some well preserved specimens from St. Simon, a central longitudinal ridge occurs that is very much like that on *H. billingsi*, from Nevada. The two species are closely related. The character of the median ridge is shown in Fig. 64.

Found also at North Attleborough, Mass., and at Manuel's Brook, Conception Bay, Newfoundland.

Nat. Mus. Cat. Invert. Foss., 15388.

HYOLITHES BILLINGSI Walcott.

(Pl. LXXV, figs. 1, 1*a–e*.)

See Bull. U. S. Geol. Survey, No. 30, 1886. p. 134.

Found also at North Attleborough, Mass.

Nat. Mus. Cat. Invert. Foss., 14903.

Among some specimens, from St. Simon, Canada, received from Sir William Dawson, there is one of this species showing three transverse septa. The septa are strong, apparently flat and imperforate.

Nat. Mus. Cat. Invert. Foss., 14884.

HYOLITHES COMMUNIS Billings.

(Pl. LXXVII, figs. 3, 3*a–g*.)

See Bull. U. S. Geol. Survey, No. 30, 1886. p. 136.

Fig. 65.—*Hyolithes communis*, Bill. Natural section of a portion of the tube in which three transverse septa are shown. Collection Peter Redpath Museum, McGill College, Montreal, Canada.

HYOLITHES COMMUNIS var. EMMONSI Ford.

(Pl. LXXVII, figs. 4, 4*a–b*.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 137.

Hyolithes inæquilateralis Foerste, 1889. Boston Soc. Nat. Hist. Proc., vol. xxiv, p. 7.

This species has been found near North Attleborough, Mass., since the publication of the list of localities in Bulletin 30.

Nat. Mus. Cat. Invert. Foss., 15386.

HYOLITHES IMPAR Ford.

(Pl. LXXVII, figs. 1, 1*a–f*.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 139.

This species also occurs in association with the Olenellus fauna at Manuel's Brook, Conception Bay, Newfoundland.

Nat. Mus. Cat. Invert. Foss., 15391.

HYOLITHES PRINCEPS Billings.

(Pl. LXXVI, figs. 1, 1*a–l*.)

Hyolithes excellens Billings, 1874. Geol. Sur., Canada; Pal. Foss., vol. 2, pt. 1, p. 70, Fig. 39.
See Bull. U. S. Geol. Survey, No. 30, 1886, p. 135.

This large, fine species was found in great abundance in the lowest portion of the Olenellus zone, on Manuel's Brook, Newfoundland. It also occurs near North Attleborough, Mass., as reported by Prof. N. S. Shaler.

Nat. Mus. Cat. Invert. Foss., 18320.

HYOLITHES QUADRICOSTATUS S & F.

(Pl. LXXVIII, figs. 1, 1*a*, *b*.)

Hyolithes quadricostatus Shaler & Foerste, 1888. Bull. Mus. Comp. Zool., vol. 16, pp. 31, 32, Pl. ii, Fig. 15.

"Shell straight, elongate, tapering gradually to an acute point; apical angle 17°. The external cast of the type specimens is 20^{mm} long; including an additional length represented by an internal cast of the same specimen, but extending farther from the apical extremity, it is 25^{mm} long. As the end of the cast is broken, a length of 30^{mm} may be presumed for the entire specimen. The supposed dorsal side is broad and flat or slightly concave along the center; when depressed, a low elevation may occur along the median line; in all cases, the surface retains a rather flat appearance. The lateral angles are rounded. The supposed ventral side is as usual flattened along the median line for about half the width of the shell. The sides of this flattened surface are more or less elevated, giving it a slightly concave appearance along the median line. Immediately beyond the flattened surface on either side is a more or less distinct groove. The result is, that, in addition to the two lateral angles, there are two angles or ridges on the ventral side, giving the entire shell the quadricostate appearance indicated by the specific name. The two ventral ridges increase in distinctness as they recede from the apical extremity, and are usually more distinct, or at least less rounded, than the lateral angles. At a distance of six or seven millimeters from the apical extremity the shell is crossed by an apparently imperforate septum. The cast of this septum from the upper side had the appearance of a flattened surface with a slightly elevated border around the margin. The surface of the shell is marked by fine transverse striæ. The longitudinal ridges are less prominent on the interior cast of the shell than on the exterior.

"Taken by itself this species would appear to be very distinct from the usual forms of Hyolithes, but in reality it forms only the extreme of a series of intermediate species, which begins with specimens characterized by numerous fine longitudinal striæ, these striæ increasing in size and diminishing in number until we have such forms as *Hyolithes hexagonus* Barrande, with only four ridges in addition to the normal two lateral angles. In the specimens here described, this number is reduced to two additional costæ. The character of the variation is quite distinct from that afforded by a more acute or salient ventral median line alone.

"*Locality and position.*—Station No. 2, North Attleborough, Mass.; Cambrian; rare."

This species of the North Attleborough Olenellus zone fauna was found in the lower part of the Olenellus zone, in Newfoundland. The figure of the type specimen, described above, shows a crushed, flattened shell, quite unlike the other specimens now before me.

Nat. Mus. Cat. Invert. Foss., 18318.

HYOLITHES SIMILIS Walcott.

(Pl. LXXV, figs. 3, 3*a*-*d*.)

Hyolithes similis Walcott, 1889. U. S. Nat. Mus. Proc., vol. 12, p. 38.

Form an elongate subtriangular pyramid, gradually and regularly tapering to an acute extremity. The apical angle of the dorsal side is about 13°. Transverse section subtriangular. The ventral angle is sharp and the lateral angles rounded. Dorsal face slightly arched longitudinally, transversely nearly flat, except at the sides, where it curves slightly to meet the two planes of the ventral face, which is strongly angular at the center. Aperture oblique; the peristome is indented at the center of the ventral side and arched over the subspatulate extension of the dorsal face. Operculum unknown. Shell comparatively thin.

Surface of the shell marked by tranverse or concentric striæ that arch forward on the dorsal face and slightly backward to the center on the ventral face. The ventral face is further marked by four raised lines on each side of the central angle, and between the raised lines by very fine longitudinal striæ.

The portion preserved of the largest specimen collected has a length of 43^{mm}. When entire it was about 50^{mm} in length, with a width at aperture of 13^{mm} and a depth of 7^{mm}.

In general form this shell is closely related to *H. americanus*. It differs in the strongly marked ventral surface.

Formation and locality same as *H. terranovicus*.

Nat. Mus. Cat. Invert. Foss., 18317.

HYOLITHES TERRANOVICUS Walcott.

(Pl. LXXVIII, figs. 3, 3*a–d*.)

Hyolithes terranovicus Walcott, 1889. U. S. Nat. Mus. Proc., vol. 12, pp. 37, 38.

Form an elongate subtriangular pyramid, gradually and regularly tapering to an acute extremity. The apical angle of the dorsal side is very nearly 15°. Transverse section subtriangular or semi-elliptical. Dorsal face slightly convex and curving gently from the extremity to the anterior subspatulate portion. Ventral face strongly and regularly convex transversely; the dorsal and ventral faces meet to form the rounded lateral angles of the shell. Aperture oblique, the margin extending on the dorsal side; the peristome of the ventral side is slightly curved backward. Operculum unknown. Shell thick and strong.

Surface of the shell transversely or concentrically striated. On the dorsal surface the striæ are faintly defined, and on the ventral surface strongly marked, and also cancellated by raised lines with finer striæ between.

The largest specimen collected has a width of 16^{mm} at the aperture, and a length of about 55^{mm} is indicated, the portion preserved being 48^{mm} in length.

I do not know of any closely allied species, although the surface markings are like those of *Hyolithes nobilis* Barrande.[1]

The presence of a septum near the extremity of the shell is shown very distinctly in one specimen, where the point is broken off.

Formation and locality.—Lower Cambrian. This species was found in irregular masses of limestone resting on and among the bowlders of gneiss forming the base of the Olenellus zone on Manuel's Brook, Conception Bay, Newfoundland.

Nat. Mus. Cat. Invert. Foss., 18319.

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[1] Syst. Sil. Bohême, vol. 3, 1867, Pl. 13, Figs. 22–26.

HYOLITHELLUS Billings.

HYOLITHELLUS MICANS Billings.

(Pl. LXXIX, figs. 1, 1*a–e*.)

See Bull U. S. Geol. Survey, No. 30, 1886, p. 142.

This is a widely distributed species. It is reported from Newfoundland, eastern Massachussetts, and eastern New York, the St. Lawrence Valley, and, doubtfully, from Nevada.

Nat. Mus. Cat. Invert. Foss., 15381, 15382.

HYOLITHELLUS MICANS var. RUGOSA Walcott.

(Pl. LXXIX, fig. 2.)

Hyolithellus micans var. *rugosa* Walcott, 1887. Am. Jour. Sci., 3d series, vol. 34, p. 191, pl. i, fig. 10.

This name was proposed for a variety of *Hyolithellus micans* that has well marked concentric ridges with longitudinal striæ between them. The substance of the shell appears to be similar to that of *H. micans*. (See Bull. 30, U. S. Geol. Survey, p. 142.)

Formation and localities.—Lower Cambrian; limestones interbedded in the shaly slates on the roadside just west of Low Hampton crossing on the Poultney River; lowest fossiliferous horizon on D. W. Reid's farm and on hill back of Reid's farm-house, one and one-half miles west of North Greenwich; two miles south of North Granville; and in the north part of Easton, about one mile south of the village of Greenwich, Washington County, N. Y.

Nat. Mus. Cat. Invert. Foss., 17444.

COLEOLOIDES Walcott.

Coleoloides Walcott, 1889. U. S. Nat. Mus. Proc., vol. 12, p. 37.

Shell slender, elongate, cylindrical, straight or slightly curved, apparently thin.

Surface marked by very fine, slightly oblique or spiral longitudinal striæ, in the only species known.

In form this shell is like that of *Hyolithellus micans*, but the surface markings are unlike those of either *Hyolithellus* Billings or *Coleolus* Hall.

COLEOLOIDES TYPICALIS Walcott.

(Pl. LXXIX, figs. 6, 6*a*.)

Coleoloides typicalis Walcott, 1889. U. S. Nat. Mus. Proc., vol. 12, p. 37.

Straight, elongate, cylindrical shells, that taper so gradually that the diminution in size is apparent only in long pieces of the tube, and then only by the closest examination. Shell apparently very thin.

Surface marked by very fine, slightly oblique, longitudinal striæ, that are a little irregular in their course, as shown by a strong magnifier. The striæ make one revolution around the tube in a length of sixteen diameters of the tube.

The longest specimen found has a length of 23^{mm} and is about one-half a millimeter in diameter. It is broken off at each extremity.

I do not know of any related species.

Formation and Locality.—Same as *Hyolithes terranovicus.*

Nat. Mus. Cat. Invert. Foss., 18326.

SALTERELLA Billings.

SALTERELLA PULCHELLA Billings.

(Pl. LXXIX, figs. 5, 5*a-e*.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 144.

Nat. Mus. Cat. Invert. Foss., 15375.

SALTERELLA RUGOSA Billings.

(Pl. LXXIX, fig. 4.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 145.

Nat. Mus. Cat. Invert. Foss., 14901.

SALTERELLA CURVATUS S. & F.

(Pl. LXXIX, figs. 3, 3*a*.)

See Bull. Comp. Zool., Harvard College, vol. 16, 1888, p. 34.

Type in collection of N. S. Shaler.

CRUSTACEA.

ISOXYS, n. gen.

Carapace large; dorsal margin slightly curved; dorsal angles produced into sharp points; anterior and posterior ends alate, subequal in outline, and merging into the rounded ventral margin without forming an angle; marginal rim narrow; valves equal; surface apparently smooth.

Type *Isoxys chilhoweana*, n. sp. This species varies so decidedly from the usual type of Leperditia and allied genera that there is little comparison to be drawn between them. The most nearly related form known to me is *Leperditia ? argenta*[1] of the Middle Cambrian zone of Utah. The latter has the characteristic outline of Leperditia, but that of Isoxys is more like that of a brachiopod shell of the genus Leptæna.

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[1] Bull. U. S. Geological Survey, No. 30, 1886, p. 146, pl. 8, fig. 5.

ISOXYS CHILHOWEANA, n. sp.

(Pl. LXXX, figs. 10, 10*a*.)

The generic description includes the principal characters of the species. The specimens are nearly all flattened in the rock and indicate by the wrinkles that the shell was thin and readily compressed. The narrow furrow within the wire-like ventral rim retains its form, and one specimen shows the two valves with a slight convexity in each.

Dimensions.—The largest specimen has a length, at the dorsal margin, of 40^{mm}, with a depth of 15^{mm}.

The associated species are Hyolithes, like *H. americanus*, *Olenellus sp.* and numerous finely preserved annelid trails. The subjacent sandstones are full of slender Scolithus borings.

Formation and localities.—Lower Cambrian; in shale resting on Chilhowee quartzite, Little River Gap, and near Montvale Springs, Chilhowee Mountain, Tennessee.

Nat. Mus. Cat. Invert. Foss., 18444.

LEPERDITIA Roualt.

LEPERDITIA (I) DERMATOIDES Walcott.

(Pl. LXXX, figs. 1, 1*a*.)

Leperditia (I) dermatoides Walcott, 1887. Am. Jour. Sci., 3d series, vol. 34, pp. 192, 193, Pl. i, Figs. 13, 13*a*.

Outline of the valves elongate, suboval, with the extremities of the hinge line rounded, subangular; moderately convex, sloping more rapidly to the ventral than the dorsal margin; in many specimens, however, it is difficult to determine the ventral from the dorsal margin, owing to their almost equal curvature and similar rounding of the ends; the hinge line is arched and but slightly marked. It is difficult to determine the anterior and posterior ends of the valves in many of the specimens, but in others the narrower end is considered as the anterior, and a small, round depression on the inner side of the valve places the muscular scar well toward the posterior end. The scar is barely visible on the outer surface.

The test is finely punctate, and so thin that it wrinkled in some instances like a membrane or skin.

Length of undistorted specimen, 6^{mm}; greatest height, 3.5^{mm}.

The strongly punctate surface is so unlike that of all the species referred to Leperditia that it may be that this species should be referred to a distinct genus.

In its punctate surface and general form it is unlike any other species known to me.

Formation and localities.—Lower Cambrian; limestones interbedded in the shaly slate, north part of Easton, about one mile south of the village of Greenwich; on the west side of D. W. Reid's farm and on the summit of the hill northwest of his farm-house, about one and one-half miles west of North Greenwich; about three miles northeast and one-half mile east of North Greenwich; near Rock Hill school-house (No. 8), east of North Greenwich; and one mile south-southeast of Battenville, in the town of Jackson, Washington County, N. Y.

Nat. Mus. Cat. Invert. Foss., 17448.

ARISTOZOE Barrande.

ARISTOZOE ROTUNDATA Walcott.

(Pl. LXXX, fig. 3.)

Aristozoe rotundata Walcott, 1887. Am. Jour. Sci., 3d series, vol. 34, pp. 193, 194, Pl. i, Fig. 9.

General outline of the valves subrotund, with the exception of the nearly straight hinge line; anterior end slightly narrower than the posterior; general surface rather strongly convex, marked all around, except along the hinge line, by a strong marginal groove within a rounded marginal rim; a single elongate protuberance extends from the main body of the shell upward, just within the anterior marginal groove and the hinge line, where it is most prominent, and separated from the main body of the valve by a broad sulcus extending from the hinge line down on the valve over two-fifths the distance to the ventral margin.

The shell is thin and apparently very finely granulose.

A comparison with the types of the genus Aristozoe shows this species to be congeneric with them and specifically distinct from any described species of the genus. *Aristozoe bisulcata*[1] has a similar outline, but the tubercle is unlike that of *A. rotundata*, and it is differently situated on the valves. It is distinguished from *A. troyensis* by its form and also the elongate tubercle or ridge.

The discovery of this species and the generic identification of *A. troyensis* adds another Silurian genus to the Cambrian fauna, and extends its range from the true Silurian down to the Middle Cambrian. As yet I do not know of the presence of the genus in the Lower Silurian (Ordovician) rocks.

Formation and locality.—Lower Cambrian; limestones interbedded in the shaly slates on M. C. Tefft's farm, about two miles southeast of North Greenwich, Washington County, N. Y.

Nat. Mus. Cat. Invert. Foss., 17446.

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[1] Barrande, Syst. Sil. Bohême., vol. i, 1872, Supplement, p. 477.

ARISTOZOE TROYENSIS Ford (sp.)

(Pl. LXXX, figs. 2, 2*a*.)

Leperditia troyensis Ford, 1873. Am. Jour. Sci., 3d series, vol. 6, p. 138; Walcott, 1886, Bull. 30, U. S. Geol. Survey, p. 146.

Aristozoe troyensis Walcott, 1887. Am. Jour. Sci., 3d series, vol. 34, p. 193, Pl. i, fig. 8.

The discovery of another specimen of this species enables me to refer it to the genus Aristozoe of Barrande. The thin test, grooved and reflected ventral margin, anterior tubercle and general form, all serve to connect it with that genus. In Bull. 30, U. S. Geol. Survey, a figure is given of the right valve, and I am now able to figure the left valve. The tubercle on the anterior end is elevated and directed forward.

A third species of Aristozoe occurs in the upper portion of the Olenellus zone, in Washington County, N. Y. Owing to the imperfection of the specimens it is not practicable to give a specific description.

Formation and localities.—Lower Cambrian; limestones interbedded in the shaly slates, on the ridge east of the city of Troy, N. Y.; also at the lowest fossiliferous horizon, on the west side of D. W. Reid's farm, about one-half mile west of North Greenwich, Washington County, N. Y.

Nat. Mus. Cat. Invert. Foss., 17447.

NOTHOZOE Barrande.

NOTHOZOE ? VERMONTANA Whitfield.

(Pl. LXXX, figs. 4, 4*a*, *b*.)

See Bull. Am. Mus. Nat. Hist., vol. 1, 1884, p. 144, Pl. 14, Figs. 14, 15.

The specimens described and illustrated by Mr. Whitfield are more or less distorted by compression. A number of specimens were found in a bowlder on Sunset Hill, near Lake Dunmore, that appear to have retained their original outline and convexity. There is considerable variation in outline, as shown by the specimens figured on Plate LXXX. In many instances we appear to have an undoubted lamellibranchiate shell before us, but in other cases the resemblance to Nothozoe or some related bivalve crustacean is so marked that the weight of evidence favors the provisional reference to Nothozoe.

I found this species in situ in the quartzite east of Bennington, Vt. The associated fossils are *Olenellus* sp.? and *Hyolithes impar*.[1]

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[1] Identified from more imperfect material as *Hyolithes communis* (Am. Jour. Sci., 3d series, vol. 35, 1888, p. 234), and by Mr. Whitfield as *H. gibbosus*, of the Potsdam sandstone. Bull. Am. Mus. Nat. Hist., vol. 1, 1884, p. 144.

PROTOCARIS Walcott.

PROTOCARIS MARSHI Walcott.

(Pl. LXXXI, fig. 6.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 148

Nat. Mus. Cat. Invert. Foss., 15400.

TRILOBITA

AGNOSTUS Brongniart.

AGNOSTUS NOBILIS Ford.

(Pl. LXXX, fig. 8.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 150.

The generic reference of this species is doubtful, as it may be a Microdiscus.

Type reported lost by S. W. Ford.

AGNOSTUS DESIDERATUS Walcott.

(Pl. LXXX, fig. 5.)

Agnostus desideratus Walcott, 1889. U. S. Nat. Mus. Proc., vol. 12, pp. 39, 40.

Cephalic shield about as broad as long, broadly rounded in front, sides curving in very slightly towards the posterior margin; posterior margin sloping obliquely inward from the postero-lateral angles to the median lobe. A narrow raised rim extends all around the margins except across the base of the glabellar or median lobe. The space between the rim and the glabella is slightly convex. Glabella less than two-thirds the length of the head, narrow, subcylindrical and with a small tubercle on the posterior third. Surface smooth. A pygidium, associated with the head on the same piece of rock, has a prominent median lobe, bordered by a narrow, convex space between it and the marginal rim. The median lobe does not show any indication of lateral or transverse furrow. An elongate median tubercle is the only ornament.

This type of Agnostus occurs in the Middle Cambrian zone of the Atlantic Basin as *A. parvifrons* Linnarsson, and *A. brevifrons* Linnarsson of Sweden, and *A. tessella* Matthew and *A. umbo* Matthew of New Brunswick.

Formation and locality.—In the upper portion of the Lower Cambrian rocks, a short distance northeast of Salem, Washington County, N. Y.

Nat. Mus. Cat. Invert. Foss., 18327.

AGNOSTUS sp.?

(Pl. LXXX, fig. 6, 6*a*.)

This species is represented by two imperfect heads of the type of *Agnostus fallax* Linnarsson, of the Middle Cambrian of Sweden, or *A. acadicus* Hartt, of New Brunswick. It is found at the same locality with *A. desideratus*, and also two miles south-southeast of Granville, Washington County, N. Y.

Nat. Mus. Cat. Invert. Foss., 18328.

MICRODISCUS (Emmons) Walcott.

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 152.

MICRODISCUS BELLIMARGINATUS S. & F.

(Pl. LXXXI, figs, 2, 2*a*, *b*.)

Microdiscus bellimarginatus Shaler & Foerste, 1888. Bull. Mus. Comp., p. 35, 36, Pl. ii, Fig. 19.

"Head semicircular, 4.3^{mm} long and 5^{mm} broad. The glabella is oblong, strongly convex, slightly narrowed in front. It is well defined by a deep, distinct groove, which continues around the sides and anterior part of the glabella; it is not connected at the front with the groove which lies along the border of the head and within the rim. The marginal groove is deep, broad in front, gradually growing narrower toward either side; it gives a high relief to the rim. The marginal rim has very nearly the same breadth throughout its length; it is beset with small tubercles, usually sixteen or eighteen in number, which lie near the interior margin of the ridge. The tubercles directly in front of the glabella are often indistinct or obsolete. The occipital furrow behind the glabella is low and not very distinct. It serves chiefly to bring into greater prominence a tubercle on the middle of the occipital ring. This tubercle is directed backward, varies in size, and is often low, and again may become a large sharp-pointed tubercle in the form of an incipient nuchal spine. The extension of the occipital furrow along the posterior part of the cheeks is very deep and marked, giving high relief to the cheeks. The posterior rim is very narrow, but sharp and distinct, and the postero-lateral extremities of the head have very small acute terminations, without which they would appear somewhat rounded. The cheeks are connected in front by a narrow, sharply rounded ridge, which lies a short distance from the glabella, along its anterior border.

"The pygidium is of an oval form, and is about 5^{mm} broad and 4.3^{mm} long. The middle lobe is strongly divided from the side lobes by grooves. It is very convex, and is also curved antero-posteriorly, giving the pygidium a strongly convex outline from front to rear as well as from side to side. It is divided into nine or ten segments; along the median line is a series of tubercles, very distinct on the anterior segments, diminishing in size near the posterior extremity. The sides show no traces of segmentation. They are connected posteriorly by a narrow ridge similar to that connecting the cheeks The rim is sharp and distinct, being well defined by a furrow which lies between it and the side lobes. The specimens are usually of the size above noted, but one almost entire pygidium found at locality No. 2 must, when perfect, have been at least 8^{mm} long.

"*Locality and position.*—Stations Nos. 2 and 3, North Attleborough, Mass.; Cambrian; thirty specimens."

This species is very closely related to *Microdiscus meeki* Ford. I found *M. bellimarginatus* associated with *Olenellus* (*H.*) *bröggeri* 300 meters north of Manuel's Brook, Conception Bay, Newfoundland.

Nat. Mus. Cat. Invert. Foss., 18329.

MICRODISCUS CONNEXUS Walcott.

(Pl. LXXX, figs. 9, 9 *a*, *b*.)

Microdiscus connexus Walcott, 1887. Am. Jour. Sci., 3d series, vol. 34, p. 194, Pl. i, Figs. 4, 4*b*.

Head semicircular, convex; bordered by a well defined rim that is crenulated across the front and narrowed posteriorly toward the glabella, where it terminates; cheeks most prominent at the posterolateral portion, from whence they slope to the deep dorsal furrow about the glabella; the glabella and its backward spinose extension form, together, a fusiform median lobe, as there is no occipital furrow or ring and the glabella and the spine are continuous. The glabella approaches the frontal margin more closely in some specimens than in others. The surface of both the head and pygidium appears smooth under a strong magnifying glass.

A glance at the head of this species recalls *Microdiscus punctatus*, *M. punctatus* var. *pulchellus*, and *M. dawsoni* of the Lower Cambrian. It has the frontal rim and form of *M. dawsoni*, but it is a smooth, not granulose species; and the associated pygidium is unlike that of *M. dawsoni*. To *M. punctatus* it is related by its general form, but differs in the more coarsely crenulated margin, the form of the cheeks and its smooth surface, also in the characters of the associated pygidium. The presence of this type of the genus Microdiscus in association with well known Lower Cambrian fossils is another link between the Middle Cambrian fauna of New Brunswick and the Lower Cambrian fauna. It is the first instance known to me of the probable occurrence of a species with the long nuchal spine below the Paradoxides horizon in America.

This species has recently been found a little northeast of Salem, Washington County, N. Y., also near Volatie Creek, in the southern part of Rensselaer County, N. Y., and in a limestone bowlder in the Sillery conglomerate on the south shore of the Island of Orleans.

Formation and localities.—Lower Cambrian; limestones interbedded in the shaly slates, on the roadside just west of Low Hampton crossing of the Poultney River; one mile west of North Hebron; and two miles south of North Granville, Washington County, N. Y.

Nat. Mus. Cat. Invert. Foss., 17449.

MICRODISCUS MEEKI Ford.

(Pl. LXXXI, fig. 3.)

See Bull. U. S. Geol. Survey, No. 30, p. 155.

Type in collection of S. W. Ford.

MICRODISCUS PARKERI Walcott.

(Pl. LXXX, figs. 7, 7*a*.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 157.

Nat. Mus. Cat, Invert. Foss., 15396.

MICRODISCUS LOBATUS Hall (sp.)

(Pl. LXXXI, figs. 4, 4*a*, *b*.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 156.

The head, represented by Fig. 1a, Pl. 16, of Bulletin 30, was referred to this species. It is probably a very young specimen of *Microdiscus speciosus*. This species also occurs near North Attleborough, Mass.[1]

Nat. Mus. Cat. Invert. Foss., 15394.

MICRODISCUS SPECIOSUS Ford.

(Pl. LXXXI, figs. 5, 5*a*–*c*.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 154.

Since Bulletin 30 was written, this species has been found in many localities in Washington County, N. Y., also near North Attleborough, Mass.

Nat. Mus. Cat. Invert. Foss., 15397.

MICRODISCUS HELENA Walcott.

(Pl. LXXXI, figs. 1, 1*a*.)

Microdiscus helena Walcott, 1889. U. S. Nat. Mus. Proc., vol. 12, p. 40.

Head convex, bordered all around by a continuous marginal rim that is narrow at the back and sides and broad in front. Three small

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[1] Bull. Mus. Comp. Zool., Harvard College, vol. 16, 1888, p. 36.

nodes occur on the anterior lateral portion of the rim, the center one being on the line of the frontal margin of the glabella. Glabella prominent, cylindro-conical, tumid posteriorly; two furrows cross the middle third so as to separate a narrow central lobe, an anterior lobe nearly twice as long as the central lobe, and a tumid posterior lobe that equals the anterior lobe in length. Dorsal furrows strong; the furrow within the margin is broad and well defined all around except at the occipital furrow crossing the glabella, where it is very narrow; it curves backward inside the very narrow rim at this point. Cheeks tumid, and overhanging the outer marginal groove.

The pygidia associated with the heads are strongly convex. The median lobe, at the center, is a little more than one-third of the entire width of the pygidium; it is crossed by five transverse furrows that divide it into five segments and a short terminal segment just inside the strongly defined marginal groove; dorsal furrows strong; marginal rim narrow; lateral lobes slightly convex, smooth.

The head of this species is related to that of *M. meeki* and *M. lobatus*. The tumid posterior lobe of the glabella serves to distinguish it from them and also all described species. The associated pygidium differs from that of *M. bella-marginatus* in being more convex and in having five instead of nine segments in the median lobe.

Formation and locality.—Lower Cambrian.; in a decomposed limestone 600 meters west of Manuel's Brook, Conception Bay, Newfoundland.

Nat. Mus. Cat. Invert. Foss., 18361.

MICRODISCUS, sp. undet.

This species is indicated by a number of pygidia that occur in the Olenellus-bearing limestone of Brigus and Topsail Heads, Conception Bay, Newfoundland. It may be that they should be referred to *M. meeki*, but at present I do not think this is warranted by the material.

OLENELLUS Hall.

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 162.

Thinking that Olenellus succeeded the genus Paradoxides in time, and accepting the interpretation given by Mr. Ford to the embryonic characters of *O.* (*M.*) *asaphoides*, I argued in favor of the descent of Olenellus from Paradoxides. It was an error, as the finding of Olenellus beneath Paradoxides abundantly proves. The discovery of more perfect specimens of *O.* (*M.*) *asaphoides* shows that what I had identified as the facial suture is a raised line in the cast of the interior of the shell that fills a depressed line occupying the position of the suture. I have since found this raised line in many specimens, but in none is there a true suture cutting through the shell, as in Paradoxides and most other genera of trilobites.

There is now brought together for the first time the means of a direct comparison of the various species that have been referred to this genus. The type of the genus, *Olenellus thompsoni*, (Pl. LXXXII, fig. 1) and the western American species, *O gilberti* (Pl. LXXXIV, fig. 1), are so manifestly congeneric that there can be no question raised as to the validity of placing them in the same genus. The form originally described as *Olenellus vermontana* (Pl. LXXXVII, fig. 1*a*) I have referred to the genus Mesonacis on account of the extraordinary extension of the the thorax, the large dorsal spine, and the difference in the character of the pygidium as compared with that of *O. thompsoni*. Brögger, Holm, and Schmidt, however, were not inclined to admit a generic distinction, and I now think it quite as well to consider it as a sub-genus of Olenellus.

On account of the difference in the pygidium and the absence of the prolonged third segment in *Olenellus* (*H.*) *kjerulfi* (Pl. XCIII, fig. 2,) Matthew has proposed the genus Holmia to include it.[1] *Olenellus* (*M.*) *mickwitzia* (Pl. XCIII, fig. 1,) differs from *O. kjerulfi* in having a large spine upon the eighth segment. In speaking of this species Prof. Jules Marcou says: "In reality this trilobite possesses generic differences and constitutes a new sub-genus, closely allied to Paradoxides, and in which may be included *Mesonacis vermontana* and *Olenoides typicalis*, the latter being an extreme degenerate form of the type. I propose to call it *Schmidtia*, in honor of Prof. F. Schmidt.[2] This suggestion of Professor Marcou's shows an entire absence of knowledge of what has been done with the several species he refers to. He disregards the fact that Mesonacis was proposed as a distinct genus from Olenellus, and that *Olenoides typicalis* is the type of the genus Zacanthoides.[3] If his correlations were correct the *Olenellus mickwitzia* would be referred either to Mesonacis or Zacanthoides. *Zacanthoides typicalis* has not even a family, much less a generic relation to it; and Mesonacis has already been used to include *O. mickwitzia* by Schmidt.

We now have proposed for this group of species the genera Olenellus, Mesonacis, Holmia, and Schmidtia. There are other forms described in this review that, according to the principles of generic determination advanced by Matthew and Marcou, should receive separate generic recognition. The *Olenellus* (*H.*) *bröggeri* (Pl. XCI) varies from described species in having a great prolongation of the occipital segment and a peculiar narrowing of the glabella. In *Olenellus* (*M.*) *asaphoides* (Pl. LXXXIX, fig. 1,) we find five extended spines upon the five posterior thoracic segments. We have here again

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[1] Trans. Roy. Soc. Canada, vol. 7, sec. 4, 1890, p. 160.

[2] American Geologist, vol. 5, 1890, p. 363.

[3] Am. Jour. Sci., 3d ser., vol. 36, 1888, p. 165.

another generic (?) character, as the spines are on different segments from those in *O. vermontana* and *O. mickwitzia*. There still remains the species *O. iddingsi* (Pl. LXXXIV, fig. 2). From the character of the side spines and the glabella this is quite as much entitled to generic recognition as some of the forms that we have been considering.

There are now nine recognized species of Olenellus, and if the grounds of generic differentiation already noted are adopted they would be referred to seven genera. To me this would be an incorrect interpretation of the characters presented by the various species. I think, however, it might be convenient to divide them into sections by subgenera in the following manner:

Olenellus: *O. thompsoni, O. gilberti, O. iddingsi ??*

Mesonacis: *O.* (*M.*) *vermontana, O.* (*M.*) *mickwitzia,* and *O.* (*M.*) *asaphoides.*

Holmia: *O.* (*H.*) *kjerulfi, O.* (*H.*) *bröggeri, O.* (*H.*) *calevi.*

Little attention has been given, since the appearance of Holm's memoir, to the fact of the absence of true facial sutures in the genus Olenellus. In the desire to correlate this genus with Paradoxides this most essential character of classification appears to have been entirely ignored. It is true that Holm has shown the presence of the suture along the doublure of *O. kjerulfi*, but in none of the species is there a facial suture such as characterizes the family Paradoxidiæ. On this account I think it would be well to separate the Olenellus entirely from the family, and as it is not advisable to use the name Olenellidiæ, on account of its similarity to Olenidiæ, I propose that the various genera and subgenera be grouped under the name Mesonacidiæ, taking the *Olenellus* (*Mesonacis*) *vermontana* as typical of the family, in connection with its associated species *O. thompsoni.*

The distinguishing characteristic of the family, when compared with the Paradoxidiæ, is the absence of facial sutures. In this respect it resembles the Trinuclidiæ in having the sutures submarginal or none, and differs decidedly from the Paradoxidiæ, which includes Paradoxides, Anopolenus, etc.

The development of the third segment into prolonged pleural lobes is a character that appears in the young of *Olenellus* (*M.*) *asaphoides*, but not in the adult. A similar character is prominent in *Paradoxides bohemica* and *P. spinosus* in the development of the second segment.

OLENELLUS THOMPSONI Hall.

(Pl. LXXXII, figs. 1, 1*a*; Pl. LXXXIII, figs. 1, 1*a*, *b*.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 167.
Nat. Mus. Cat. Invert. Foss., 15418, 15419.

OLENELLUS GILBERTI Meek.

(Pl. LXXXIV, figs. 1, *1a–g;* Pl. LXXXV, figs. 1, *1a–g;* Pl. LXXXVI, figs. 1, *1a–m*, 4.)

See Bull. U.S. Geol. Survey, No. 30, 1886, p. 170.
Nat. Mus. Cat. Invert. Foss., 15411, 15412, 15416.

OLENELLUS IDDINGSI Walcott.

(Pl. LXXXIV, fig. 2.)

Nat. Mus. Cat. Invert. Foss., 14510.

OLENELLUS WALCOTTI S. & F.

(Pl. LXXXVIII, fig. 2.)

Paradoxides walcotti Shaler & Foerste, 1888. Bull. Mus. Comp. Zool., Harvard College, vol. 16, pp. 36–37, Pl. *ii*, Fig. 12.

"A single specimen was found showing the under side of the integument which covered the head 2.8^{mm} long and 3.8^{mm} broad. The cheeks are in position, and the facial suture is barely indicated by a faint line running from the anterior extremity of the palpebral lobe forward, bending at first a little outward, then more rapidly inward near the margin, which it cuts; posterior to the palpebral lobe it almost immediately cuts the margin in a slight outward curve. The outline of the head forms a curve, which would be semicircular were it not for its disproportionate breadth. There are faint indications of a spine at the postero-lateral extremities. The glabella is broad in front, the posterior half, with incurved sides, narrowing to half its anterior width. The occipital furrow is distinct and the occipital ring has a distinct tubercle at the middle. The glabella is marked by three pairs of shallow furrows, with perhaps a fourth scarcely discernible pair. The second and third pairs are not seen to meet across the median line; but owing to the position of two very low and rather indistinct tubercles, one anterior and one posterior to the first or posterior pair of furrows along the median line, these furrows seem to meet in a curve bending slightly backward along the middle of the glabella. The palpebral lobes are large and prominent, beginning a little anterior to the third pair of furrows and curving around to within a very short distance of the extension of the occipital furrow across the cheeks. The curve along the anterior border of the head is regular. A shallow groove runs within a short distance of the anterior border, gradually becoming deeper and broader and receding more from the border on the sides of the head, so that the rim here becomes broader. A faintly discernible, shallow pit near the anterior extremity of the glabella may in this case be only accidental.

"*Paradoxides tenellus* Billings is in size like this species, but otherwise very distinct. It is interesting to find a Paradoxides in the Olenellus Cambrian, since its occurrence there diminishes the importance of the Paradoxides Cambrian as a Paradoxides division.

"*Locality and position.*—Station No. 2, North Attleborough, Mass.; Cambrian; one specimen."

This species is described under the genus Paradoxides, but, on comparing the type specimen with specimens of the head of *Olenellus asaphoides*, of similar size and condition of preservation, I can find no characters of generic difference between them. The specific characters are very close to those of *O. asaphoides*, and the specific name is only retained tentatively until more material can be collected from the original locality. The facial suture, shown on the original figure, represents the depressed line that is seen in the interior of the shell of *Olenellus gilberti*, etc. It is not a true suture.

This species is found with six species that occur in association with *Olenellus* (*M.*) *asaphoides*, in Rensselaer and Washington Counties, N. Y., viz.: *Fordilla troyensis*, *Stenotheca rugosa*, *Platyceras primævum*, *Hyolithes communis* var. *emmonsi*, *H. americanus* and *Hyolithellus micans*.

Formation and locality.—Lower Cambrian, near North Attleborough, Mass.

Subgenus MESONACIS Walcott.

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 158.

With the discovery of entire specimens of *Olenellus asaphoides*, and *O. mickwitzia*, it appears that *Mesonacis vermontana* is to be grouped with them, and all referred to Mesonacis as a subgenus, on account of the peculiar pygidium of *Olenellus thompsoni*, the type of the genus, as compared with that of *O.* (*Mesonacis*) *vermontana*, the type of the subgenus *O.* (*M.*) *vermontana*.

OLENELLUS (MESONACIS) VERMONTANA Hall.

(Pl. LXXXVII, figs. 1, 1*a*, *b*.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 158.

Nat. Mus. Cat. Invert. Foss., 15399.

OLENELLUS (MESONACIS) ASAPHOIDES Emmons (sp.)

(Pl. LXXXVI, figs. 3, 3*a*-*b*; Pl. LXXXVIII, figs. 1, 1*a*–*g*; Pl. LXXXIX, figs. 1, 1*a*; Pl. XC, figs. 1, 1*a*.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 168.

The discovery of entire specimens of this species shows that it has 18 segments in the thorax, and a small transverse pygidium of the

Parodoxides type. On each of the five short posterior segments of the thorax there is a long, slender spine that projects back over the pygidium. The entire specimens were found at the original locality of the species, near the old Reynolds Inn buildings, one mile west of North Greenwich, Washington County, N. Y. Bald Mountain is given as the type locality by Emmons, but Dr. Fitch found the specimens used by Emmons a mile to the north, near Reynolds's Inn.

Nat. Mus. Cat. Invert. Foss., 18350.

OLENELLUS (HOLMIA) BRÖGGERI Walcott.

(Pl. XCI, fig. 1; Pl. XCII, figs. 1, 1*a-h*.)

Olenellus bröggeri Walcott, 1888. Name proposed at exhibition of specimens at the International Geological Congress, London. Name used in "Nature," vol. 38, p. 551, 1888.

General form ovate, the length and breadth nearly as 3 to 2, in comparing the length of the entire body with the width of the head. Head broad, semicircular in outline and moderately convex, when preserved in limestone, but very much compressed in the shales. Margin rather broad, but varying in width one-half in different individuals; it is slightly rounded and separated from the frontal limb and cheeks by a shallow groove and narrow, low ridge; posteriorly, it terminates in a comparatively short, strong spine. The posterior margin of the head, between the glabella and postero-lateral spine, is broken just within the latter by a deep notch and a short spine that corresponds to the "interocular" spine (Ford) of *Olenellus* (*M.*) *asaphoides* and the spine at the pleural angles of the posterior margin of *O.* (*H.*) *kjerulfi*; a low ridge extends from back of the eye, next to the glabella, out to the spine, much as in *O.* (*H.*) *kjerulfi*; the spine varies in size and direction from the young individual, where it is directed backward (Pl. XCII, fig. 1*h*), to the large adult, in which it extends obliquely outward (Fig. 1*b*). The under side of the margin forms a broad "doublure," as shown in Fig. 1*e*. It is slightly arched downward, and narrows towards the postero-lateral angles of the head. A slight curved indentation occurs at the point of attachment of the hypostoma. It is a very common occurrence to find the "doublure" on the reflected under margin lying free from the other parts of the head (on the shale) and with the hypostoma attached. This fact leads to the conclusion that a suture passes around near the frontal margin, in the same manner as Holm describes it in *O.* (*H.*) *kjerulfi*.[1]

Glabella clavate, narrow at the base, reaching its greatest width just back of the anterior termination of the eye-lobes; it narrows rapidly towards the rather sharply rounded frontal margin. Three pairs of glabellar furrows occur as shallow depressions, the anterior one being opposite the point where the eye-lobe merges into the

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[1] Aftryck. vr. Geol. Fören. i Stockholm. Förhandl., Bd. ix, Haft 7, p. 116' 887.

frontal lobe of the glabella; the furrows on the opposite sides extend in towards the center, but do not unite. Occipital furrow shallow and extending back from each side towards the center. Occipital ring narrow at the sides and increasing rapidly in width to the center, where it supports a long, strong spine that curves back over the thorax. None of the specimens show the entire spine, but I think it extends back fully one-half the length of the thorax. Eye-lobes crescentiform, narrow, elongate, arching from the base of the anterior lobe of the glabella, into which they merge, back to a line with the occipital furrow and some distance from the glabella; visual surface unknown. The area between the glabella and eye-lobe is slightly depressed, a narrow, shallow furrow extending along the inner edge to the eye-lobe. The frontal limb and cheeks slope gently to the ridge within the outer margin. No traces of facial sutures observed, although in some of the casts of the inner side of the shell a depressed line in the shell is indicated by a raised line on the cast. This line follows the direction I should theoretically give to the suture. Hypostoma moderately convex, broad in front and narrowing towards the posterior margin.[1] One specimen is 18^{mm} across the greatest width and 12^{mm} across the posterior end. The anterior margin shows a rounded smooth edge that fits into the slight curved recess of the "doublure" of the head except laterally, where it extends out to meet the side margin of the anterior wings to form a blunt point; back of the anterior wings, the margin is raised to form an elevated rim and then curves under; the rim extends around to and across the posterior margin, becoming most prominent at the postero-lateral angles; the marginal rim is separated from the body by a sulcus that disappears on the anterior wings; the posterior groove, in front of the marginal sulcus, is well defined and arches backward from side to side, and, although very shallow at the center, it leaves a prominent ridge on each side between it and the posterior marginal sulcus; the anterior grooves are short and present scarcely more than pits just back of the main body of the hypostoma. This hypostoma differs from that of *O.* (*H.*) *kjerulfi* and *O.* (*M.*) *asaphoides* in being narrower anteriorly, more elongate, and with a smooth instead of a spinose posterior margin.

Thorax with 18 segments.[2] Axial lobe convex; the center of each segment bears a short, strong, curved spine, the base of which reaches longitudinally across the segment. Pleural lobes flattened about

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[1] The front margin is the point of attachment to the head, and the posterior margin that next to the mouth of the animal and facing the posterior margin of the head.

[2] A note, made in the field, records eighteen segments in the only entire specimen found. Owing to the fragile, decomposed rock the pygidium and five segments of this specimen were ground to a fine powder in transporting the large slab containing it over the rough roads to St. John.

three-fifths the distance from the axial lobe to the outer edge and then gently curving to the ends of the remaining falcate portion of the pleuræ. The narrow, median pleural grooves extend outward to the beginning of the curvature of the broad, falcate extremity of the pleura.

Pygidium small, transverse, almost quadrangular in outline. None of the examples show the details of structure with sufficient clearness to describe them.

The surface of the head and thoracic segments is ornamented with the peculiar, inosculating, fine, raised fretwork that, as far as known, is confined to the genus Olenellus.

Dimensions.—*O.* (*H.*) *bröggeri* and *O. thompsoni* are the two largest species of the genus yet described. Fragments of *O.* (*H.*) *bröggeri* now before me indicate a length of 24^{cm}. One head has a length of 8^{cm}. A bed of greenish argillaceous shale, six inches in thickness, is almost entirely formed of fragments of large specimens.

The associated fauna includes some well known Lower Cambrian species and others not heretofore described. As known now it embraces 14 genera, 23 species, and 6 varieties.

Formation and localities.—Lower Cambrian; the best specimens were secured in a reddish brown argillaceous shale in a railroad cut, about one mile west of Manuel's Brook bridge, on Conception Bay, Newfoundland. It was also found in the limestone beneath Topsail Head and on Brigus Head, on the same bay; at the base of the Manuel's Brook section, where it ranges through eighty feet of strata, and in the decomposed limestone, four hundred yards west of the brook, in a railroad cut. Stratigraphically its position is three hundred feet beneath the Paradoxides zone, in the Manuel's Brook section.

Nat. Mus. Cat. Invert. Foss., 18331.

Comparison.—The great occipital spine, small "pleural" spine of the head, broad falcate extension of the pleuræ, and short transverse pygidium distinguish *O.* (*H.*) *bröggeri* from *O.* (*H.*) *kjerulfi* and *O.* (*M.*) *mickwitzia* of Europe. With the exception of the form of the pleuræ, the same characters separate it from *O.* (*M.*) *asaphoides, O. thompsoni, O.* (*M.*) *vermontana* and *O. gilberti.* The head of *O. ? iddingsi* is quite distinct.

The species of Olenellus found in Shropshire, England, and named *O. callavei*, by Prof. Charles Lapworth, is very closely allied to, if not identical with, *O.* (*H.*) *bröggeri.* In notes on this species received from Professor Lapworth, he says:

> It is most intimately allied to *Olenellus kjerulfi* and *Olenellus bröggeri.*
>
> From *O. kjerulfi* it is distinguished by—
>
> (1) Its size, being four or five times as large.
>
> (2) The contraction of glabella towards the front.
>
> (3) The more rounded and broader form of the free portions of the pleuræ.

(4) The excessive development of the meso-occipital spine.
(5) The relative position of the latero-occipital processes.
To *Olenellus bröggeri* it is far more closely allied; differing only in—
(1) The smaller size and more backward position of the eyes.
(2) The shorter meso-occipital spine.
(3) The stronger latero-occipital processes.
(4) The much longer and broader spines.

The three forms, *O. kjerulfi*, *O. bröggeri*, and *O. callavei* form a special group, lying between Olenoides and Mesonacis, wanting the meso-dorsal spine of both and having instead a strongly developed meso-occipital spine. They might form a new subgenus which could be called *Cephalacanthus*.

The letter containing the preceding was received in June, 1890, but the subgeneric name will have to give way to *Holmia*, suggested by Matthew and published in June, 1890.

OLENOIDES Meek.

See Am. Jour. Sci., 3d series, vol. 36, 1888, p. 165.

OLENOIDES FORDI Walcott.

(Pl. XCIV, figs. 3, 3*a*–*c*.)

Olenoides fordi Walcott, 1887. Am. Jour. Sci., 3d series, vol. 34, pp. 195–196, Pl. i, figs. 5, 5*b*.

Head rather strongly convex, frontal margin rounded, moderately elevated, and separated from the glabella by a groove of medium width and depth. Glabella prominent, subquadrilateral, narrowing very slightly towards the broadly rounded front; three pairs of short obscure furrows occur well down toward the dorsal furrow surrounding the glabella; occipital ring well defined and bearing a spine that projects upward and backward. Fixed cheeks about one-half the width of the glabella and curving slightly downward from the glabella to the palpebral lobe; ocular ridge strong and extending to and connecting with the rim of the palpebral lobe; eye situated midway of the facial suture and rather prominent in size and position; postero-lateral limbs short, broad, and deeply grooved by the furrow within the posterior margin; at a point midway of the latter a broad angle is formed and a rudimentary spine indicated.

The direction of the facial suture is well shown in the figure of the head on the plate. A free cheek, associated in the same hand specimen of rock, shows a low visual surface for the eye, a marginal rim similar to that between the facial sutures, and a short spine at the postero-lateral angle.

The associated pygidium is moderately convex and bears a narrow, convex, median lobe, divided into five transverse segments and a short terminal segment; the lateral lobes are marked by four coalesced segments, indicating the continuation of the anterior segments of the median lobe; although broken by a smooth border, the segments may be traced into the four anterior of the six spines of the outer margin. Surface granulose under a strong magnifier.

A comparison with *Olenoides quadriceps* and *O. wasatchensis* (Bull. 30, U. S. Geol. Survey) shows a marked resemblance in the pygidia, but in the head certain differences occur, such as the narrower glabella and the wider furrow between the glabella and frontal rim of *O. fordi.*

The species referred to this genus from the American Cambrian strata are: *O. nevadensis* (the type), *O. marcoui, O. quadriceps, O. wasatchensis,* and *O. fordi.* In Bulletin 30, U. S. Geol. Survey, I referred *O. typicalis, O. ? flagricaudus, O. levis,* and *O. spinosus* to Olenoides, but they have since been included in the genus Zacanthoides.[1]

O. fordi is associated with *Olenellus asaphoides, Microdiscus connexus, Linnarssonia granvillensis,* etc.

The specific name is given in honor of Mr. S. W. Ford, who has done such excellent work at this horizon about Troy and Schodack Landing, N. Y.

Formation and localities.—Lower Cambrian; limestones interbedded in shaly slates, on the roadside just west of the Low Hampton crossing of the Poultney River, 2 miles south of North Granville and 1 mile north of Middle Granville, Washington County, N. Y.

Nat. Mus. Cat. Invert. Foss., 17450.

OLENOIDES MARCOUI Whitfield.

(Pl. XCIV, figs. 2, 2*a*, *b*.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 186.

Nat. Mus. Cat. Invert. Foss., 15446.

OLENOIDES ELLSI, n. sp.

This species is represented by the head within the facial sutures, the separate free cheeks, a thoracic segment, the pygidium and the hypostoma. The head is semicircular in outline, rather strongly convex, and with the postero-lateral angles prolonged into sharp narrow spines; marginal rim narrow in front, wider at the sides, rounded and separated from the head by a narrow rounded groove; a strong furrow separates the narrow posterior rim from the body of the fixed cheek. Glabella elongate, sides subparallel and diverging slightly towards the broadly rounded front; surface convex and marked by three pairs of slightly defined glabellar furrows that do not unite at the center; in the smaller heads the posterior furrows are strongly marked and the two anterior pairs are scarcely perceptible, while in the adult the posterior pair are much like the two anterior pairs, except that they extend more obliquely backward;

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[1] Am. Jour. Sci., 3d ser., vol. 36, 1888, p. 165.

a shallow, rounded pit occurs on the margin of the glabella and in the dorsal suture near the front angle that corresponds to a fourth pair of furrows; occipital ring strong and with a strong, sharp spine extending upward and backward from the center; occipital furrow well defined; dorsal furrows well defined on the sides and front of the glabella; fixed cheek of medium and nearly uniform width to where it merges into the strong postero-lateral limb; eye-lobe crescentiform, well defined from the cheek by a narrow groove that crosses the cheek to the dorsal furrow and separates off a narrow, short, ocular ridge; free cheek rather broad, moderately convex, and deeply cut to receive the base of the elongate, curved visual surface of the eye. The associated hypostoma is elongate, strongly convex, alate at the base and narrow in front; a small node occurs at the anterior third of the lateral margin, and the somewhat transverse frontal margin has a short spine at each lateral angle; a strong furrow separates the oval central portion from the margin back to the posterior third; a transverse furrow cuts across the anterior part of the body parallel to the rounded margin.

An associated thoracic segment has a rounded axial lobe with a base for a spine at the posterior center; the pleural lobe is bent backward half-way out from its base to the extremity; extremity not preserved; pleural groove broad and extending nearly to the end of the segment; anterior margin with a narrow facet that extends from the geniculation to the extremity.

Pygidium nearly semicircular; anterior margin broadly rounded; axial lobe narrow, convex, and divided into four rings, a frontal doublure and a terminal lobe, by five transverse furrows; lateral lobes divided by four furrows that extend obliquely backward to the broad denticulated margin; the four posterior annulations terminate before reaching the margin, while the narrow anterior one extends out as the frontal margin and passes into the anterior border spine; the flattened outer margin bears six short, rather sharp, flattened spines that extend backward on each side of the central axis; the posterior spine is the shortest and is nearly opposite the dorsal furrow, separating the axial and lateral lobes.

Surface of head, thorax, pygidium and hypostoma smooth, with the exception of some fine striæ on the rim of the head and the base of the hypostoma.

The species differs from described species in the details of the head and pygidium. The specific name is given in honor of Dr. R. W. Ells, of the geological survey of Canada, who guided me to the locality.

I found this species in a bowlder of the Sillery conglomerate. A number of heads, pygidia, and hypostomas were so associated that I think they belong to the one species. With them were two small species of Ptychoparia, a small Orthisina, like *O. transversa*, and a fragment of a species of Stenotheca. As a whole the fauna is more like that of the Lower Cambrian than that of the Middle Cambrian, and, as far as known, this belt of conglomerate has afforded only Lower Cambrian fossils.

Formation and locality.—In a bowlder of the Sillery conglomerate, four miles below Quebec, Canada, on the south shore of the St. Lawrence River.

Nat. Mus. Cat. Invert. Foss., 18450.

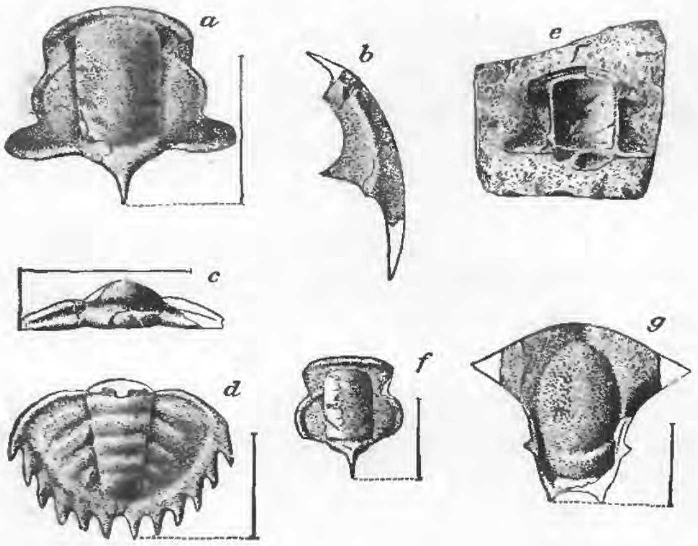

FIG. 66.—Olenoides ellsi; *a*, head within the facial sutures; *b*, interior of associated free cheek; *c*, thoracic segment; *d*, large pygidium; *e*, interior surface of a head that is longitudinally compressed; *f*, small head for comparison with FIG. *a*; *g*, enlargement of hypostoma; the outlined portions are taken from another specimen.

OLENOIDES (DORYPYGE) DESIDERATA, n. sp.

Head semicircular in outline, convex; marginal rim narrow in front, wider at the sides, and extended posteriorly into narrow, elongate, rounded spines at the union with the narrow posterior rim; within the marginal rim a narrow furrow separates the cheeks and glabella. Glabella subquadrangular, sides nearly subparallel in the larger, and slightly divergent anteriorly in the smaller specimens; surface convex and marked by three pairs of short furrows that divide the sides into four subequal lobes; occipital ring strong and provided with a short pointed spine extending upward and backward from the center; occipital furrow transverse and well defined; dorsal furrows of moderate depth at the sides of the glabella; fixed cheeks rather narrow at the eye-lobe and broader in front and back; eye-lobe about one-third the length of the head, crescentiform, and separated from the fixed cheek by a narrow groove that crosses the cheek just inside the short ocular ridge; free cheek subtriangular in outline, of medium convexity, and truncated on the inner side to support the visual surface of the eye.

Pygidium convex, semicircular, with a moderately rounded frontal margin; axial lobe prominent, convex, and divided into five rings, a frontal doublure and a terminal lobe by six transverse furrows. A sixth ring is sometimes formed by the terminal lobe being cut across by a transverse furrow. A short spine has its origin at the center of each of the five rings; lateral lobes divided by five broad furrows that extend obliquely backward towards the margin; the frontal rim and the first anterior annulation cross the border and terminate in rounded spines that curve slightly backward; the remaining annulations merge with the furrows into a broad, companulate margin that extends out back of the pygidium and rounds in nearly to the base of the axial lobe at the center. The undulation at the center, and also at the middle of the margin, varies considerably in different specimens. In some of the smaller pygidia the posterior margin closely resembles that of *Protypus senectus,* while in the larger it is more like that of *Dicellocephalus misa* of the Upper Cambrian.

Surface of glabella strongly granulose, with the granulations arranged in obscure lines parallel to the sides; surface of fixed and free cheeks and pygidium granulose.

The head of this species is much like that of *O.* (*Dorypyge*) *richthofeni* Dames[1] and it has a similarly granulated test. The associated pygidium differs from that of *O.* (*Dorypyge*) *richthofeni* in having an expanded instead of a spinous posterior margin. It may be desirable to distinguish the species with a granulose from those with a smooth test; if so, the former may be grouped under Dorypyge as a subgenus of Olenoides.

Formation and locality.—Lower Cambrian; limestone and calcareous sandstone, one and one-half miles east-southeast of Highgate Springs, Vt.

Nat. Mus. Cat. Invert. Foss., 18452.

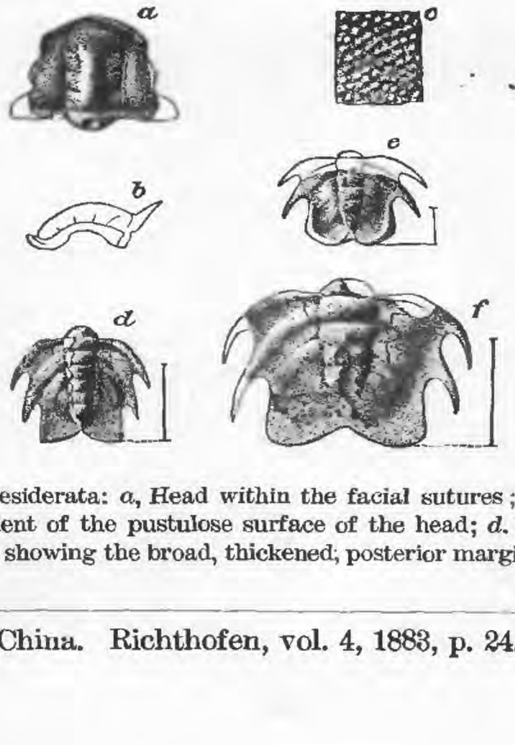

FIG. 67.—Olenoides (D.) desiderata: *a*, Head within the facial sutures; *b*, side view of head and occipital spine; *c*, enlargement of the pustulose surface of the head; *d*. pygidium, compressed laterally; *e*, a small pygidium, showing the broad, thickened, posterior margin; *f*, the largest pygidium found.

[1] China. Richthofen, vol. 4, 1883, p. 24.

OLENOIDES QUADRICEPS H. & W.

(Pl. XCIV, figs. 4, *4a–d*.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 187.

This is one of the few species that ranges from the Lower Cambrian up into the Middle Cambrian.

Nat. Mus. Cat. Invert. Foss., 15449.

ZACANTHOIDES Walcott.

See Am. Jour. Sci., 3d series, vol. 36, 1888, p. 165.

ZACANTHOIDES LEVIS Walcott.

(Pl. XCIV, figs. 5, *5a*.)

Described as *Olenoides levis*. Bull. U. S. Geol. Survey, No. 30, 1886, p. 187.
Nat. Mus. Cat. Invert. Foss., 15445.

ZACANTHOIDES EATONI Walcott.

(Pl. XCIV, fig. 6.)

Zacanthoides eatoni Walcott, 1889. U. S. Nat. Mus. Proc., vol. 12, p. 45.

This species differs from *Zacanthoides levis* in having the glabella clavate instead of subcylindrical; also in the more elongate form of the head. Pygidium unknown.

Nat. Mus. Cat. Invert. Foss., 18362.

BATHYNOTUS Hall.

BATHYNOTUS HOLOPYGA Hall.

(Pl. XCV, figs. 1, *1a*.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 191.
Nat. Mus. Cat. Invert. Foss., 15409.

AVALONIA Walcott.

AVALONIA MANUELENSIS Walcott.

(Pl. XCV, figs. 3, *3a*.)

Avalonia manuelensis Walcott, 1889. U. S. Nat. Mus. Proc., vol. 12, p. 44.

As the types of the genus and species are the same, one description only will be given.

The genus and species are founded on the central portion of the head of a trilobite, that differs from any described species known to me in the form of the dorsal and ocular furrows and fixed cheek.

Head semicircular, moderately convex. Glabella subquadrangular, slightly convex; sides parallel; three pairs of narrow, shallow furrows divide the glabella into four subequal lobes; the two posterior furrows extend about one-third the distance across the glabella, the anterior pair being very short and indistinct. Occipital ring narrow, transverse, and separated from the glabella by a strong furrow. The dorsal furrows are well defined grooves, extending from the posterior margin to the frontal rim. Fixed cheeks broad, very slightly convex; the anterior fourth is separated by a narrow furrow that starts at a slight deflection in the glabellar suture, and extends outward and backward to the facial suture, where it passes into what, in many trilobites, is the furrow on the eye-lobe. This furrow, or groove, occupies the position of the ocular ridge from the dorsal furrow to the facial suture. The extension of the furrow backward joins the furrow extending from the occipital furrow outward, just inside the posterior margin. Frontal margin of medium width and separated from the glabella by a strong furrow; posterior rim of the head narrow, rounded, and separated from the fixed cheek by a strong furrow that unites at the postero-lateral angle with the furrow on the outer edge of the fixed cheek. The eye-lobe is not distinctly shown in any of the specimens. If present, it is probably long and narrow, as in the genus Centropleura of Angelin or Anopolenus of Salter. Surface reticulated with fine, inosculating, raised lines as shown by Fig. 3*a*. If the surface is partially worn it has a punctate appearance.

Free cheeks unknown. From the form of the fixed cheeks they were evidently long and narrow. The broad fixed cheek, with its furrows on the lateral and posterior margins, recalls the cheek of Anopolenus, while the quadrangular glabella is that of the genus Olenoides. As far as known to me, the depressed ocular furrow is peculiar to the genus.

Formation and locality.—Lower Cambrian; in a railway cut about 600 meters north of Manuel's Brook, Conception Bay, Newfoundland.

Nat. Mus. Cat. Invert. Foss., 18333.

CONOCORYPHE Corda.

CONOCORYPHE TRILINEATA Emmons.

(Pl. XCV, figs. 5, 5*a*–*e*)

See Bull. No. 30, U. S. Geol. Survey, p. 203, and Am. Jour. Sci., 3d series, vol. 34, p. 197, 1887.

Since the publication of the description and figures in Bulletin 30, in 1886, and the American Journal of Science, in 1887, I have secured very perfect specimens from the original locality. These show the generic identity of the species with *Conocoryphe sulzeri* Barr, as restricted by Corda.[1]

On Plate xxvii, Bull. 30, U. S. Geol. Survey, Figs. 1*a*, 1*b*, there are figures drawn by Mr. Ford of the species as identified by him at Troy, N. Y. The pygidium is similar to that associated with *Solenopleura ? nana* at other localities, and the head may be that of this species, but it is uncertain, owing to the imperfection of the specimens.

Formation and localities.—Lower Cambrian; in black, argillaceous, shaly slate, on the roadside near the old Reynolds Inn, now D. W. Reid's farm buildings, about one mile west of North Greenwich; also in the northern part of Easton, about one mile south-southwest of the village of Greenwich, Washington County, N. Y.

Nat. Mus. Cat. Invert. Foss., 17453.

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[1] Mr. S. W. Ford states that this species has been shown to belong to the genus Conocoryphe (Am. Jour. Sci., III, vol. xix, p. 152), but up to the present time I have not seen any proof of its true generic relations, nor could it well be shown before more perfect specimens of the head were obtained than those illustrated by Emmons.

The genus Atops was proposed by Dr. Emmons, in 1844, for the head of a trilobite which "seemed to belong to an intermediate genus between Calymene and Triarthrus." The head and three segments of the body are preserved in the specimens figured, as shown in an accompanying illustration. He says of it: "No 1, I have named *Atops trilineatus*. The absence of eyes, however, is not a distinctive mark; the three species are blind. The *Atops* is evidently allied to the *Triarthrus beckii*, so abundant in the Utica slate; the lines in this, however, are direct or transverse to the middle lobe; there is an additional pair in the *Atops*." (The Taconic System, Albany, 1844, p. 20.)

When Professor James Hall studied the faunas of the Lower Paleozoic rocks of New York he had the type specimen of *Atops trilineatus* before him, as figured by Emmons, and he concluded that it was a specimen of *Triarthrus beckii* of the Utica shale. In 1848 Haldeman recognized the species as distinct from *Triarthrus beckii*. (Am. Jour. Sci., 2d series, vol. 5, p. 107.)

Before the publication of Part II of the "American Geology" by Emmons, in 1856, he discovered more perfect specimens of the species, which show without question that it is distinct from *Triarthrus beckii*. Prior to this, however, Corda had described the genus Conocoryphe, which as we now know, is identical with Atops. There does not appear to have been sufficient data for the correct generic determination of the genus Atops until 1886, when it was shown to be identical with Conocoryphe, published in 1847 by Corda. (Am. Jour. Sci., 3d series, vol. 34, 1887, p. 197.) If the genus Atops is to be recognized it replaces Conocoryphe, as the two genera are identical.

It appears to me that if a genus is so badly defined and illustrated that its generic characters were unknown and unrecognized until perfect specimens of the type species were discovered, and this nearly forty years after an identical genus had been well defined, it would be straining the law of priority to an unwarrantable extent to insist upon its recognition.

CONOCORYPHE RETICULATA, n. sp.

(Pl. XCV, figs. 6, *6a*.)

Head transversely subcircular; surface unequally trilobate, somewhat convex; marginal rim of medium width, continuous, separated from the body of the head by a marked groove all around, except in front of the glabella, where it is narrower and less strongly defined. Glabella with subparallel sides that converge slightly toward the rounded frontal margin; surface convex and broken by three pairs of narrow, well defined furrows that extend obliquely backward, subparallel to each other, to the central third of the surface; frontal lobe strongly defined, rounded but not raised above the general sursurface of the glabella; second and third lobes narrow, subparallel; posterior lobe with a narrow center, uniting the subtriangular lateral lobes. Occipital ring of medium width, with the occipital furrow uniting with the marginal sulcus back of the cheeks.

The cheeks are moderately convex, subtriangular in outline, and unbroken by facial sutures or eye-lobes; a pseudo-ocular ridge curves from a point in front of the anterior glabellar furrow, first forward and then outward and backward to where it is lost in the marginal sulcus. The surface of the cheeks is covered with a fine network of irregularly inosculating raised lines; on the marginal rim the lines are more regular and the meshes of the network are elongated; the surface of the glabella is smooth with the exception of fine raised lines on the anterior portion.

This species is clearly distinct from described forms. Its surface ornamentation is unique in the Conocephalidæ, and approaches that of *Olenellus* (*M.*) *asaphoides*, with which it is associated.

Formation and locality.—Middle portion of the Lower Cambrian; northwest side of the village of Salem, Washington County, N. Y.

PTYCHOPARIA Corda.

PTYCHOPARIA ADAMSI Billings.

(Pl. XCVI, figs. 1, 1*a*–*c*.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 195.

Nat. Mus. Cat. Invert. Foss., 15435.

PTYCHOPARIA ? ATTLEBORENSIS S. & F.

(Pl. XCV, fig. 2.)

Ptychoparia attleborensis Shaler & Foerste, 1888. Bull. Mus. Comp. Zool., Harvard College, vol. 16, p. 39, Pl. ii, Fig. 14.

"Head small, often minute; in the largest specimen 4^{mm} long. The usual size is about 2.6^{mm}. The glabella is oblong or slightly attenuate anteriorly. The occipital groove is low or indistinct. The occipital ring extends beyond the general posterior outline of the head, and apparently forms part of the glabella before it. The glabella is sometimes intersected by faint lateral grooves, of which there are three pairs, the anterior pair scarcely visible; oftener these grooves are obsolete, and the glabella may, in case the occipital groove is very slight, appear as a continuous undivided body as far as the posterior margin of the head. The glabella is always convex and considerably elevated above the general level of cheeks. There is in some specimens a very slight trace of an ocular ridge, which runs from the anterior end of the glabella laterally and slightly posteriorly, joining a similar slight trace of the palpebral lobes. The most marked feature of the fixed cheeks is the existence of a depression along their postero-lateral outline. The anterior border is proportionately very broad. About the character of the rim little can be said. Near the lateral margin of the border, or rather near the facial suture, there are sometimes two or three low tubercles visible. There is also in some specimens a faint trace of a sufficient elevation of the border to indicate an incipient marginal rim. A careful comparison of these specimens with published figures of *P. subcoronata* Hall & Whitfield, a specimen of similar size, shows numerous differences, which are too marked to permit the Attleborough specimens to be placed under the same species.

"*Locality and position.*—Station No. 2, North Attleborough, Mass.; Cambrian; 20 specimens."

This species also occurs at the lowest horizon of the Olenellus zone, on Manuel's Brook, in Newfoundland.

Nat. Mus. Cat. Invert. Foss., 18332.

PTYCHOPARIA ? FITCHI Walcott.

(Pl. XCVI, fig. 5.)

Ptychoparia fitchi Walcott, 1887. Am. Jour. Sci., 3d series, vol. 34, p. 197, Pl. i, Fig. 6.

This species is founded on a minute head that occurs in association with *Microdiscus connexus* and several other species of the lower horizon of the Lower Cambrian slate series. The elongate, unfurrowed glabella, wide fixed cheeks, and strongly granulose surface, all unite to give it a facies unknown in any other species with which I am acquainted.

Formation and locality.—Lower Cambrian; in limestone interbedded in the shaly slates, 2 miles south of North Granville, Washington County, N. Y.

Nat. Mus. Cat. Invert. Foss., 17455.

PTYCHOPARIA MISER Billings.

(Pl. XCVI, fig. 8.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 199.
Nat. Mus. Cat. Invert. Foss., 15444.

PTYCHOPARIA METISENSIS, n. sp.

Head convex, semicircular in outline. Glabella convex, truncato-conical, tapering gradually to the rounded front, a little longer than wide at the occipital furrow and marked by three pairs of slightly impressed furrows; the posterior pair extends obliquely inward a short distance and then each connects by a smooth surface on the granulated shell, with a round, shallow depression situated directly back of its termination; the two anterior pairs trend slightly backward. Occipital furrow deep, arching forward a little at the center; occipital segment strong, rounded, broadest at the center and narrowing towards the sides; dorsal furrows strongly defined. Fixed cheeks relatively narrow; anteriorly they widen and merge into the frontal limb, and posteriorly into the postero-lateral limbs. Frontal limb at the center about as long as the width of the rounded frontal limb. Postero-lateral limbs strong and marked by the broad, rounded posterior marginal furrow of the head. Palpebral lobes narrow, rather long, and confluent with the ocular ridge that crosses to the dorsal furrow near the anterior end of the glabella. The course of the facial sutures is shown in the accompanying figure of the head. The associated free cheek has a strong marginal border that is prolonged into a rather stout spine; central area moderately convex. The broad marginal border in the figure results from the position in which the cheek was viewed by the draughtsman.

Thorax unknown.

Pygidium semicircular in outline, moderately convex; axial lobe prominent, truncato-conical above and merging into the marginal rim at its base, divided into five rings by four narrow transverse furrows, the two anterior of which are well defined; the posterior ring has two small nodes upon it in some specimens; the lateral or pleural lobes are grooved by about three rather broad furrows that separate ridges, which unite with the strong, rounded marginal border.

Surface of head and pygidium finely granulose. On the central area of the free cheeks the granulations are much larger. The larger heads vary in length from 10^{mm} to 12^{mm}.

This species is allied to *P. granulosus* H. & W. of the Upper Cambrian of Nevada, but differs in character of granulation and details of head. It was found by Sir William Dawson in a limestone bowlder of the conglomerate at Metis. No other species are associated with it; but from the fact that all the species known to me from the bowlders in the conglomerates of Bic, St. Simon, and Metis belong to the Lower Cambrian fauna, this is considered as *probably* of the same age.

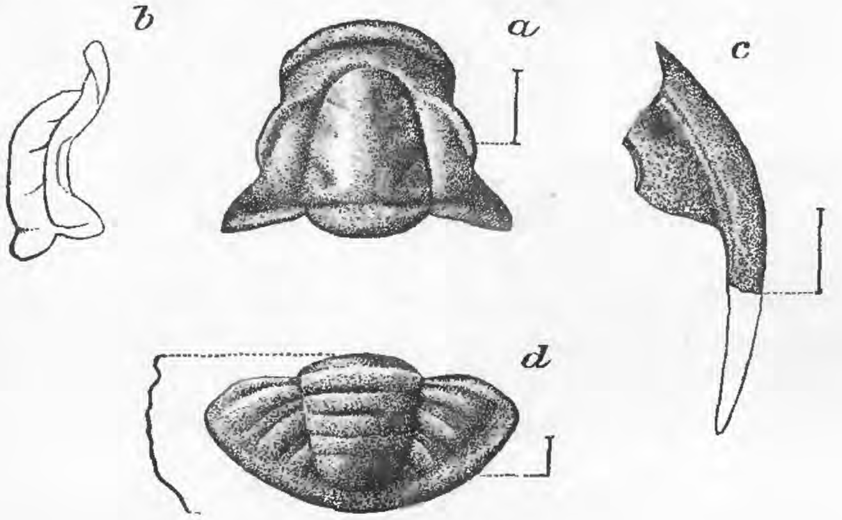

FIG. 68.—PTYCHOPARIA METISENSIS.

FIG. 68*a*. Enlargement of central portion of head.
FIG. 68*b*. Outline side view of fig. 68*a*
FIG. 68*c*. Enlargement of free cheek. The specimen is represented as it lies flat in the rock and thus the margin is too broad as compared with that of the head.
FIG. 68*d*. Enlargement of pygidium.

Collection: Peter Redpath Museum, McGill College, Montreal, Canada.

Formation and locality.—In a bowlder of limestone supposed to be of Lower Cambrian age, in conglomerate at Metis, province of Quebec, Canada.

Nat. Mus. Cat. Invert. Foss. 23838.

PTYCHOPARIA SUBCORONATA H. & W.

(Pl. XCVI, fig. 6.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 205.

Specimens that are apparently identical with the types from Utah occur in the upper part of the Olenellus zone, in Washington County, N. Y. This gives a wide geographic range to the species, but with our present material it is impossible to separate the specimens collected from the distant localities.

Nat. Mus. Cat. Invert. Foss., 15442.

PTYCHOPARIA TEUCER Billings.

(Pl. XCVI, fig. 3.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 197.

Nat. Mus. Cat. Invert. Foss., 15436.

PTYCHOPARIA VULCANUS Billings.

(Pl. XCVI, figs. 4, *4a*.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 198.
Nat. Mus. Cat. Invert. Foss., 15437.

CREPICEPHALUS Owen.

CREPICEPHALUS AUGUSTA Walcott.

(Pl. XCVI, figs. 9, *9a–b*.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 208.
Nat. Mus. Cat. Invert. Foss., 15430.

CREPICEPHALUS LILIANA Walcott.

(Pl. XCVI, figs. 7, *7a–c*.)

See Bull. U. S. Geol. Survey, No 30, 1886, p. 207.
Nat. Mus. Cat. Invert. Foss., 15428.

ORYCTOCEPHALUS PRIMUS Walcott.

(Pl. XCV, figs. 4, *4a*.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 210.
Nat. Mus. Cat. Invert. Foss., 15427.

ANOMOCARE Angelin.

ANOMOCARE ? PARVUM Walcott.

(Pl. XCVI, fig. 2.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 209.
Nat. Mus. Cat. Invert. Foss., 15426.

AGRAULOS Corda.

AGRAULOS STRENUUS Billings.

(Pl. XCVII, figs. 1, *1a–c*.)

Agraulos strenuus Billings, 1874. Geol. Survey Canada; Pal. Foss., vol. 2, part 1, pp. 71–72.

"Head (without the movable cheeks) irregularly quadrangular, broadly rounded in front. Glabella rather strongly convex, conical, variable in its proportional length and width, either smooth or with several obscure impressions on each side representing the glabella furrows; neck segment with a strong triangular projection backward; neck furrows all across, but usually obscurely impressed. In some specimens the front of the head has a thick convex marginal rim separated from the front of the glabella by a narrow groove. In others this rim is scarcely at all developed. The eyes, shown by the form of the lobe, appear to have been semi-annular and about one-third the length of the head. The surface appears to be smooth. The following are the dimensions of the best preserved specimen:

"Length of the head, including the large posterior projection, six lines; width of the convex marginal rim, one line; width of the groove between the rim and the front of the glabella, one-third of a line; length of the glabella, including the projection, five and two-thirds lines; width of the glabella at the posterior margin, three lines; width of the fixed cheek from the center of the edge of the eye-lobe to the side of the glabella, two lines. A line drawn across the head at two and a quarter lines from the front margin would pass through the anterior angles of the eyes. The length of the eye appears to be nearly two lines.

"As above remarked, this species varies somewhat in its proportional length and width, and hence the dimensions above given would not be found to be exactly parallel in all the specimens.

"Occurs in the gray limestone of Topsail Head and also in the pinkish limestone of Brigus, Conception Bay."

Ptychoparia mucronatus Shaler & Foerste[1] appears to be identical with this species when a comparison is made between the respective types from Newfoundland and Massachusetts.

Nat. Mus. Cat. Invert. Foss., 18334.

AGRAULOS STRENUUS var. NASUTUS, n. var.

(Pl. XCVII, figs. 2, 2*a*–*c*.)

This variety of *A. strenuus* has a broad, extended frontal limb, that gives a marked character to the head. It occurs in association with *A. strenuus* at the base of the Olenellus zone at Manuel's Brook, Conception Bay, Newfoundland.

Nat. Mus. Cat. Invert. Foss., 18335.

AGRAULOS REDPATHI, n. sp.

Glabella and fixed cheeks convex, rhomboidal in outline. Glabella converging slightly from the base to its broadly rounded, truncated frontal margin; length and greatest width at the occipital furrow subequal; marked by two pairs of slightly impressed furrows. Occipital furrow relatively broad and deep, arching forward at the center; occipital ring tumid, round and broad at the center, tapering so rapidly towards the sides that it does not equal the width of the glabella. Dorsal furrow distinct. Fixed cheeks broad, rising rapidly from the facial suture and graduating into the frontal limb

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[1] Bull. Mus. Comp. Zool., Harvard College, vol. 16, 1888, p. 37.

anteriorly and into the short, postero-lateral limbs at the back. Frontal limb rather broad and separated from the partially defined frontal rim by two faint grooves that do not unite at the center. Postero-lateral limbs scarcely defined from the fixed cheeks; a strong furrow crosses from their outer margin to the base of the glabella. Palpebral lobes narrow, short, and confluent anteriorly with the ocular ridges that cross the cheeks to the dorsal furrow nearly opposite the anterior end of the glabella. The facial sutures have the direction shown in the accompanying figure.

Free cheeks, thorax, and pygidium unknown.

Surface apparently smooth.

This small species is strongly distinct from other forms found associated with the Lower Cambrian fauna. The specimen figured is the interior cast of the shell. The exterior of the shell scarcely shows the glabellar furrows, ocular ridge, and the groove separating the frontal limb and margin.

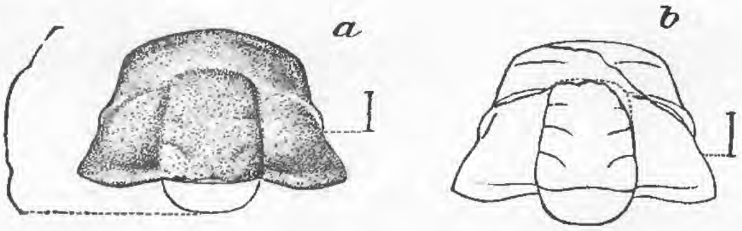


FIG. 69.—AGRAULOS REDPATHI, n. sp. *a*, Enlarged figure of the central portion of the head. Collection Peter Redpath Museum, McGill College, Montreal, Canada; *b*, outline view of a more convex specimen preserving a portion of the outer shell.

Formation and locality.—Lower Cambrian; associated with Olenellus in limestone bowlder of conglomerate at St. Simon, province of Quebec, Canada.

Nat. Mus. Cat. Invert. Foss., 23839. This is a plaster cast and matrix of the head.

PROTYPUS Walcott.

PROTYPUS HITCHCOCKI Whitfield.

(Pl. XCVIII, fig. 6.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 211.

Nat. Mus. Cat. Invert. Foss., 15424.

PROTYPUS SENECTUS Billings.

(Pl. XCVIII, figs. 7, 7*a*–*c*.)

See Bull. U. S. Geol. Survey, No. 30, 1886, p. 213.

Nat. Mus. Cat. Invert. Foss., 15421.

PROTYPUS CLAVATUS Walcott.

(Pl. XCVIII, fig. 4.)

Ptychoparia ? (subgenus?) *clavata* Walcott, 1887. Am. Jour. Sci., 3d series, vol. 34, p. 198, Pl. i, Fig. 3.

This is a minute trilobite, whose true relations are unknown. With the exception of its clavate glabella, it is related to *Solenopleura ? nana* and *S. ? tumida* by the course of the facial sutures, wide fixed cheeks, and small eye-lobes.

Formation and localities.—Lower Cambrian; limestones interbedded in the shaly slates, one and one-quarter miles south of North Granville, on the roadside a little north of school-house No. 4, in the northeast part of Whitehall; on the roadside just west of the Low Hampton crossing of the Poultney River; and near Rock Hill school-house (No. 8), about one mile east of North Greenwich, Washington County, N. Y.

Nat. Mus. Cat. Invert. Foss., 17454, 17487.

SOLENOPLEURA Angelin.

SOLENOPLEURA BOMBIFRONS Matthew.

(Pl. XCVIII, figs. 5, 5*a*, *b*.)

Solenopleura bombifrons Matthew, 1887. Trans. Roy. Soc. Canada, 1887, vol. 4, sec. 4, p. 156.

This species was founded on a small head from the limestone at Topsail Head, Conception Bay, Newfoundland. I found other specimens at the same locality, and also at Manuel's Brook, two miles north, in association with *Olenellus* (*M.*) *bröggeri*. The larger specimens vary in details from the type, but they are connected with it by forms, graduating in size down to that of the type.

Nat. Mus. Cat. Invert. Foss., 18337.

SOLENOPLEURA ? HARVEYI Walcott.

(Pl. XCVII, figs. 7, 7*a*.)

Solenopleura harveyi Walcott, 1889. U. S. Nat. Mus. Proc., vol. 12, p. 45.

Of this species only the central portions of the head have been found. These belong to a very large species, as the heads vary in length from 40^{mm} to 45^{mm}.

The glabella is conical, about twice as long as wide, and separated from the slightly rounded occipital ring by a shallow furrow. Two very shallow furrows extend obliquely backward from the dorsal furrow on each side, and scarcely indent the smooth convex surface of the glabella. An anterior pair of furrows are indicated by a short, shallow depression on a line with the anterior margin of the eye-lobe. The glabella is separated from the fixed cheeks and frontal limb by a shallow groove on the sides, and in front it is separated by the difference in slope of its surface and that of the frontal limb. Frontal limb broad and gently convex down to the slight depression separating it from the relatively broad depressed margin; laterally, it passes into the broad, smooth, free cheeks. The frontal margin of the eye-lobe is at about half way between the posterior and anterior margins of the head, and is of medium size. A well defined ocular ridge extends obliquely backward across the fixed cheek, from the glabella to the eye-lobe. The posterior margin of the head is separated from the main part of the fixed cheek by a broad, shallow groove.

With the material at hand for study, the species is referred provisionally to Solenopleura.

The specific name is given in honor of Rev. M. Harvey, the author of the best work yet published on Newfoundland and the enthusiastic helper of every scientific student who visits the colony.

Formation and locality.—Lower Cambrian; about 600 meters north of Manuel's Brook, Conception Bay, Newfoundland.

Nat. Mus. Cat. Invert. Foss., 18338.

SOLENOPLEURA? HOWLEYI Walcott.

(Pl. XCVII, figs. 8, 8*a*.)

Solenopleura howleyi Walcott, 1889. U. S. Nat. Mus. Proc., vol. 12, pp. 45, 46.

A second large species is referred to Solenopleura. It is associated with *S. harveyi*, and is much nearer the types of the genus Solenopleura than the latter species. It is known only by the central portion of the head and a few segments of the thorax.

The glabella is elongate, conical, convex, and marked by three pairs of shallow furrows that penetrate obliquely backward one-third of the distance across the glabella; occipital ring rounded and well defined from the glabella by a deep furrow; a small node occurs at the center; the glabella rises rather abruptly from the broad, slightly convex, fixed cheeks and narrow frontal limb, a shallow dorsal furrow serving to give it more prominence. The broad fixed cheeks are crossed by a narrow ocular ridge that passes obliquely outward and backward, from a point on the dorsal furrow, opposite the anterior fourth of the glabella, to the anterior margin of the eye-lobe, where it unites with the outer rim of the rather large, prominent eye-lobe. Anterior rim of the head of medium width, rounded and separated from the frontal lobe by a narrow, distinct furrow. The posterior rim or margin is more rounded than the anterior, and the furrow defining it is deeper. The short postero-lateral limb of the fixed cheek slopes abruptly down to its half truncated margin.

Surface strongly granular or pustulose.

Formation and locality.—Lower Cambrian; associated with *Solenopleura ? harveyi.*

The specific name is given in honor of Mr. James P. Howley, geologist of Newfoundland.

Nat. Mus. Cat. Invert. Foss., 18336.

SOLENOPLEURA ? NANA Ford.

(Pl. XCVIII, figs. 1, 1*a–e*, 2.)

Solenopleura nana Ford, 1878. Am. Jour. Sci., 3d series, vol. 15, p. 126; Walcott, 1886. Bull. 30, U. S. Geol. Survey, p. 214.

Solenopleura ? nana Walcott, 1887. Am. Jour. Sci., 3d series, vol. 34, p. 196; Pl. i, Figs. 1–1*d*

This species was not illustrated by Mr. Ford, and the specimens I had when preparing Bulletin 30, U. S. Geol. Survey, were so poor that the illustrations then given were not satisfactory. Among the specimens in the collections from Washington County I find considerable variation in the convexity of the glabella and also in the granulose surface; and I suspect that with a large series of more perfect specimens there could be separated a variety if not a distinct species. The pygidium associated with *S. ? nana* at Troy and also in Washington County, 2 miles south of North Hebron and 1 mile north of Middle Granville, has a spinose margin that recalls the pygidæ of certain species of Peltura from the Swedish Cambrian.

Nat. Mus. Invert. Foss., 15425.

SOLENOPLEURA ?? TUMIDA Walcott.

(Pl. XCVIII, figs. 3, 3*a*.)

Solenopleura ?? tumida Walcott, 1887. Am. Jour. Sci., 3d ser., vol. 34, p. 196, Pl. i, Figs. 2–2*a*.

This species differs from *Solenopleura ? nana*, with which it is associated at several localities, in having a more tumid glabella, narrower frontal lobe, and in the absence of an ocular spine. Some specimens of *S. ? nana* have almost as tumid a glabella, but usually it is less elevated.

The generic reference is provisional, as both *S. ? tumida* and *S. ? nana* appear to belong to a genus distinct from the typical species of Solenopleura.

Formation and localities.—Lower Cambrian. Limestones, interbedded in the shaly slates near Rock Hill school-house (No. 8), east of North Greenwich; 1½ miles east and 3 miles northeast of North Greenwich; on the west side of D. W. Reid's farm, about 1½ miles west of North Greenwich; one-half a mile east of South Hartford post-office; in the village of East Hebron; on the roadside just west of Low Hampton crossing of the Poultney River and 1 mile south of Shushan, Washington County, N. Y.

Nat. Mus. Cat. Invert. Foss., 17452.

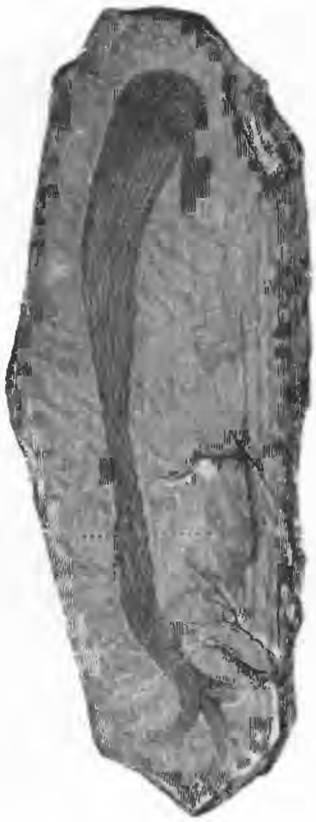
PLATES.

PLATE XLIX.

PLATE XLIX.

	Page.
LEPTOMITUS ZITTELLI	597
FIG. 1. View of the type specimen. Natural size. 1*a*. Enlargement of a portion of 1, between the dotted lines. Collection U. S. National Museum.	
PROTOSPONGIA, sp.?	597
FIG. 2. Characteristic spicula. from Washington County, N. Y.	

1



1*a*

2

SPONGIÆ.

PLATE L.

PLATE L.

Page.

SPIROCYATHUS ATLANTICUS... 600

FIG. 1. A portion of a transverse section from the type specimen 1*e*, showing the characters of the primary and supplementary layers of the wall laminæ. (After Hinde.) Enlarged ten diameters.

1*a*. Portion of a transverse section, showing the arrangement of the laminæ of the wall; for the most part irregular, but apparently radial in some places. From the type specimen. (After Hinde.) Enlarged four diameters.

1*b*. Longitudinal section of a specimen from Silver Peak, Nevada.

1*c*. Longitudinal section showing more regularity in the arrangement of the skeleton than in the type specimen, Pl. L, fig. 1*f*. Collection U.S. National Museum.

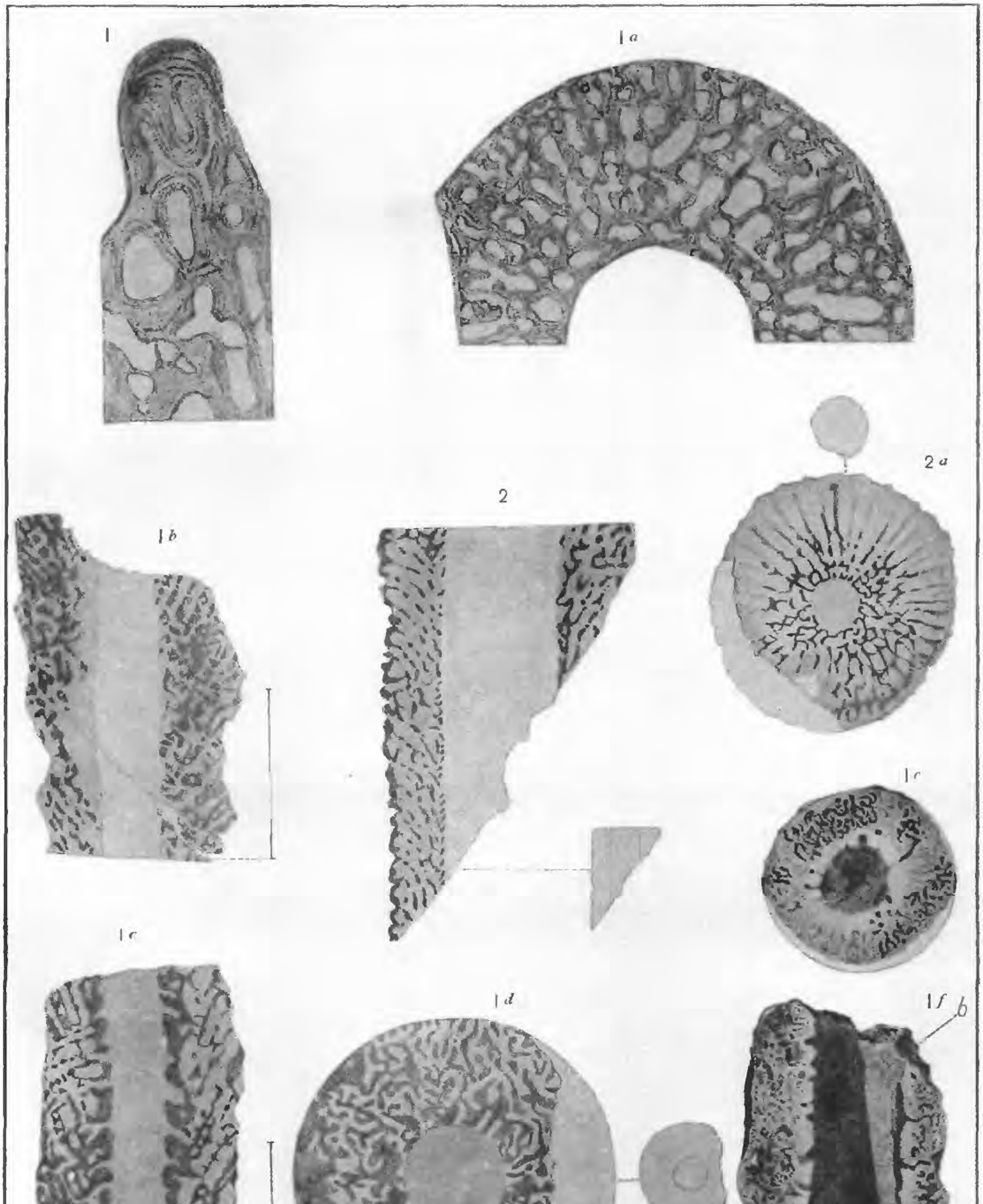
1*d*. Transverse section of specimen from L'Anse au Loup, Labrador, enlarged to show the irregular openings. Collection U.S. National Museum.

1*e*. Transverse section of the type specimen now in the museum of the Geological Survey of Canada.

1*f*. Longitudinal section of 1*e*. At *a* the growth within the cup, spoken of in the text, is shown. The elongate body, *b*, is probably a foreign body introduced into the cup.

2. Longitudinal section of specimen from Silver Peak that shows still more regularity in the interior structure than either 1*b* or 1*f*. Collection U.S. National Museum.

2*a*. Transverse section of Fig. 2.



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ACTINOZOA.

PLATE LI.

PLATE LI.

Page.

PROTOPHARETRA, sp.? 599

FIG. 1, 1*a*. Enlargement of a transverse and longitudinal section of a specimen from Silver Peak, Nevada.

COSCINOCYATHUS BILLINGSI 600

FIG. 2. Longitudinal section showing the central cavity, transverse septa, etc. The outer walls are mostly worn away. Collection U. S. National Museum.

2*a*. Transverse section of a small specimen. Collection U. S. National Museum.

2*b*. Enlargement of a few transverse septa, showing the irregular vertical septa, and the spicula-like pieces in the interseptal spaces.

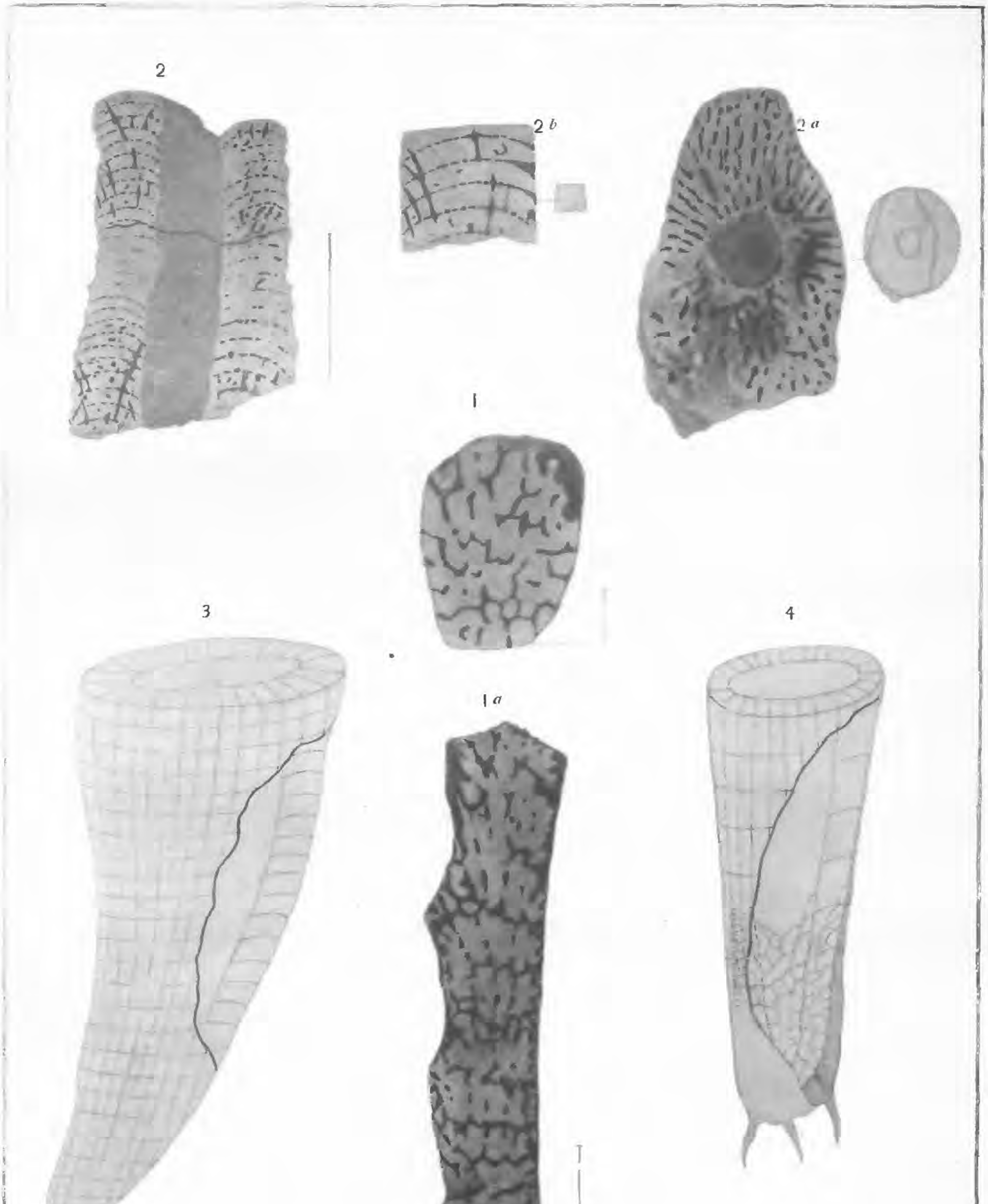
COSCINOCYATHUS CORNUCOPIÆ 666

FIG. 3. Restoration to show the form and structure of the cup. (After Bornemann.).

COSCINOCYATHUS PROTEUS 666

FIG. 4. Restoration to show mode of growth, structure, and form of cup. (After Bornemann.)

Figs 3 and 4 are introduced to illustrate the genus Coscinocyathus.



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ACTINOZOA.

PLATE LII.

PLATE LII.

	Page
ARCHÆOCYATHUS PROFUNDUS..........................	600

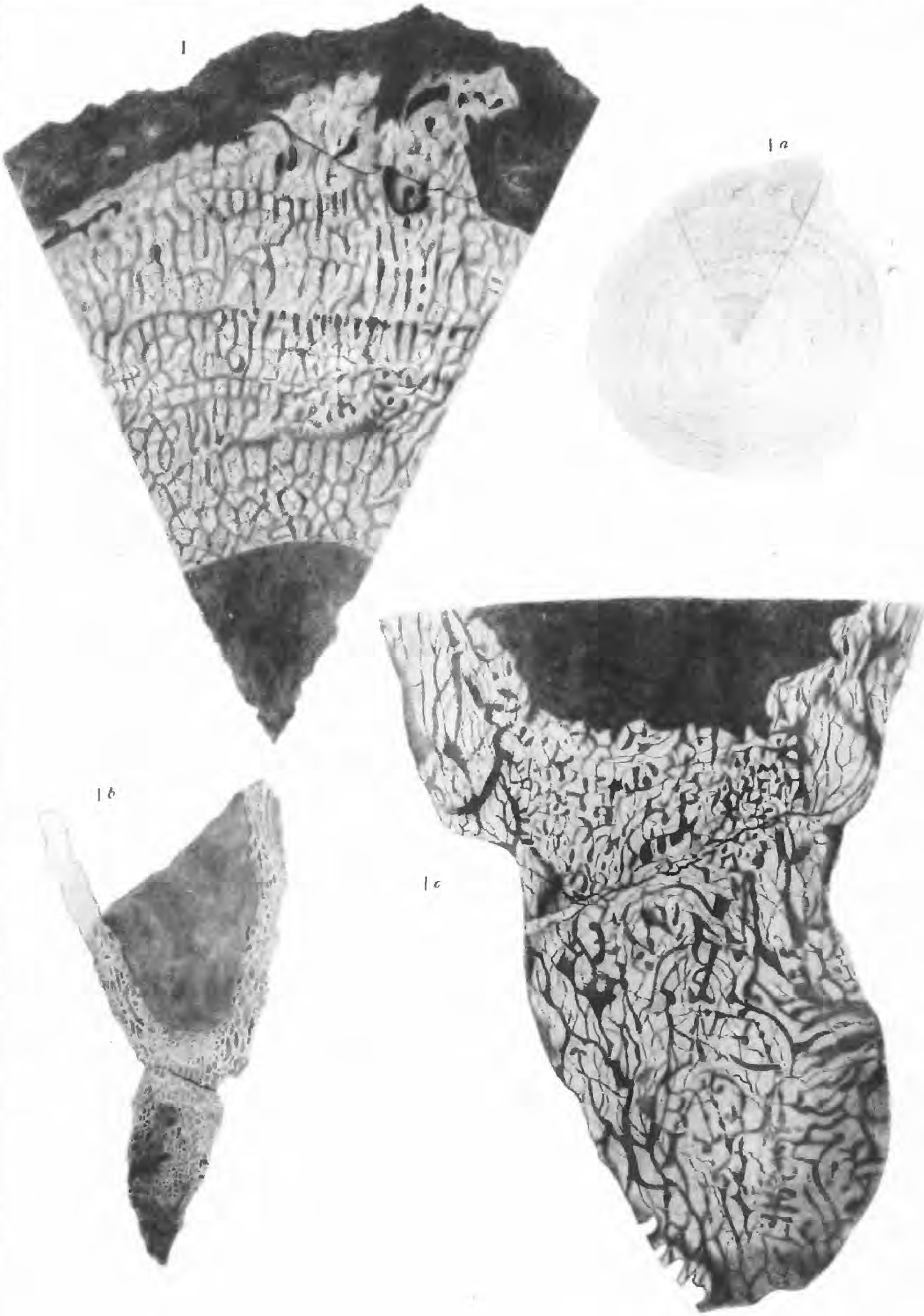
FIG. 1. Enlargement of a portion of a transverse section of specimen in which the growth appears to have been in layers. Collection U. S. National Museum.

1*a*. Outline of the section from which Fig. 1 was enlarged.

1*b*. Longitudinal section showing the depth of the cup and the vesiculose character of the space between the walls. An enlarged view of the lower portion of this figure is shown by Fig. 1*c*. Collection U. S. National Museum.

1*c*. Enlargement of a portion of the section shown by Fig. 1*b*. The vesiculose structure is well shown. Collection U. S. National Museum.

See Pls. LIII and LIV.



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ACTINOZOA.

PLATE LIII.

PLATE LIII

Page

ARCHÆOCYATHUS PROFUNDUS 600

FIG 1 Enlargement of a portion of the section represented by Fig 1 Pl LII to show the radial septa and the dissepiments

1a Portion of a longitudinal section of the wall showing in places the perforations in the septa and the dissepiments (After Hinde) Enlarged five diameters

1b View of the cup of a small specimen Collection U S National Museum

See Pls LII and LIV

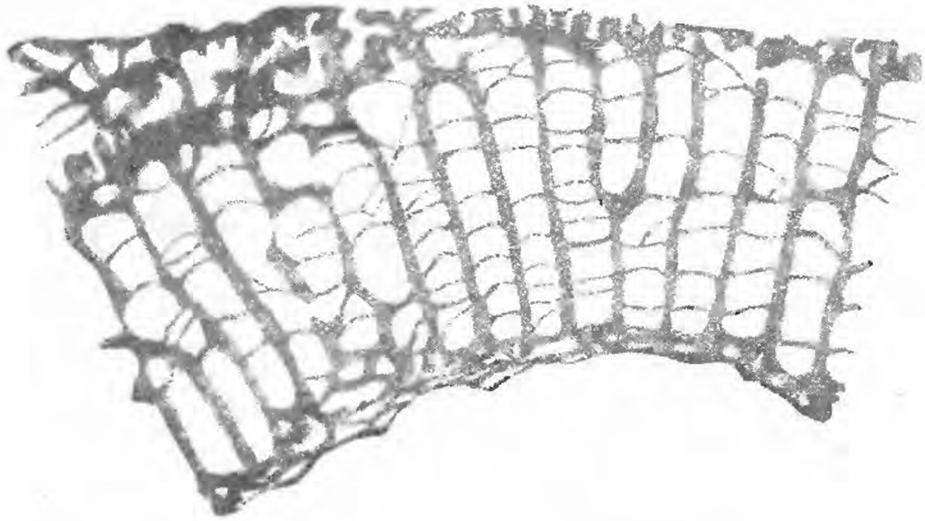
ETHMOPHYLLUM MARIANUS 601

FIG 2 Enlargement to show the septa and poriferous outer wall (After Roemer) See Pl LV figs 3 3a c

ETHMOPHYLLUM 601

FIG 3 Diagrammatic section of the inner and outer wall and the longitudinal septa The plates on the inner wall are not represented

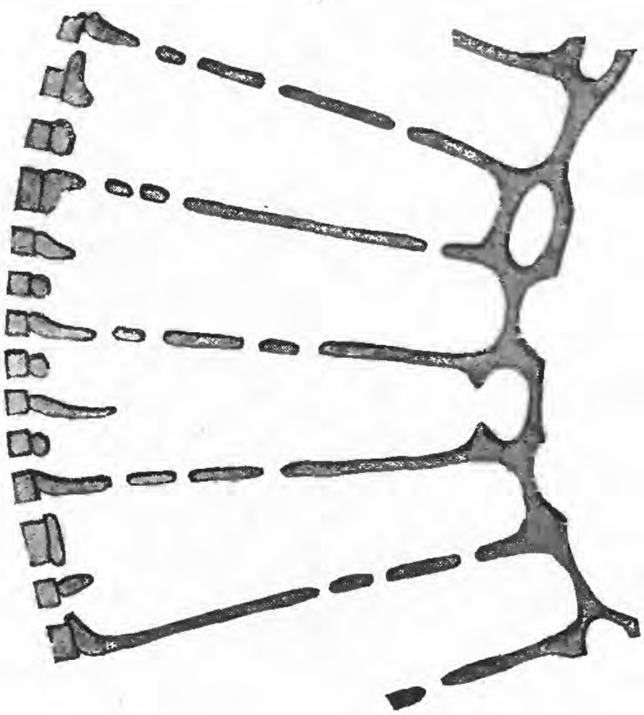
1



1a

1b

2



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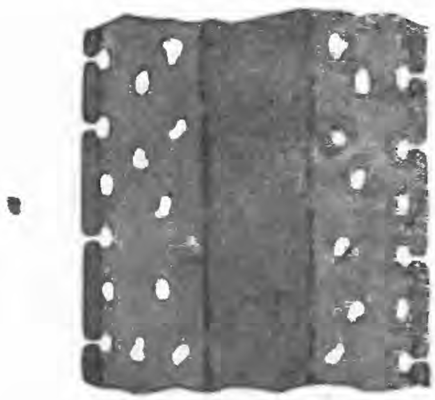


ACTINOZOA.

PLATE LIV.

PLATE LIV.

Page.

ARCHÆOCYATHUS (A.) RENSSELÆRICUS 600

FIG. 1. A nearly perfect specimen, showing the summit and the outer poriferous surface. Collection U. S. National Museum.

1*a*. A specimen with portions of outer wall removed, so as to show the septa and the poriferous surface of the inner wall. Collection U. S. National Museum.

1*b*. Transverse section, showing 12 septa and the pores of the inner and outer walls, enlarged. Collection U. S. National Museum.

1*c*. Transverse section of the upper end of 1*a*, with 18 septa. Collection U. S. National Museum.

1*d*. Transverse section where the walls and septa are thickened by additional layers. Collection U. S. National Museum.

1*e*. Enlargement of the outer poriferous surface.

ARCHÆOCYATHUS (A.) RARUS 601

FIG. 2. View of the only specimen that can be referred to this species in the collection. The outer surface is entirely removed. Collection U. S. National Museum.

2*a*. Transverse section of the lower end of 2, showing 9 septa.

2*b*. Drawing of the type specimen, by Mr. S. W. Ford. There are about 21 septa and the outer surface is removed. Collection S. W. Ford.

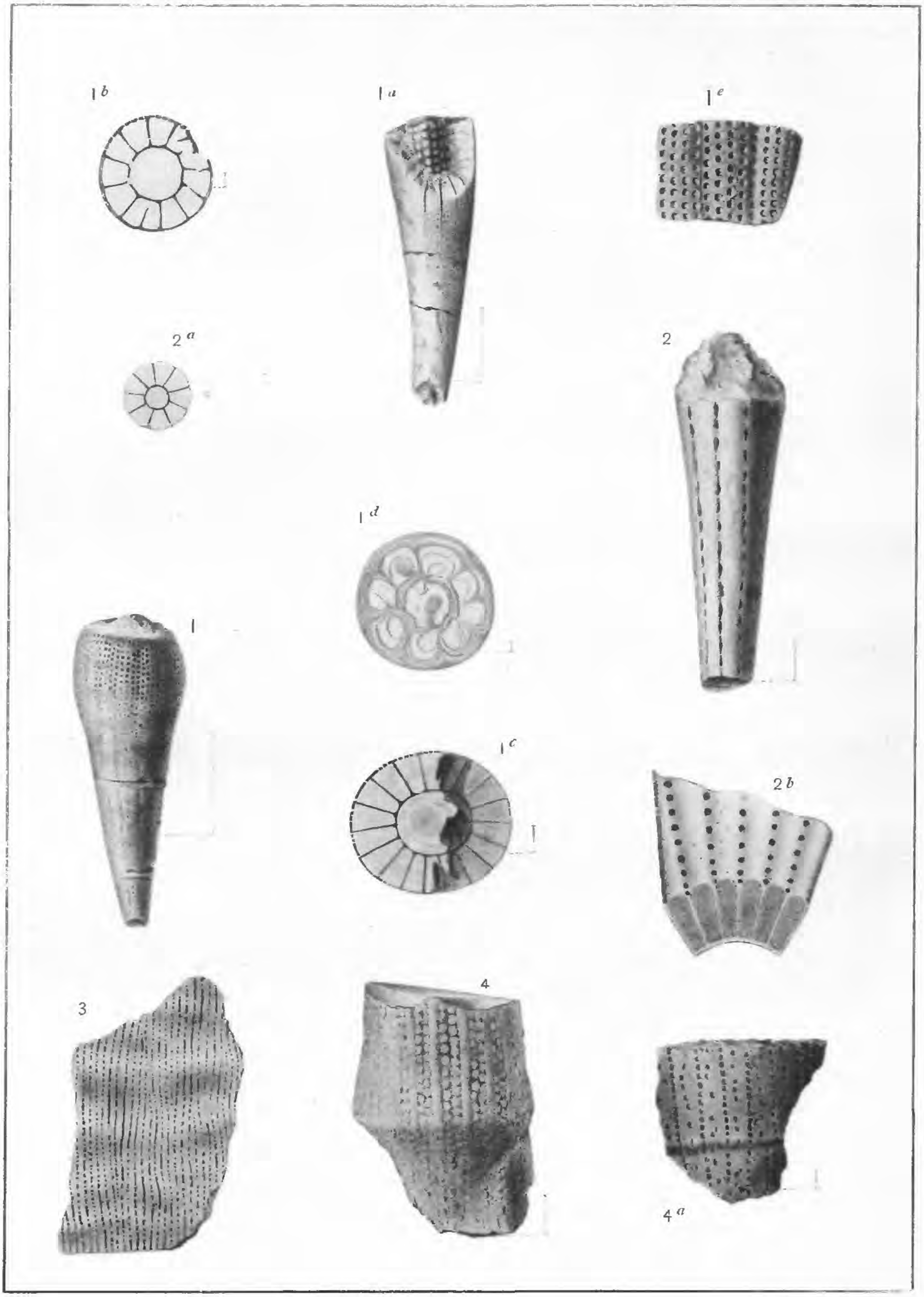
ARCHÆOCYATHUS PROFUNDUS 600

FIG. 3. Portion of a cast of the interior portion of the outer wall, showing the openings in the septa. Collection U. S. National Museum. See Pls. LII and LIII.

ARCHÆOCYATHUS DWIGHTI 601

FIG. 4. Cast showing the arrangement of the pores and the longitudinal grooves.

4*a*. A specimen provisionally referred to this species. It may be a fragment of the outer wall.



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ACTINOZOA.

PLATE LV.

PLATE LV.

Page.

ETHMOPHYLLUM WHITNEYI.. 601

FIG. 1. Enlargement to two diameters of one of the type specimens. Collection U. S. National Museum.

1*a*. Enlargement of the outer surface to ten diameters. Collection U. S. National Museum.

1*b*. Longitudinal section of a specimen showing the vesiculose inner wall, which, when the outer wall and septa are broken away, gives the form described by Mr. Meek as *E. gracilis*. Collection U. S. National Museum.

1*c*. Transverse section showing the structure mentioned of Fig. 1*b* still more clearly ; also, the septa and poriferous outer wall; 37 septa. Collection U. S. National Museum.

1*d*. Transverse section, 1.5^{mm} in diameter, showing 8 septa. Collection U. S. National Museum.

1*e*. Similar section to 1*d*, with 14 septa.

ETHMOPHYLLUM MEEKI.. 601

FIG. 2. A large transverse section, with 58 septa ; numerous partitions between the septa, the outer poriferous wall, and the openings between the septa. Collection U. S. National Museum.

2*a*. A fragment showing the inner and outer walls, septa, dissepiments, outer surface with large pores, and the interior cup.

2*b*, 2*c*. Transverse section of a small specimen referred doubtfully to this species.

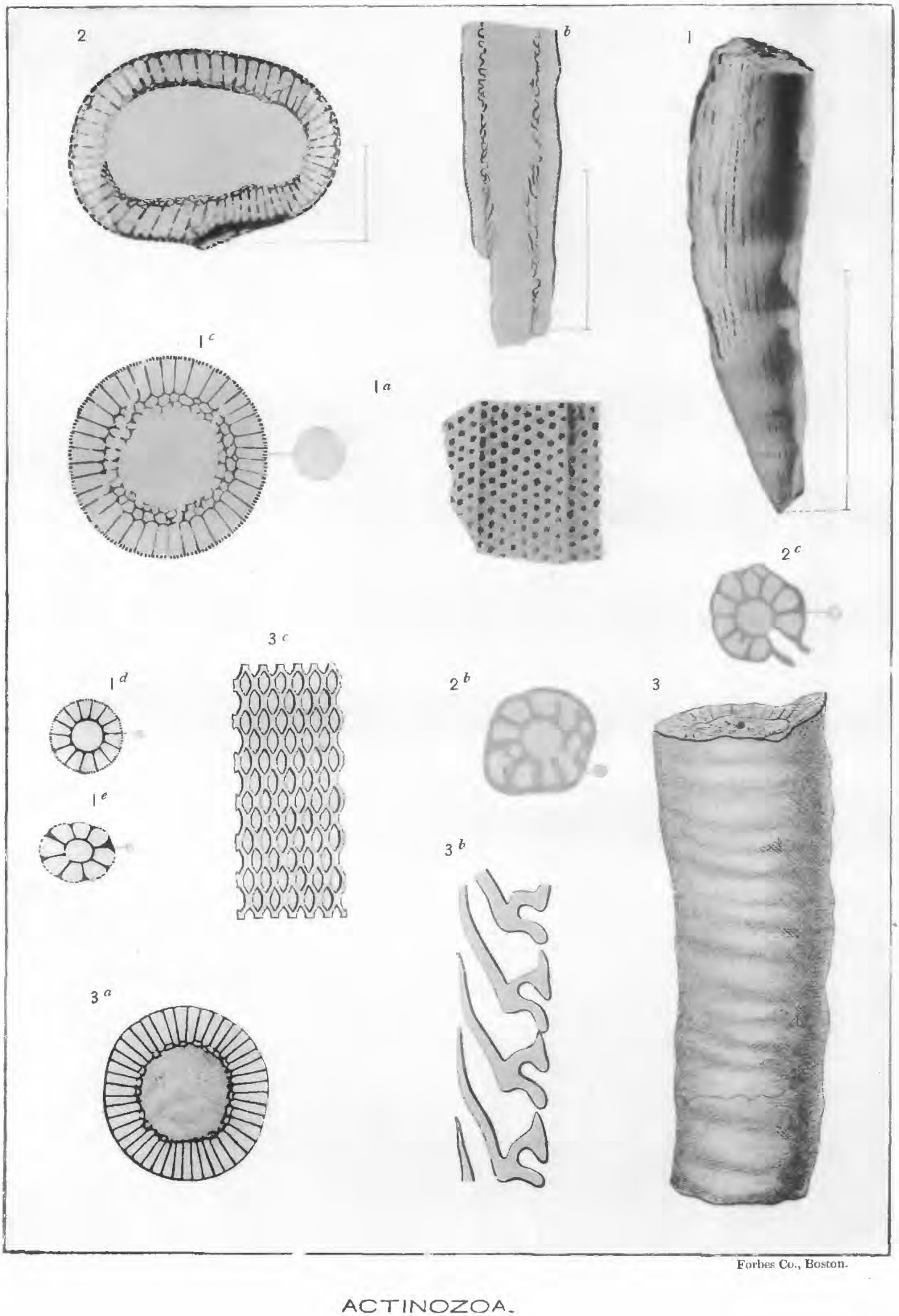
ETHMOPHYLLUM MARIANUS.. 601

FIG. 3. Exterior view of a subcylindrical tube, showing the septa and interior wall at the apex. (After Roemer.)

3*a*. Transverse section. (After Roemer.)

3*b*. Enlargement of the plates on the inner wall that separate the openings into the wall pores. (After Roemer.)

3*c*. Enlargement of the poriferous surface. (After Roemer.)
See Pl. LIII.



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ACTINOZOA.

PLATE LVI.

PLATE LVI

Page

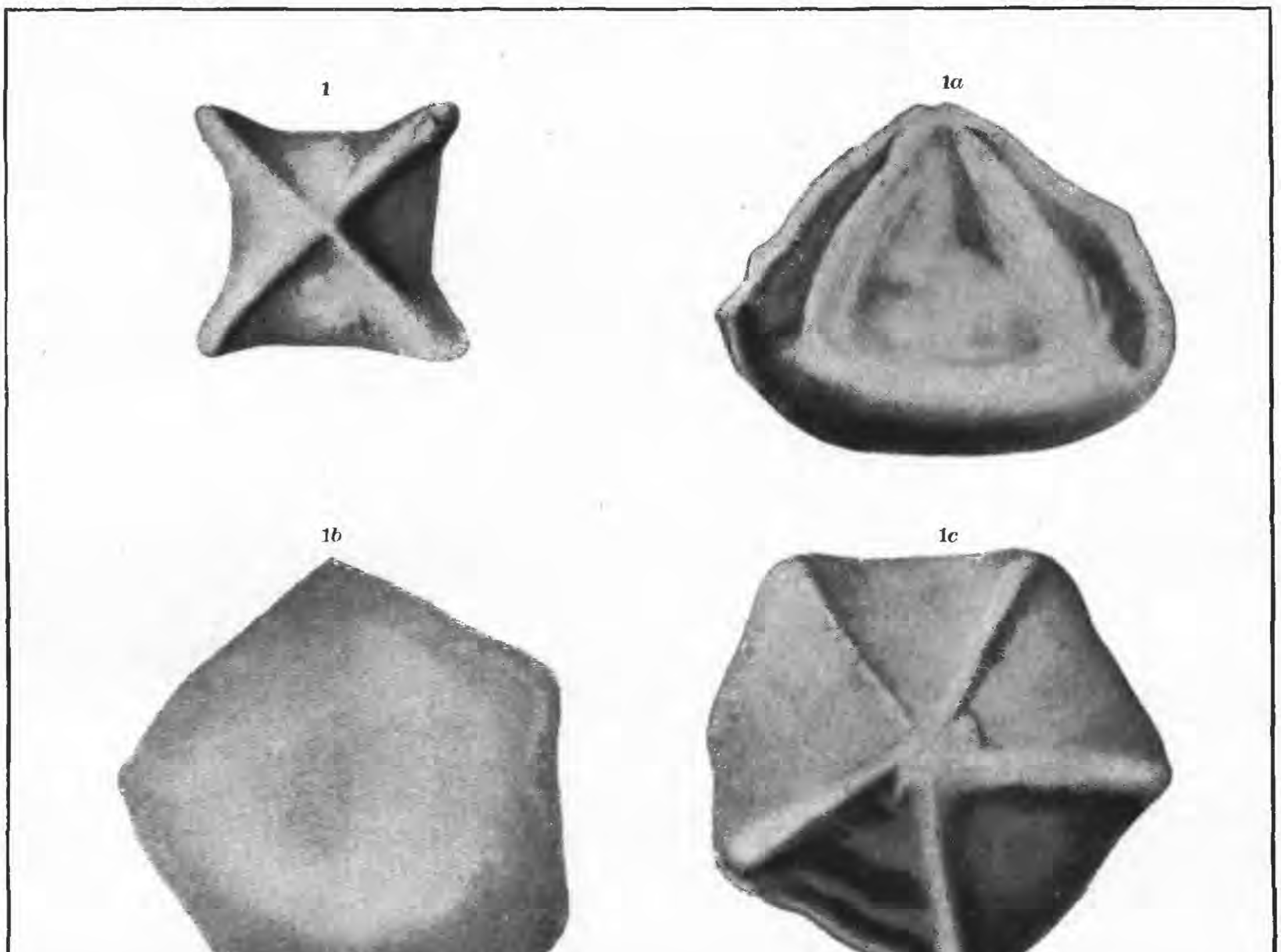
MEDUSITES LINDSTROMI 587

FIG 1 Sketch of a specimen in the collections of the National Museum This is the supposed cast of the gastric cavity of a Medusa, according to Nathorst

1*a*, 1*b*, 1*c* Three views of a cast showing five angles (After Linnarsson)

MEDUSITES RADIATUS 587

FIG 2, 2*a* Casts of what Nathorst considers to be the radial canals of a species of a craspedot Medusa belonging to the family Æequoridæ (After Linnarsson)



HYDROZOA.

PLATE LVII.

PLATE LVII.

	Page.
DACTYLOIDITES ASTEROIDES	605

FIG. 1. Reproduction of a photograph of a portion of a slab of slate in the New York State Museum of Natural History.

A. A specimen showing six rays and a thick central portion.

B. An imperfect specimen similar to that shown by the original figure of the species by Dr. Fitch.

C. A specimen with five divisions of the type illustrated by Professor Hall.

D, E. Two specimens with apparently seven divisions.

The traces of annelid trails scattered over the surface were referred to *Fucoides flexuosa* by both Fitch and Hall.

PLATE LVIII.

PLATE LVIII.

	Page
DACTYLOIDITES ASTEROIDES	607

FIG. 1. The five specimens represented on this plate illustrate the variation of 5, 6, and 7 rays, and the widest range in the character of the species yet observed Dr Fitch's type is of the form of the small individual in the upper corner, and Prof Hall's is like that of the large upper one. These specimens are scattered over the surface of a large slab of slate now in the collections of the U. S National Museum.

HYDROZOA.

PLATE LIX.

Plate LIX.

Page.

Fig. 1. A problematical organic marking, from the Olenellus slates of Georgia, Vt.

EOPHYTON LINNÆANUM.. 587

Fig. 2. Drawing of a specimen from Sweden. This marking is regarded as the trail made by a Medusa in passing over soft mud. By Nathorst.

PHYLLOGRAPTUS? CAMBRENSIS.. 604

Fig. 3, 3*a*. Two fronds, natural size, from the fine grained argillites of Parker's quarry. Collection U. S. National Museum.

CLIMACOGRAPTUS ?? EMMONSI.. 605

Fig. 4. A flattened stipe in the fine grained shales containing *Olenellus thompsoni*, at Parker's quarry, Georgia, Vt.

1

3

3a

2

4

HYDROZOA.

PLATE LX.

PLATE LX.

Page.

HELMINTHOIDICHNITES, sp.? 603

FIG. 1. A form, from the Upper Cambrian, similar to *H. tenuis* of Fitch, equivalent to *H. marinus* Emmons.

PLANOLITES, sp.? 684

FIG. 2. A small burrow, so broken and crossed that it gives the appearance of a coral allied to Aulopora.

EOCYSTITES ? sp. 607

FIG. 3. Enlargement of a single plate, from Pioche, Nev., provisionally referred to this genus.

GIRVANELLA ? sp. ? 598

FIG. 4. The canals of *Girvanella* (*Strephochœtus*) *occellatus*. (After Seely.)

4*a*. Forms referred to the genus from the Lower Cambrian rocks of Nevada.

PLANOLITES ANNULARIUS 602

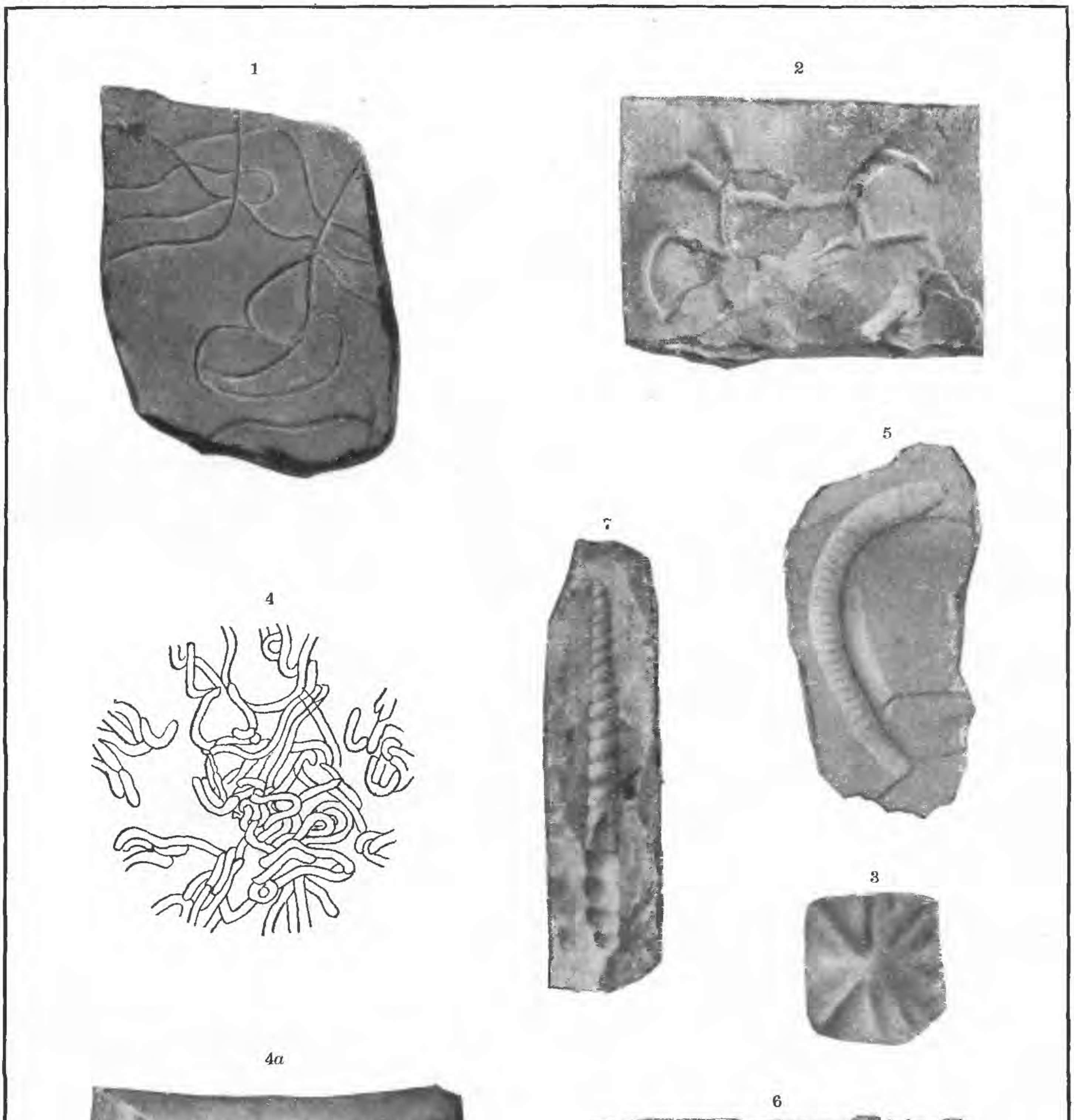
FIG. 5. Cast of the boring made by an annelid.

SPIROSCOLEX SPIRALIS 684

FIG. 6. Usually referred to the annelids, but suggested to have been made by the tentacles of Medusæ, by Nathorst. (After Linnarsson.)

EOCYSTITES ? sp. undetermined 684

FIG. 7. This peculiar form may possibly be the pedicle or stem of a cystid. It occurs in the Olenellus bearing limestones of Washington County, N. Y.



ECHINODERMATA. ANNELIDA.

PLATE LXI.

PLATE LXI.

Page.

PLANOLITES CONGREGATUS.. 602

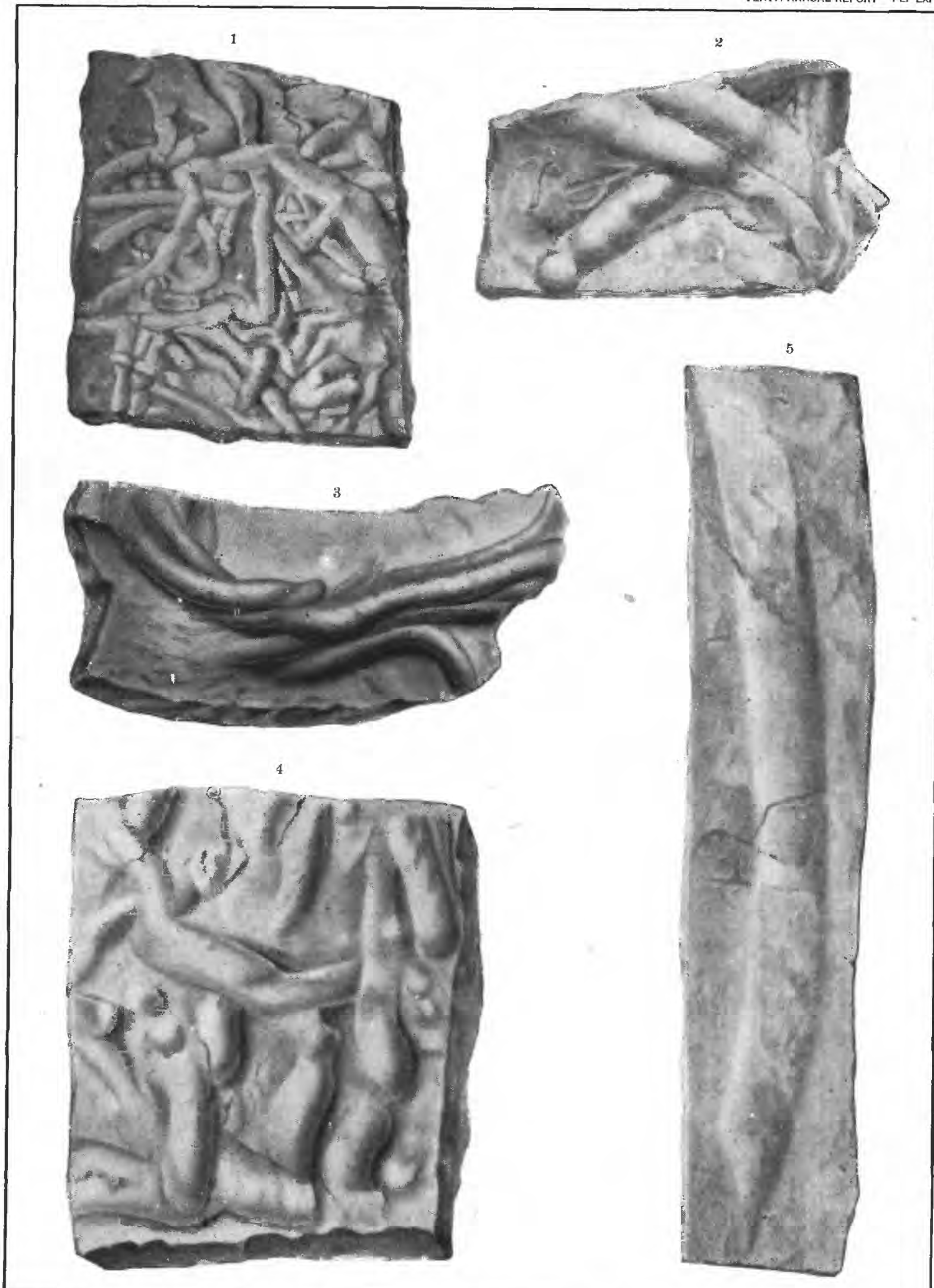
FIG. 1. Sketch of a portion of the type specimen in the collection of the Geological Survey of Canada.

PLANOLITES, sp. ?.. 686

FIGS. 2, 3, 4. Variations in size and form of various burrows.

PLANOLITES VIRGATUS.. 602

FIG. 5. The type of this species has not been identified. A figure of similar form, from the type locality, is given to illustrate it.



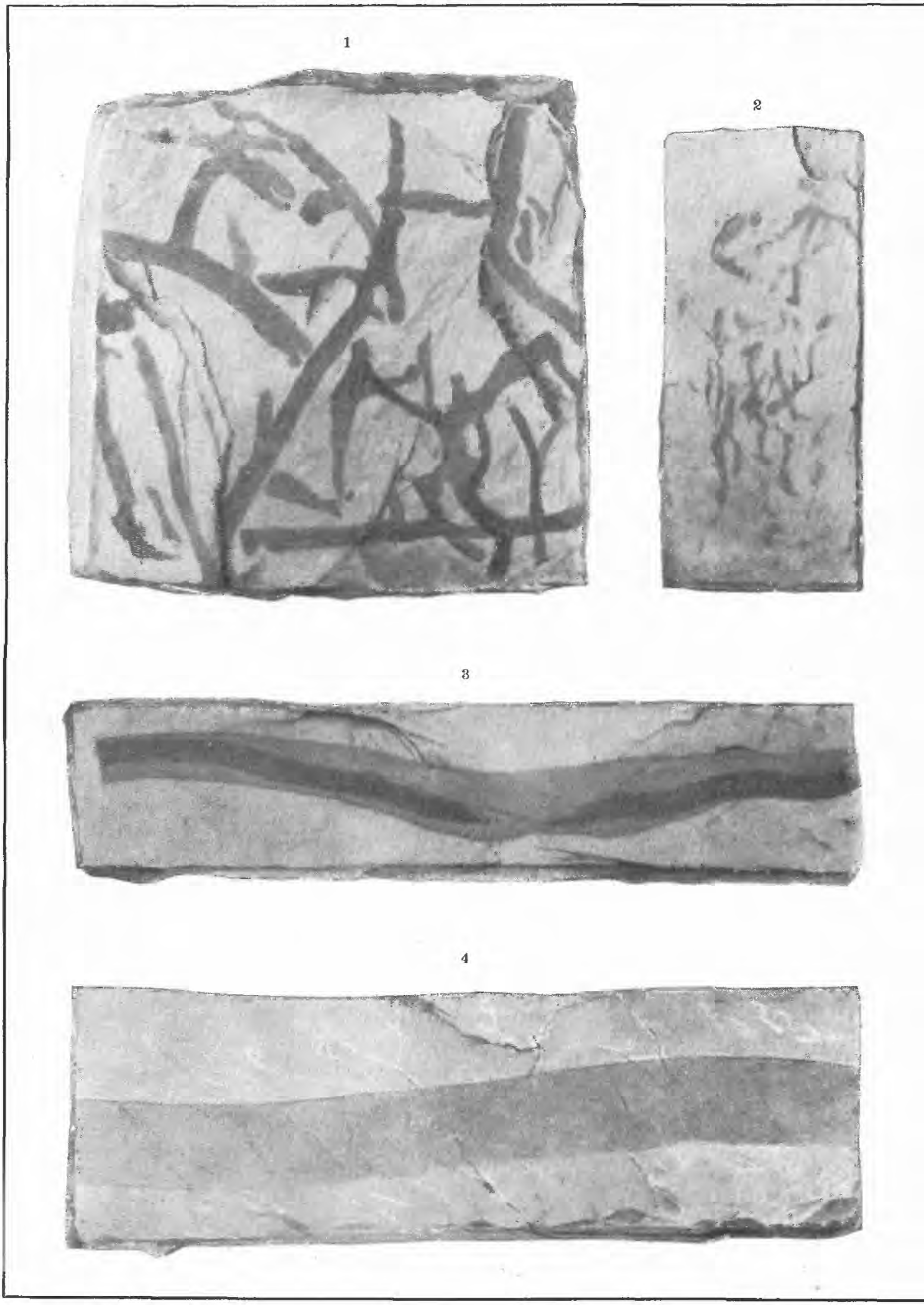
ANNELIDA.

PLATE LXII.

PLATE LXII.

	Page.
HELMINTHOIDICHNITES MARINUS?	603

FIGS. 1-4. The simple burrow or trail is shown by Figs. 3 and 4. In Figs. 1 and 2, numerous trails cross each other and give rise to what might be identified as a species of Paleophycus. All the specimens are crushed flat in the shale. The same species of worm may have made the burrows shown on Pls. LXI and LXII, the entire form being preserved in the first and only the flattened outline in the second plate.



ANNELIDA.

PLATE LXIII.

PLATE LXIII.

	Page.
SCOLITHUS LINEARIS	603

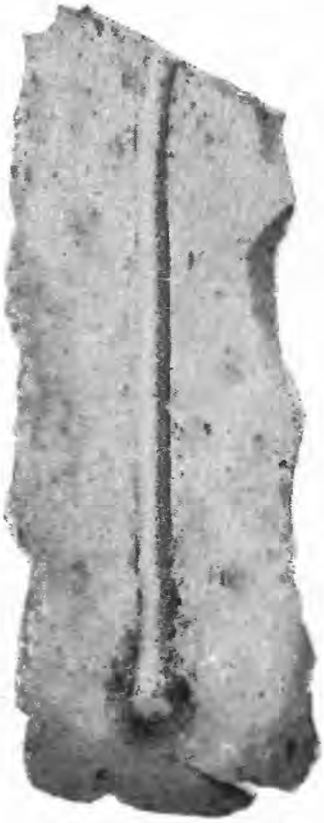
FIG. 1. The cast of a single tube preserved in a coarse sandstone.

1*a*. Tubes filled with sand of a darker color than the matrix.

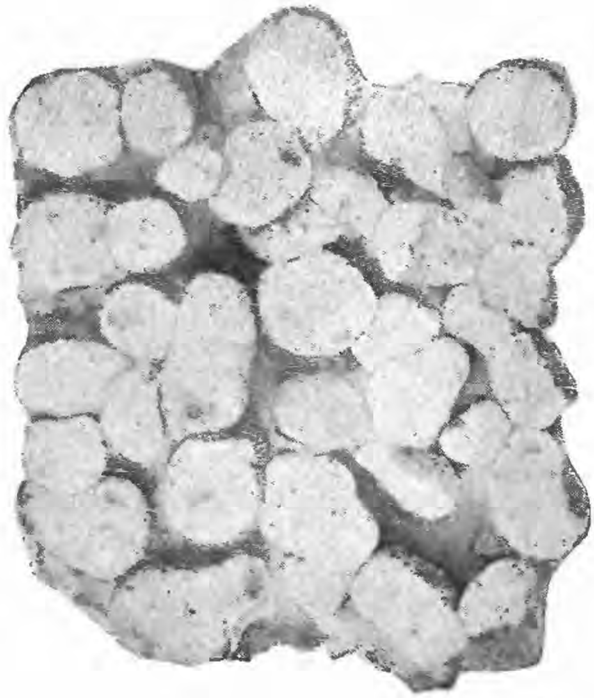
1*b*. Tube leading to the surface of the layer of sandstone, where the cast of a cup-like depression occurs.

1*c*. Summit view of a group of casts of the cup-like depressions, shown by Fig. 1*b*.

1

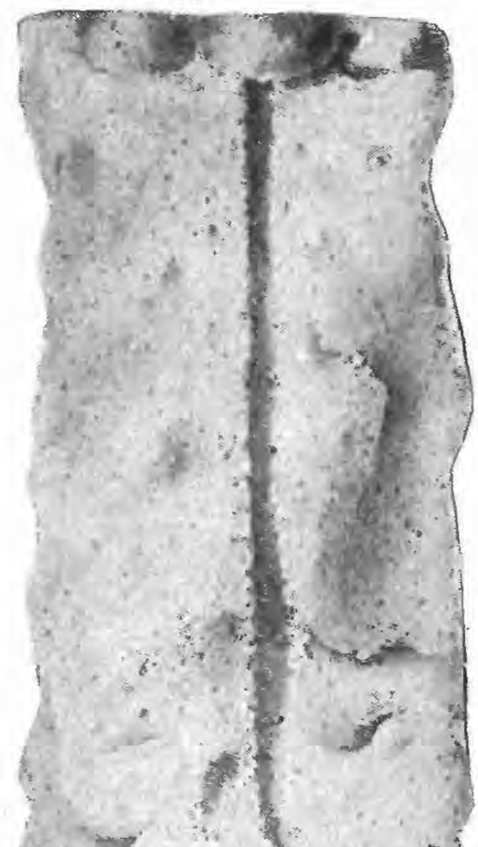


1c



1a

1b



ANNELIDA.

PLATE LXIV.

PLATE LXIV.

Page.

CRUZIANA, sp.? 604

FIG. 1. The cast of a single impression of the animal.

1*a*. Cast of Fig. 1, to show the lower surface impression left in the arenaceous mud by the animal.

1*b*. Cast of a narrow trail, in which the movement of the animal make a continuous furrow.

1*c*. Cast of 1*a*, to show the impression left by the animal.

See Pls. LXV and LXVI.

1

1*a*

1*b*

1*c*

CRUSTACEA ?

PLATE LXV.

PLATE LXV

Page.

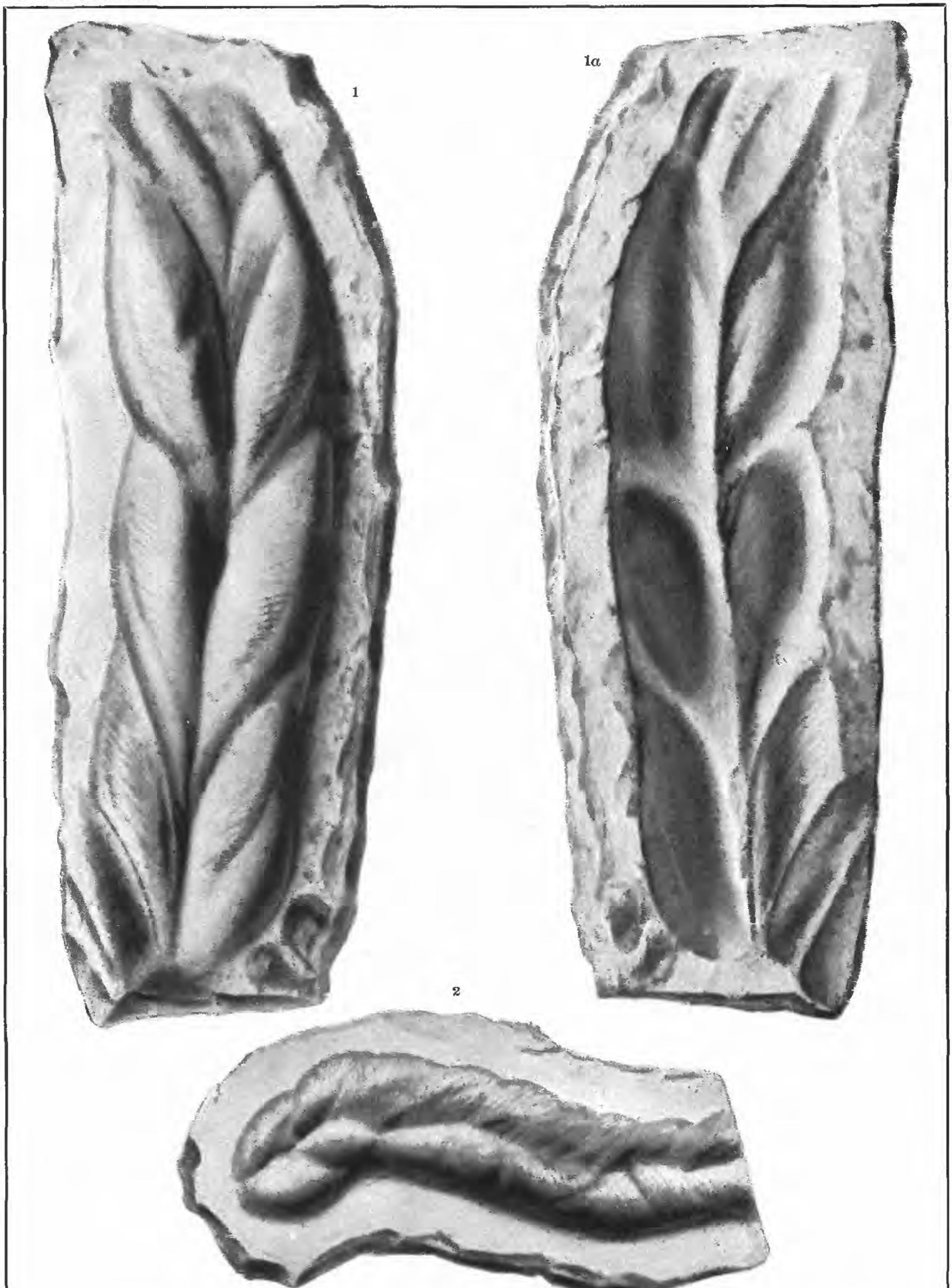
CRUZIANA, sp ? 604

FIG 1 The cast of a number of impressions, such as are represented by Fig 1, Pl LXIV

1*a* Cast of 1 to show the impression left by the animal in its successive movements In Fig 1*c* Pl LXIV, the single impressions are nearly lost sight of

2 Cast of a number of impressions in which the individual impressions are merged more into each other than in Fig 1

See Pls LXIV and LXVI



CRUSTACEA ?

PLATE LXVI.

PLATE LXVI.

Page.

CRUZIANA, sp.? 604

FIG. 1. A continuation of the illustration on Pls. LXIV, LXV to show the character of the trails made by the movement of a similar animal. Upper Cambrian of Arizona.

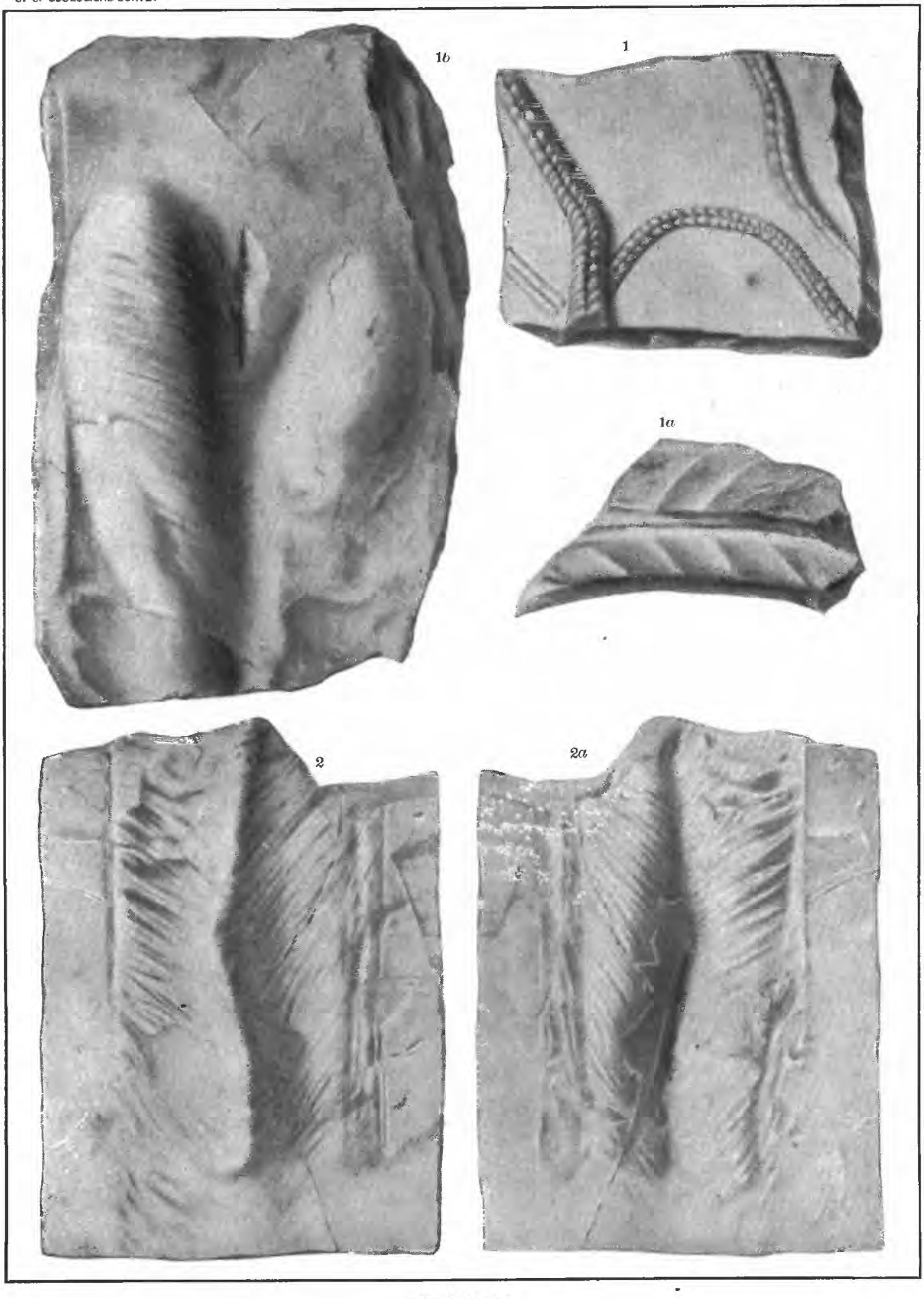
1*a*. A fragment from the Lower Cambrian of Nevada.

1*b*. Cast of a single impression of the animal from the Lower Cambrian of Nevada. Compare with Fig. 1 of Pl. LXIV.

CRUZIANA DISSIMILIS 696

FIG. 2. A trail on sandstone from Great Bell Island, Newfoundland.

2*a*. Cast taken from the trail, Fig. 2, which makes a very good Cruziana.



CRUSTACEA?

PLATE LXVII.

PLATE LXVII.

Page.

LINGULELLA CÆLATA 607

FIG. 1. Ventral valve, enlarged to 2 diameters. Collection S. W. Ford.
1*a*. Side view of same, with a view of the beak, looking from behind.
1*b*. Enlargement of a small dorsal (?) valve. Collection U. S. National Museum.
1*c*. Dorsal valve, enlarged. Collection U. S. National Museum.
1*d*. Surface of dorsal valve, greatly enlarged.
1*e*. Cast of the interior of a dorsal valve. Collection U. S. National Museum.

LINGULELLA ELLA 607

FIG. 2. Ventral valve, showing the area, deltidial opening, and cast of the exterior surface of the valve; enlarged. Collection U. S. National Museum.
2*a*. Cast of the interior of the dorsal valve, showing the position of the muscular scars. Collection U. S. National Museum.
2*b*. View of the type specimen, enlarged to two diameters. Collection U. S. National Museum.
2*c*. Cast of the interior of a very small ventral valve, enlarged six diameters. Collection U. S. National Museum.
2*d*. Cast of the interior of a very small dorsal valve, enlarged six diameters. Collection U. S. National Museum.
2*e*. Enlargement of the surface of a specimen from the shales at the Chisholm mine. Collection U. S. National Museum.

LINGULELLA ? sp. ? 698

FIG. 3. A single valve found in association with *Olenellus asaphoides*, in Washington County, N. Y. Collection U. S. National Museum.

LINGULELLA GRANVILLENSIS 607

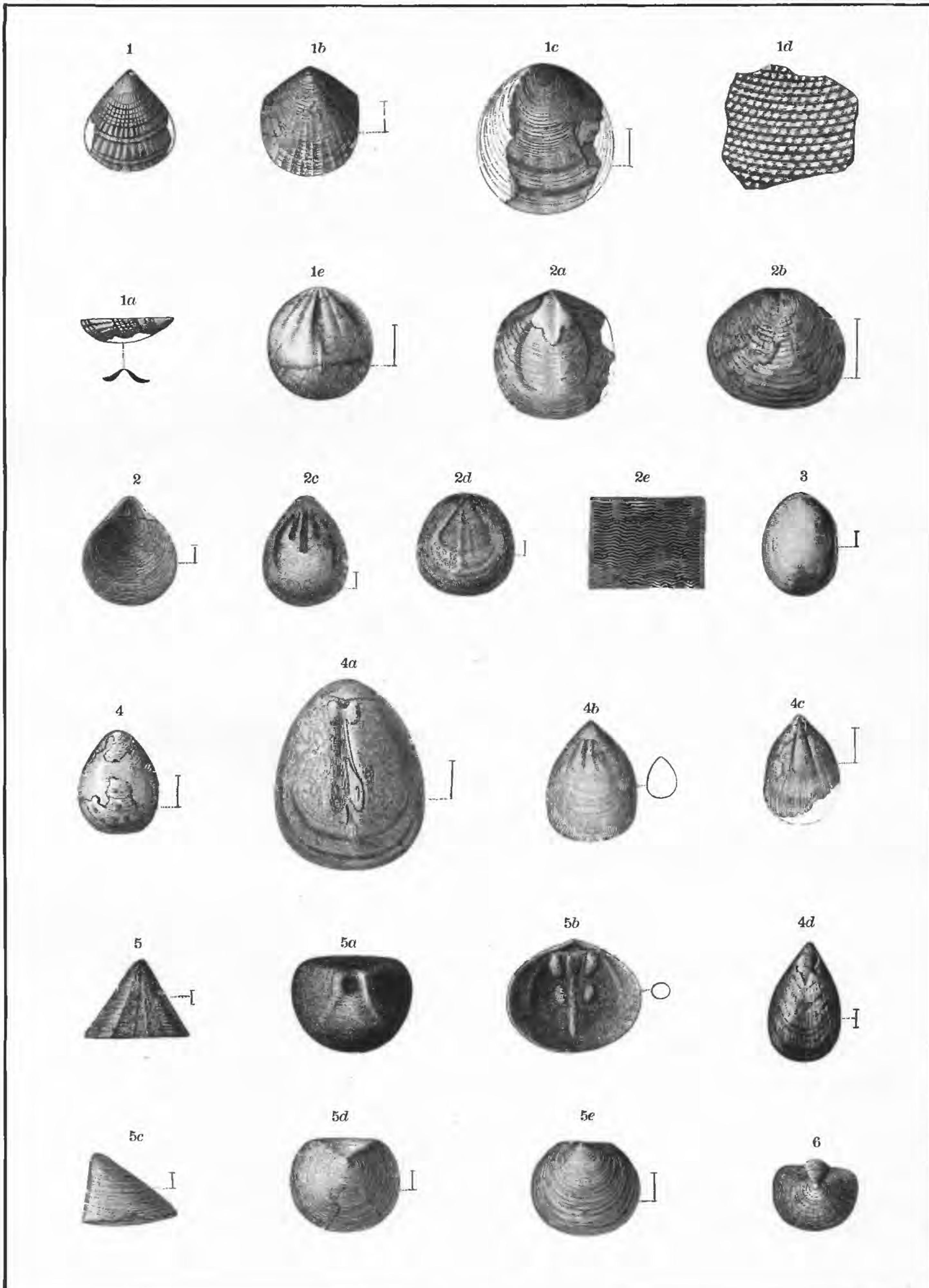
FIG. 4. Dorsal valve preserving portions of the outer shell. Collection U. S. National Museum.
4*a*. Cast of the interior of a dorsal valve, showing muscular scars and vascular markings. Collection U. S. National Museum.
4*b*, 4*c*. Ventral valves, showing elongate muscular scars and fragments of the outer shell. Collection U. S. National Museum.
4*d*. A ventral valve, doubtfully referred to this species. Collection U. S. National Museum.

ACROTRETA GEMMA 608

FIG. 5. View of the posterior side of the ventral valve, enlarged to six diameters. Collection U. S. National Museum.
5*a*. Cast of the interior of the apex of the ventral valve, showing a cast of the siphonal tubes and the elongate muscular scars, enlarged to six diameters. Collection U. S. National Museum.
5*b*. Interior of ventral valve, enlarged to six diameters. Collection U. S. National Museum.
5*c*, 5*d*. Summit and side views of the dorsal valve, enlarged to three diameters. Collection U. S. National Museum.
5*e*. Ventral valve, enlarged to three diameters. Collection U. S. National Museum.

IPHIDEA BELLA 608

FIG. 6. Copy of the original figure given by Mr. Billings. Ventral (?) valve. Collection Geological Survey, Canada.



BRACHIOPODA.

PLATE LXVIII.

PLATE LXVIII.

Page.

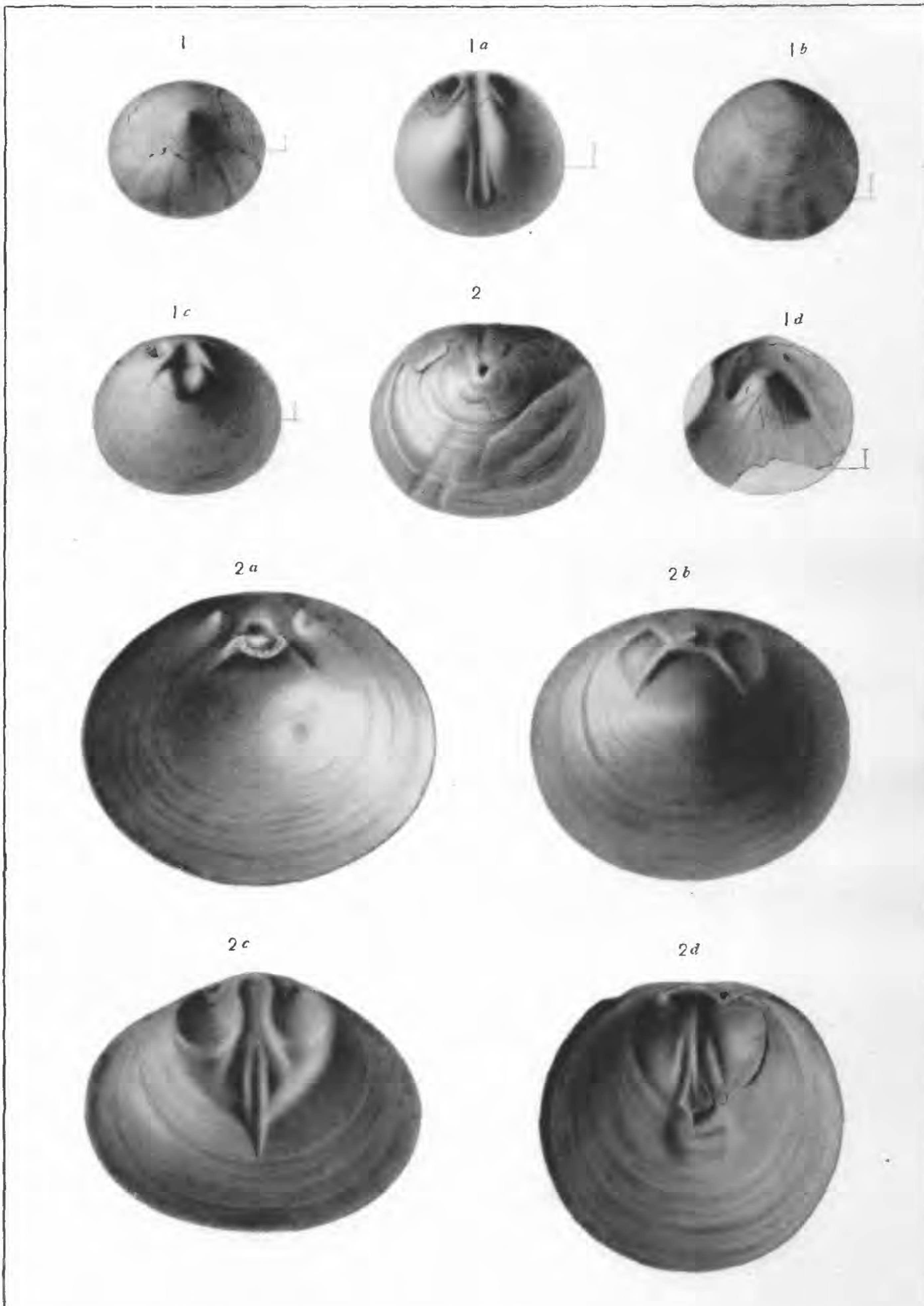
LINNARSSONIA SAGITTALIS var TACONICA 610

Fig. 1. Ventral valve, enlarged.
1*a*. Cast of the interior of a dorsal valve.
1*b*. Dorsal valve.
1*c*. Cast of the interior of a ventral valve.
1*d*. Interior of ventral valve. Collection U. S. National Museum.

LINNARSSONIA SAGITTALIS.. 610

Fig. 2. Exterior of the ventral valve, greatly enlarged.
2*a*. Interior of the ventral valve of the variety *transversa*, from St. John, New Brunswick.
2*b*. Cast of the interior of the ventral valve.
2*c*. Cast of the interior of the dorsal valve of the variety *transversa*, from St. John, New Brunswick.
2*d*. Interior of the dorsal valve of the variety *transversa*, from St. John, New Brunswick.

These figures are inserted for comparison with Figs. 1–1*d*, and to illustrate the characters of the genus.



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BRACHIOPODA.

PLATE LXIX.

PLATE LXIX.

Page.

KUTORGINA CINGULATA 609

FIG. 1, *1a*, *1b*. Ventral, lateral, and dorsal views of a large shell that is mostly denuded of the outer surface. Collection U. S. National Museum.

1c. Lateral view of a small shell, to compare with *1a*, the height of the dorsal valve being much less than that of *1a*. Collection U. S. National Museum.

1d. Cast of the interior of the dorsal valve, showing muscular scars. Collection U. S. National Museum.

1e. Dorsal valve, enlarged. Collection U. S. National Museum.

1f. Interior of dorsal valve. Collection U. S. National Museum.

1g, *1h*. Compressed shells from shales of Parker's quarry; probably ventral valves. Collection U. S. National Museum.

KUTORGINA LABRADORICA var. SWANTONENSIS 609

FIG. 2, *2a*. Ventral valves, enlarged. Collection U. S. National Museum.

2b. Dorsal valve; enlarged. Collection U. S. National Museum.

KUTORGINA LABRADORICA 609

FIG. 3. Ventral valve, from Topsail Head, Conception Bay, Newfoundland, very much enlarged. Collection U. S. National Museum.

3a. Cast of the interior of a ventral valve, from the same locality as Fig. 3. Collection U. S. National Museum.

3b. Dorsal valve associated with 3 and *3a*. Collection U. S. National Museum.

KUTORGINA PROSPECTENSIS 610

FIG. 4. Ventral valve enlarged. Collection U. S. National Museum.

4a. Dorsal valve, enlarged. Collection U. S. National Museum.

KUTORGINA PANNULA 609

FIG. 5, *5a*. Side and summit views of the dorsal valve, enlarged three diameters. Collection U. S. National Museum.

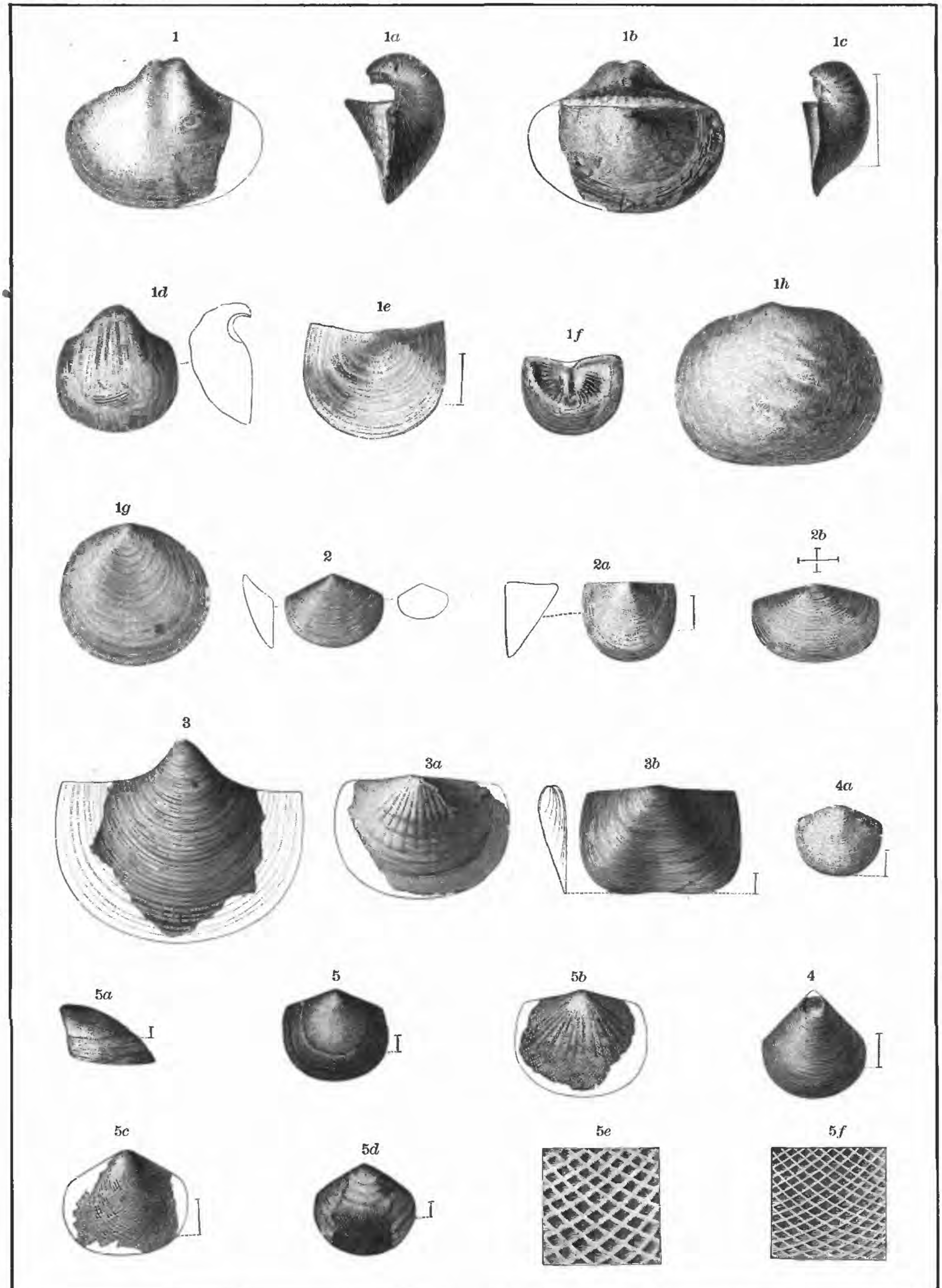
5b. Ventral valve, enlarged three diameters. From Nevada. Collection U. S. National Museum.

5c. Dorsal valve, from New York. Collection U. S. National Museum.

5d. Ventral (?) valve, enlarged. The type specimen. Collection U. S. National Museum.

5e. Enlargement of the surface of the specimen, *5c*, from New York.

5f. Enlargement of the surface of the specimen, *5b*, from Nevada.



BRACHIOPODA.

PLATE LXX.

PLATE LXX.

Page

ACROTHELE SUBSIDUA 608

FIG. 1 Ventral valve, from Pioche, Nevada, showing exterior surface, enlarged Collection U. S National Museum

1a. Interior of dorsal valve, enlarged. Collection U. S. National Museum.

1b. Ventral valve, from Antelope Spring, Utah, with exterior surface removed, enlarged. Collection U. S National Museum.

1c. Cast of interior of dorsal valve, enlarged. Collection U. S National Museum.

MICKWITZIA MONOLIFERA 704

FIG. 2. Interior of flat valve. (After Schmidt)

2a. Side view to show the form of the large tooth. (After Schmidt.)

2b. Exterior view of flat valve. (After Schmidt.)

2c. Interior of convex valve, showing a deep depression in the shell. (After Schmidt.)

2d. Anterior view, showing an oblique triangular area. (After Schmidt.)

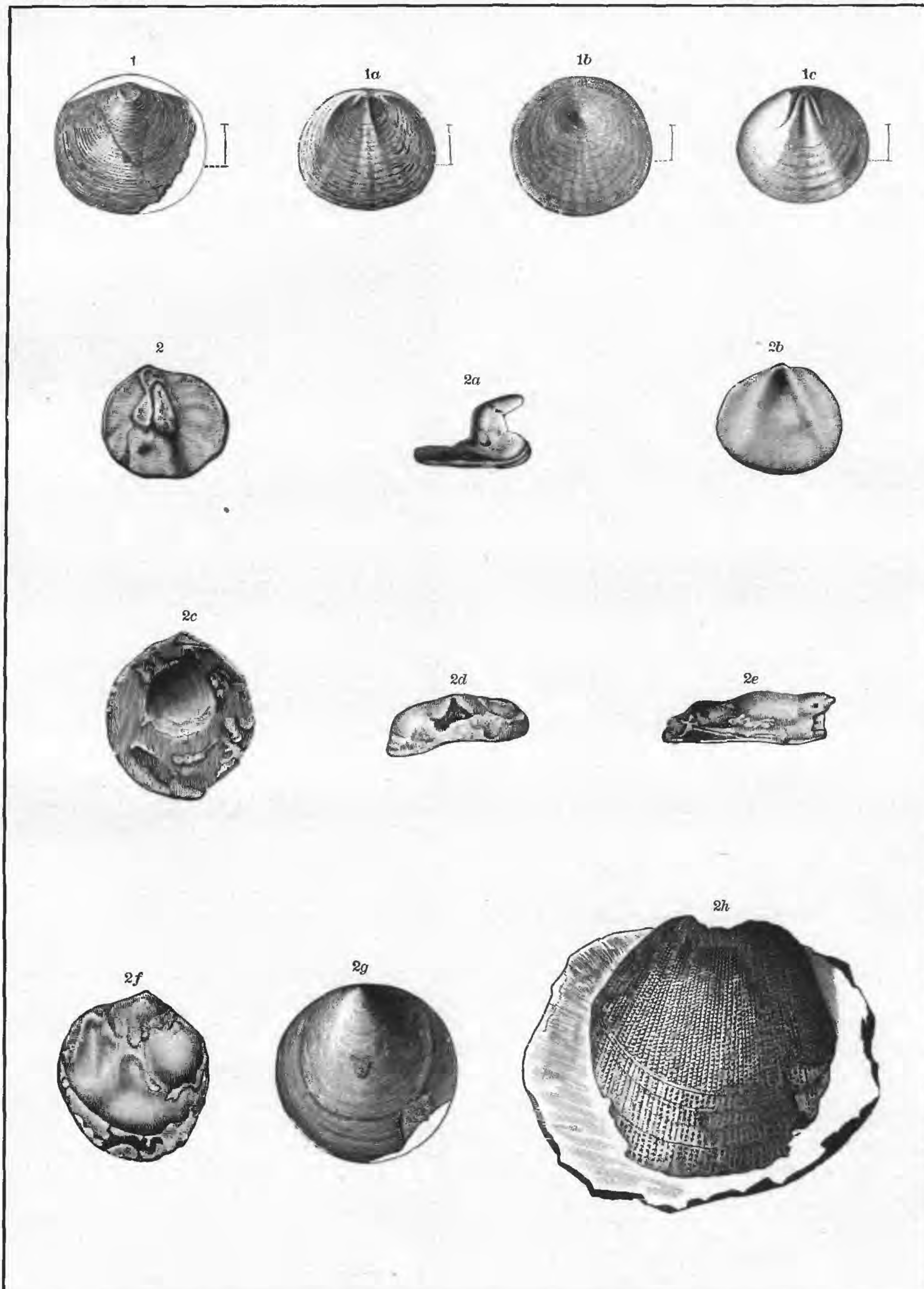
2e Side view, showing projecting beak. (After Schmidt)

2f. Exterior view of convex valve (After Schmidt,)

2g Exterior view of a ventral (?) valve, from the Lugnas sandstone of Sweden Collection U. S. National Museum

2h Outer surface of the shell, enlarged. (After Linnarsson.)

All of the views taken from Dr Schmidt's work appear to have been drawn from casts of the shell "Ueber eine neuentdeckte untercambrische Fauna in Estland" Mém Acad Imp. Sci St Pétersbourg, VIII, vol. 36, N. 2, 1888, pp 1-27, Pls. i, ii



BRACHIOPODA.

PLATE LXXI.

PLATE LXXI.

Page.

OBOLELLA ATLANTICA 611

FIG. 1. Exterior of the ventral valve. Collection U. S. National Museum.

1*a*. Cast of the interior of the ventral valve. Collection U. S. National Museum.

1*b*. Exterior of dorsal valve. Collection U. S. National Museum.

1*c*. Cast of the interior of the dorsal valve. Collection U. S. National Museum.

OBOLELLA CHROMATICA 611

FIG. 2. Dorsal valve from L'Anse au Loup, enlarged. Collection U. S. National Museum.

2*a*. Ventral valve from L'Anse au Loup, enlarged. Collection U. S. National Museum.

2*b*. Interior of dorsal valve, enlarged. Scars the same as in *O. crassa*. Collection U. S. National Museum.

OBOLELLA CIRCE 611

FIG. 3. Interior of dorsal valve. Compare with 4*c*, 4*d*. Notation same as Figs. 4*c*, 4*d*. Collection U. S. National Museum.

3*a*. Interior of ventral valve (?); 3 and 3*a* from L'Anse au Loup. Collection U. S. National Museum.

OBOLELLA CRASSA 612

FIG. 4. Ventral valve, showing well-preserved exterior surface, enlarged three diameters. Collection S. W. Ford.

4*a*. Dorsal valve, with the outer surface exfoliated, enlarged. Collection U. S. National Museum.

4*b*. Dorsal valve, preserving outer surface, enlarged to two diameters. Collection S. W. Ford.

4*c*. Cast of interior of dorsal valve: notation same as 4*d*. Collection U. S. National Museum.

4*d*. Diagrammatic drawing of the interior of dorsal valve; *a*, cardinal; *c*, central, and *d*, lateral muscular scars; *x*, area.

4*e*. Cast of interior of ventral valves; notation same as 4*f*. Collection U. S. National Museum.

4*f*. Diagrammatic drawing of the interior of ventral valve; *a*, cardinal; *c*, central, and *d*, internal muscular scars; *p*, pedicle groove.

OBOLELLA GEMMA 612

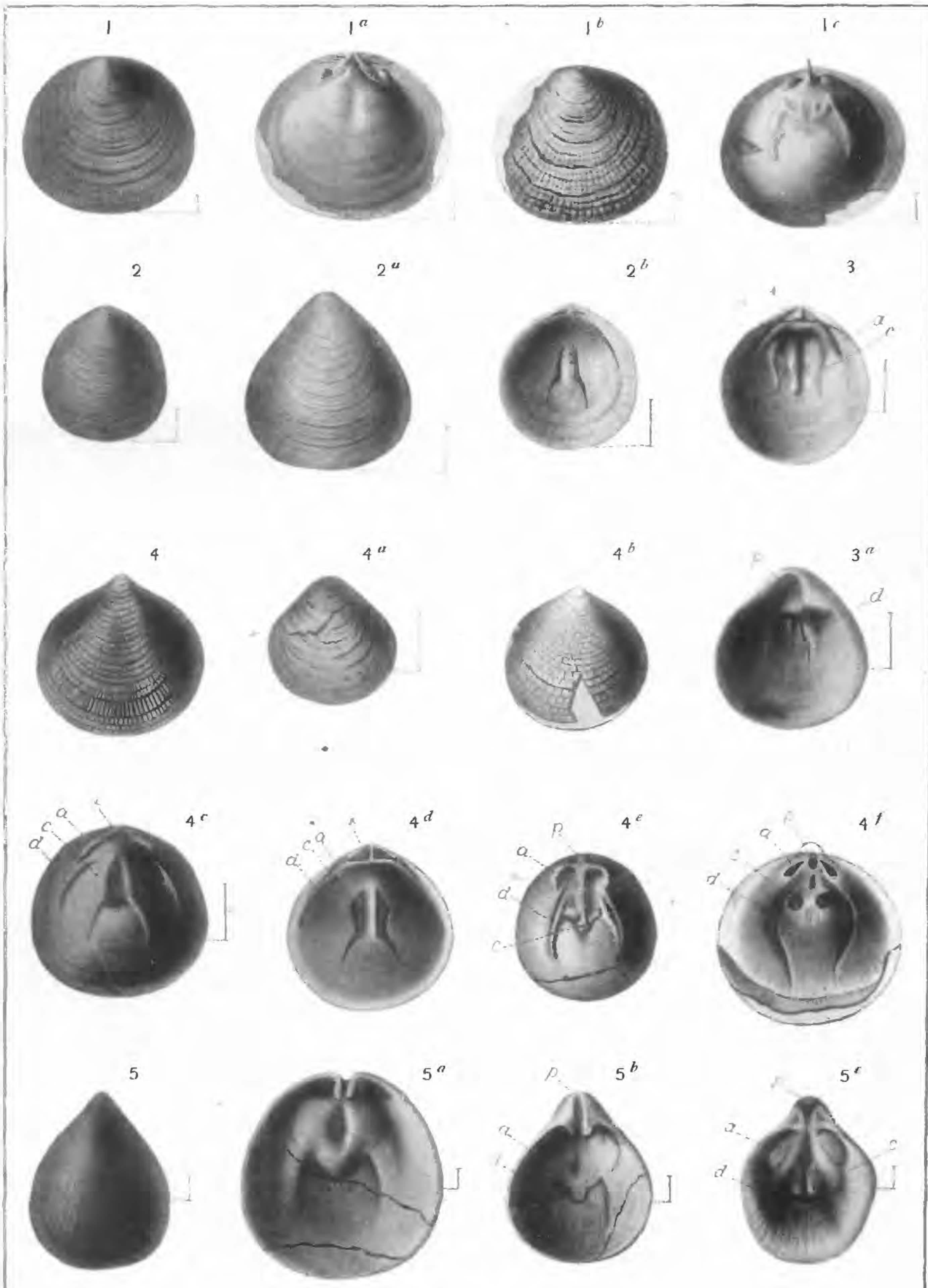
FIG. 5. Exterior of a somewhat macerated specimen of the ventral valve, from Bic Harbor, enlarged. Collection U. S. National Museum.

5*a*. Interior of dorsal valve, from Bic Harbor. Better specimens will be required in order to make out the details of structure. Collection U. S. National Museum.

5*b*. Interior of ventral valve, from Bic Harbor; *a*, cardinal; *d*, lateral, and *c*, central muscular scars; *p*, pedicle groove. Collection U. S. National Museum.

5*c*. Interior of ventral valve, from Troy, N. Y. The differences between 5*b* and 5*c* are largely owing to the condition of preservation of the shells. Notation same as 5*b*. Collection U. S. National Museum.

See Figs. 2 and 2*a*, Pl. LXXII.



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BRACHIOPODA.

PLATE LXXII.

PLATE LXXII.

Page

OBOLELLA NITIDA 612

FIG. 1 Dorsal ? valve, enlarged to five diameters. Collection U. S National Museum.

OBOLELLA GEMMA 612

FIG 2 Ventral valve, from Troy, N. Y., enlarged to six diameters. Collection S. W Ford.

2*a*. Exterior of dorsal valve, from Troy, N Y. Collection U. S. National Museum.

See Pl LXXI, Figs. 5, 5*a*–5*c*

CAMARELLA ? ANTIQUATA. 613

FIG 3 Ventral valve, enlarged. Collection U. S. National Museum.

CAMARELLA MINOR 614

FIG 4, 4*d*. Casts of ventral valves Collection U. S National Museum.

4*a*. Exterior of ventral valve. Collection U S. National Museum.

4*b* Exterior of dorsal valve

4*c*. Cast of interior of dorsal valve.

ORTHIS ? HIGHLANDENSIS 612

FIG 5 Dorsal valve, with most of the exterior shell worn away. Collection U. S. National Museum.

5*a* Cast of the interior of the ventral valve Collection U S National Museum.

5*b* Exterior of the ventral valve, with the side restored from another specimen Collection U S National Museum.

ORTHIS SALEMENSIS 612

FIG. 6 Ventral valve and outline of its convexity.

6*a* Dorsal valve.

ORTHISINA FESTINATA 613

FIG 7. Dorsal (?) valve, enlarged. Collection U S National Museum.

7*a*. View of area of 7

7*b* Ventral (?) valve and outline, natural size Collection U S National Museum.

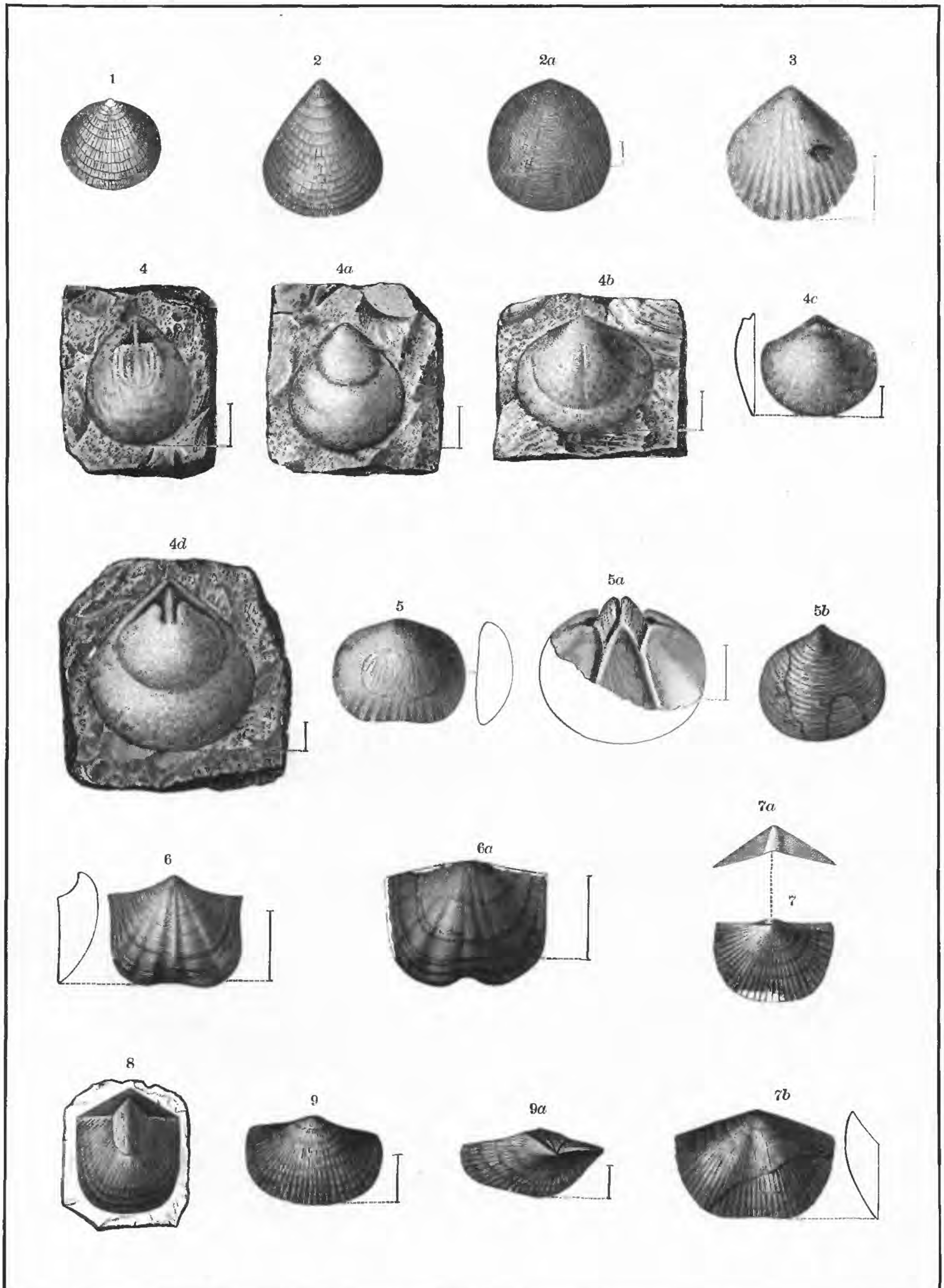
ORTHISINA ORIENTALIS 613

FIG 8. Ventral valve, natural size (After Whitfield.) Collection American Museum Natural History, New York City.

ORTHISINA TRANSVERSA 613

FIG. 9 Ventral valve, enlarged two diameters Collection U S National Museum

9*a* Another specimen, showing the area Collection U S. National Museum.



BRACHIOPODA.

PLATE LXXIII.

PLATE LXXIII.

Page

FORDILLA TROYENSIS? 615

FIG. 1. Cast of a left valve, that is doubtfully referred to this species. Collection Prof. N. S. Shaler.

FORDILLA TROYENSIS 615

FIG. 2. Right valve, enlarged. Collection U. S. National Museum.
2*a*. A shorter right valve than that of 2, enlarged. Collection U. S. National Museum.
2*b*. Cast of the interior of the right valve, enlarged. Collection U. S. National Museum.
2*c*. Left valve, enlarged. Collection U. S. National Museum.

MODIOLOIDES PRISCA 615

FIG. 3. Cast of right (?) valve, very much enlarged. The outline of the convexity of the valve is shown by lines beside the figure.

SCENELLA CONULA 616

FIG. 4, 4*a*. Side and summit views of the type specimens, enlarged to four diameters. Collection U. S. National Museum.

SCENELLA ? VARIANS 617

FIG. 5. Summit and lateral views of specimen with concentric apex. Collection U. S. National Museum.
5*a*. Lateral view of specimen with concentric apex. Collection U. S. National Museum.

SCENELLA RETUSA 617

FIG. 6. Summit and lateral views of the type specimen, enlarged three diameters. Collection S. W. Ford.
6*a*. Summit view of a specimen from Troy, N. Y., doubtfully referred to the species. Collection U. S. National Museum.

SCENELLA TUBERCULATA 710

FIG. 7, 7*a*. Side and top view. (After Schmidt.)

SCENELLA DISCINOIDES 710

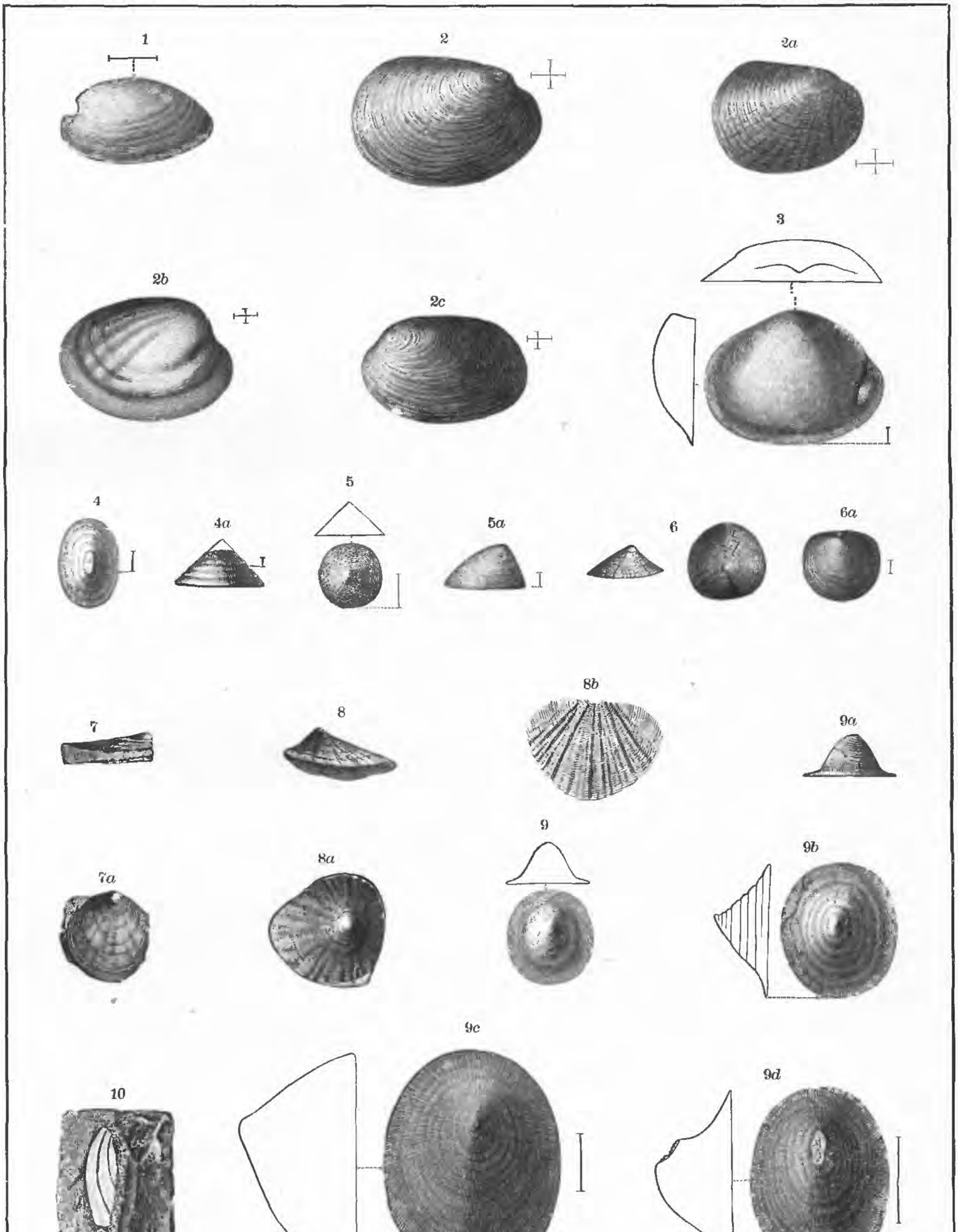
FIG. 8, 8*a*. Side and top views. (After Schmidt.)

SCENELLA RETICULATA 616

FIG. 9. Summit view and side outline of a specimen, showing a companulate margin. Collection U. S. National Museum.
9*a*. Side view of a specimen much like that represented by Fig. 9. Collection U. S. National Museum.
9*b*. Large shell, with the apex subcentral. Collection U. S. National Museum.
9*c*, 9*d*. Enlarged figures of the two supposed type specimens from Topsail Head, Newfoundland. Collection Geological Survey of Canada.

LAMELLIBRANCHIATE ? SHELL 710

FIG. 10. Summit view of the specimen described by Messrs. Shaler and Foerste. Collection Prof. N. S. Shaler.



LAMELLIBRANCHIATA AND GASTROPODA.

PLATE LXXIV.

PLATE LXXIV.

Page.

STENOTHECA RUGOSA 617

FIG. 1. Lateral view of a medium sized specimen. Collection U. S. National Museum.
1*a*. Lateral view of a more elevated and coarsely annulated specimen than 1. Collection U. S. National Museum.
1*b*, 1*c*. Summit views of two specimens, to show eccentricity of apex. Collection U. S. National Museum.
1*d*. Side view of a shell from Conception Bay, Newfoundland. Collection U. S. National Museum.
1*e*. Side view of a shell from Washington County, N. Y. Collection U. S. National Museum.
1*f*. Enlargement of surface of shell represented by Fig. 1*e*.
1*g*. Variety, with finer annulations than 1*e*. From Washington County, N. Y.
1*h*, 1*i*. Side and summit views of a very small shell from Troy, N. Y.

STENOTHECA RUGOSA var. ACUTA-COSTA 617

FIG. 2. Side view, enlarged. Collection U. S. National Museum.
2*a*. Cast of the outer surface of a specimen, lying near the one represented by Fig. 2.
2*b*. Summit view of a compressed specimen with a campanulate margin. Collection U. S. National Museum.

STENOTHECA RUGOSA var. PAUPERA 617

FIG. 3. Side view of a specimen from Manuel's Brook, Conception Bay, Newfoundland. Collection U. S. National Museum.
7. Shaler & Foerste's figure of this variety.

STENOTHECA RUGOSA var. ERECTA 617

FIG. 4. Side view of type specimen, from Conception Bay, Newfoundland.

STENOTHECA RUGOSA var. LEVIS 617

FIG. 5. Side view of a specimen having three strong ridges. Collection U. S. National Museum.
5*a*. A nearly smooth specimen, from the same locality as the shell represented by Fig. 5; Conception Bay, Newfoundland. Collection U. S. National Museum.

STENOTHECA RUGOSA var. ABRUPTA 617

FIG. 6. An average size specimen. (After Shaler & Foerste.)
6*a*. Side view of a large specimen. (After Shaler & Foerste.)

STENOTHECA, sp. undetermined 712

FIG. 8. A small portion of a shell found in the hard limestones of Washington County, N. Y. Collection U. S. National Museum.

STENOTHECA ELONGATA 617

FIG. 9, 9*a*. Summit and lateral views of specimen from the Eureka district, Nevada. Collection, U. S. National Museum.
9*b*. Summit view of specimen from l'Anse au Loup. Collection U. S. National Museum.

STENOTHECA CURVIROSTRA 618

FIG. 10. Drawing made from a gutta-percha cast, taken in the matrix of the type specimen.

PLATYCERAS PRIMÆVUM 618

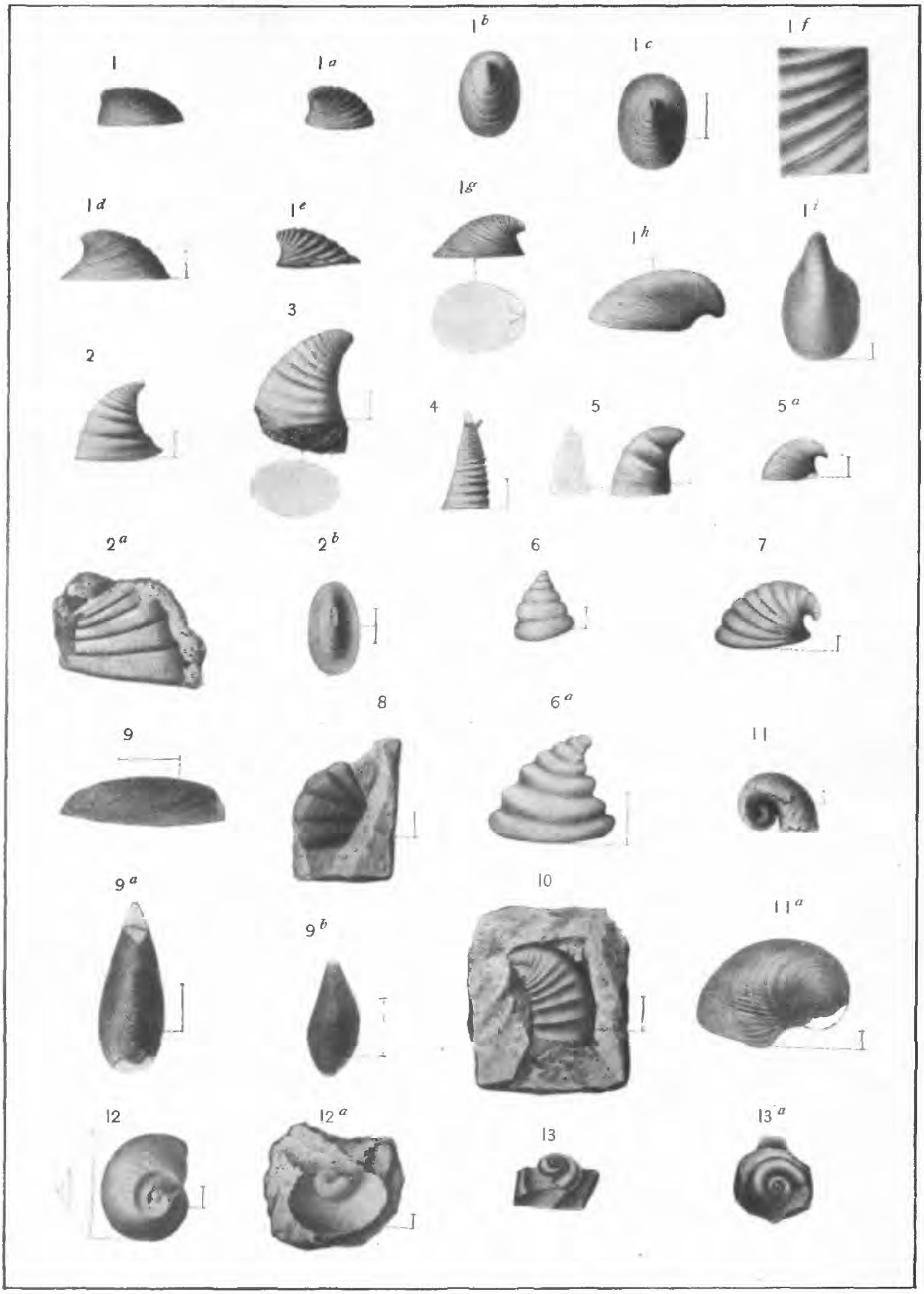
FIG. 11. View of cast, right side. Collection U. S. National Museum.
11*a*. Left side, enlarged to show characters of the outer surface of the shell. Collection U. S. National Museum.

PLEUROTOMARIA (R.) ATTLEBORENSIS 619

FIG. 12, 12*a*. Views of the type specimen. Collection Prof. N. S. Shaler.

STRAPAROLLINA REMOTA 619

FIG. 13, 13*a*. Summit and side views. (After Billings.)



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GASTEROPODA.

PLATE LXXV.

PLATE LXXV.

Page.

HYOLITHES BILLINGSI 620

FIG. 1, 1*a*, 1*b*. Lateral, ventral, and dorsal views of a specimen from Pioche, Nev. Collection U. S. National Museum.

1*c*. Transverse section of specimen from Pioche, Nev. Collection U. S. National Museum.

1*d*. Operculum associated with 1 in same fragment of rock. Collection U. S. National Museum.

1*e*. Specimen from l'Anse au Loup. Dorsal view and outline of transverse section. Collection U. S. National Museum.

HYOLITHES AMERICANUS 620

FIG. 2. Ventral view. Collection U. S. National Museum.

2*a*. Dorsal view of a narrow specimen. Compare with 2*b*. Collection U. S. National Museum.

2*b*. A small, unusually broad specimen. Collection U. S. National Museum.

2*c*, 2*d*. Opercula. Collection U. S. National Museum.

2*e*, 2*f*. Transverse sections showing differences in outline. Collection U. S. National Museum.

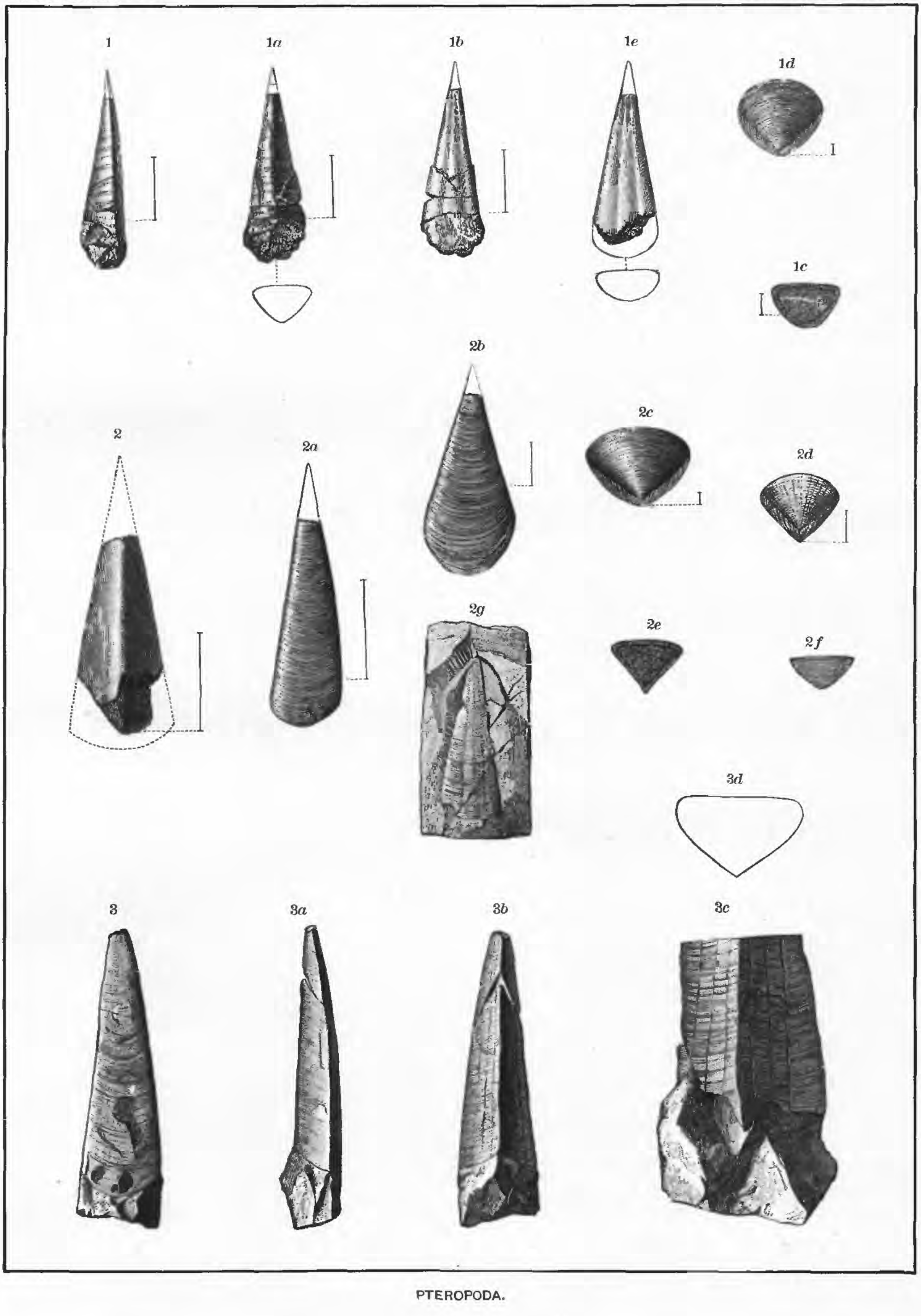
All the specimens of 2 from Troy, N.Y.

HYOLITHES SIMILIS 622

FIG. 3, 3*a*, 3*b*. Dorsal, lateral, and ventral views of a specimen from Conception Bay, Newfoundland. Collection U. S. National Museum.

3*c*. Enlargement to three diameters, to show surface characters. Collection U. S. National Museum.

3*d*. Transverse section of the end of 3*c*.



PTEROPODA.

PLATE LXXVI.

PLATE LXXVI.

Page.

HYOLITHES PRINCEPS.. 621

FIG. 1, 1*a*, 1*b*. Dorsal, ventral, and lateral views of a very perfect medium size shell. Collection U. S. National Museum.

1c. Transverse section of 1.

1*d*. Transverse section of 1*e*.

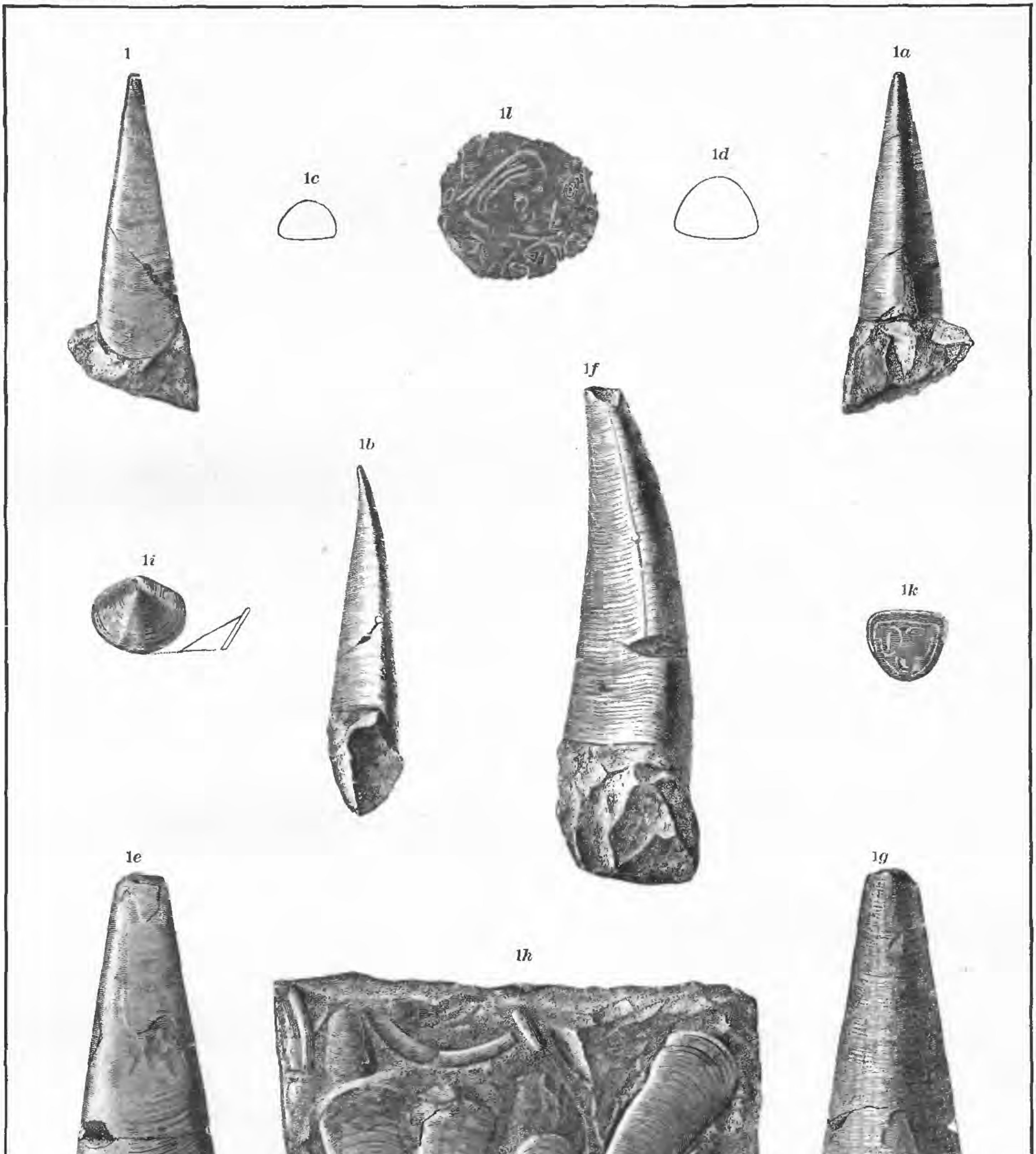
1*e*, 1*f*, 1*g*. Dorsal, lateral, and ventral views of a large shell. Collection U. S. National Museum.

1*h*. A group of shells lying on a slab of rock. Collection U. S. National Museum.

1*i*. Operculum associated with this species.

1*k*. Transverse section of a shell containing transverse sections of *Hyolithes quadricostatus* and *Helenia bella* inside of it.

1*l*. Broken sections of this species in association with sections of several other species.



PTEROPODA.

PLATE LXXVII.

PLATE LXXVII.

Page.

HYOLITHES IMPAR 621

FIG. 1, 1*a*. Lateral and ventral views of the type specimen. Collection of S. W. Ford.

1*b*. Outline of end of tube at point of septum and transverse section of same, enlarged. Collection U. S. National Museum.

1*c*. Transverse section of 1.

1*d*. Operculum from Troy, N. Y. Collection U. S. National Museum.

1*e*. Cast of tube, showing contraction at the septum. Collection U. S. National Museum.

1*f*. Dorsal ? view of a specimen from Conception Bay, Newfoundland. Collection U. S. National Museum.

HYOLITHES sp. undetermined 718

FIG. 2. From Troy, N. Y. Collection U. S. National Museum.

HYOLITHES COMMUNIS 620

FIG. 3, 3*a*. Dorsal and side views of specimen from Bic Harbor. Natural size. Collection U. S. National Museum.

3*b*. Another specimen from Bic Harbor. Collection U. S. National Museum.

3*c*. Operculum from Bic Harbor. Collection Geological Survey of Canada.

3*d*, 3*e*. Specimens from Troy, N. Y. Collection U. S. National Museum.

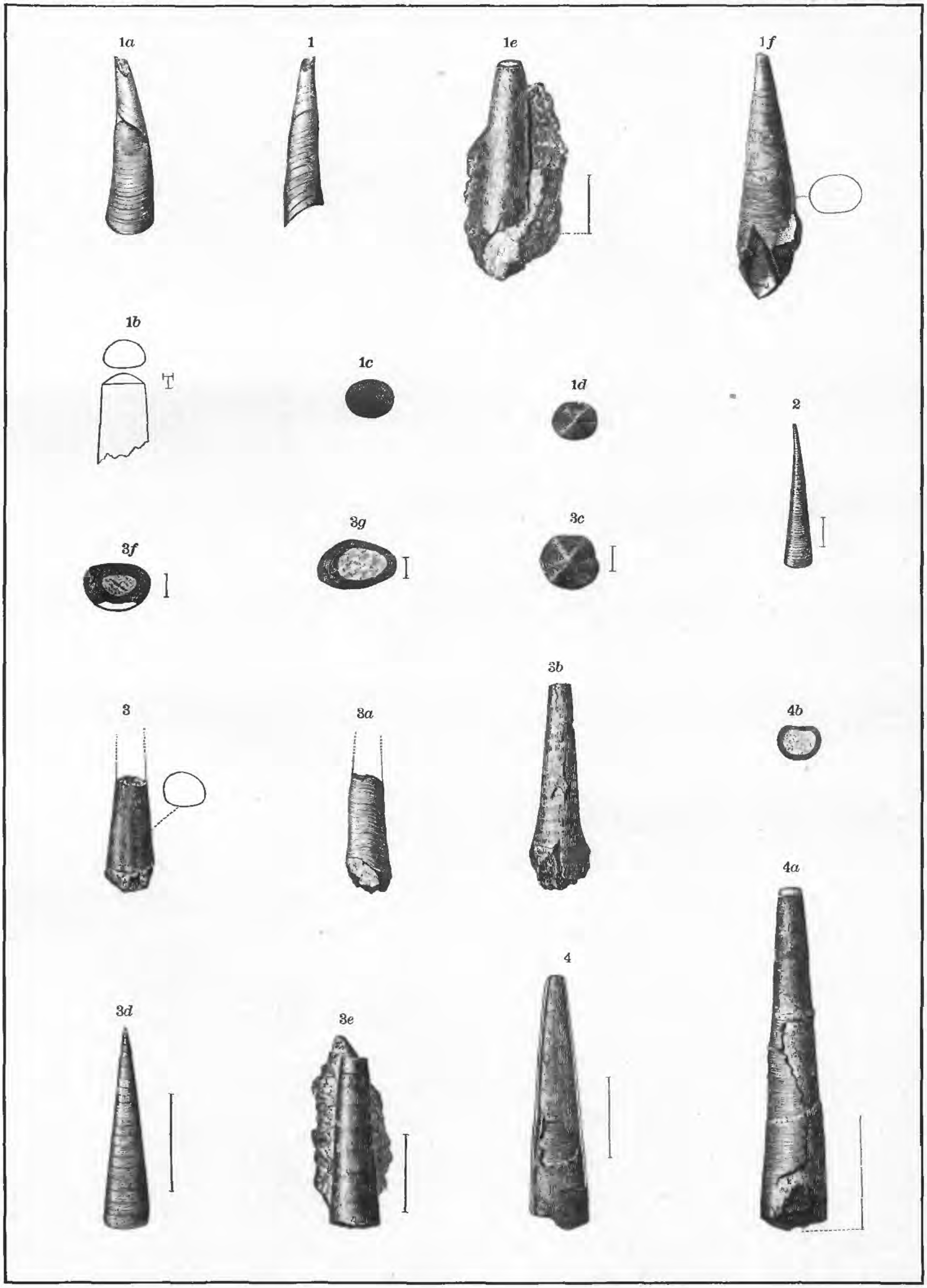
3*f*, 3*g*. Transverse section to show irregularities of thickness of shell. Collection U. S. National Museum.

HYOLITHES COMMUNIS var. EMMONSI 621

FIG. 4. Dorsal view of specimen showing evidence of three layers of shell and a septum. Collection U. S. National Museum.

4*a*. Ventral view of a specimen showing the constriction at the point of decollation of the apex. Collection U. S. National Museum.

4*b*. Transverse section of 4*a*.



PTEROPODA.

PLATE LXXVIII.

PLATE LXXVIII.

Page.

HYOLITHES QUADRICOSTATUS 621

FIG. 1, 1*a*, 1*b*. Dorsal, ventral, and lateral views of an average size specimen from Conception Bay, Newfoundland. Collection U. S. National Museum.

HYOLITHES sp. ? 720

FIG. 2. Section, in relief, of *Hyolithes princeps*, *H. similis*, and *H. quadricostatus*. Collection U. S. National Museum.

2*a*. View of the side of the block of which Fig. 2 represents the top.

HYOLITHES TERRANOVICUS 623

FIG. 3, 3*a*, 3*b*. Dorsal, lateral, and ventral views of a typical specimen. Collection U. S. National Museum.

3*c*. Enlargement to show the character of the ventral surface.

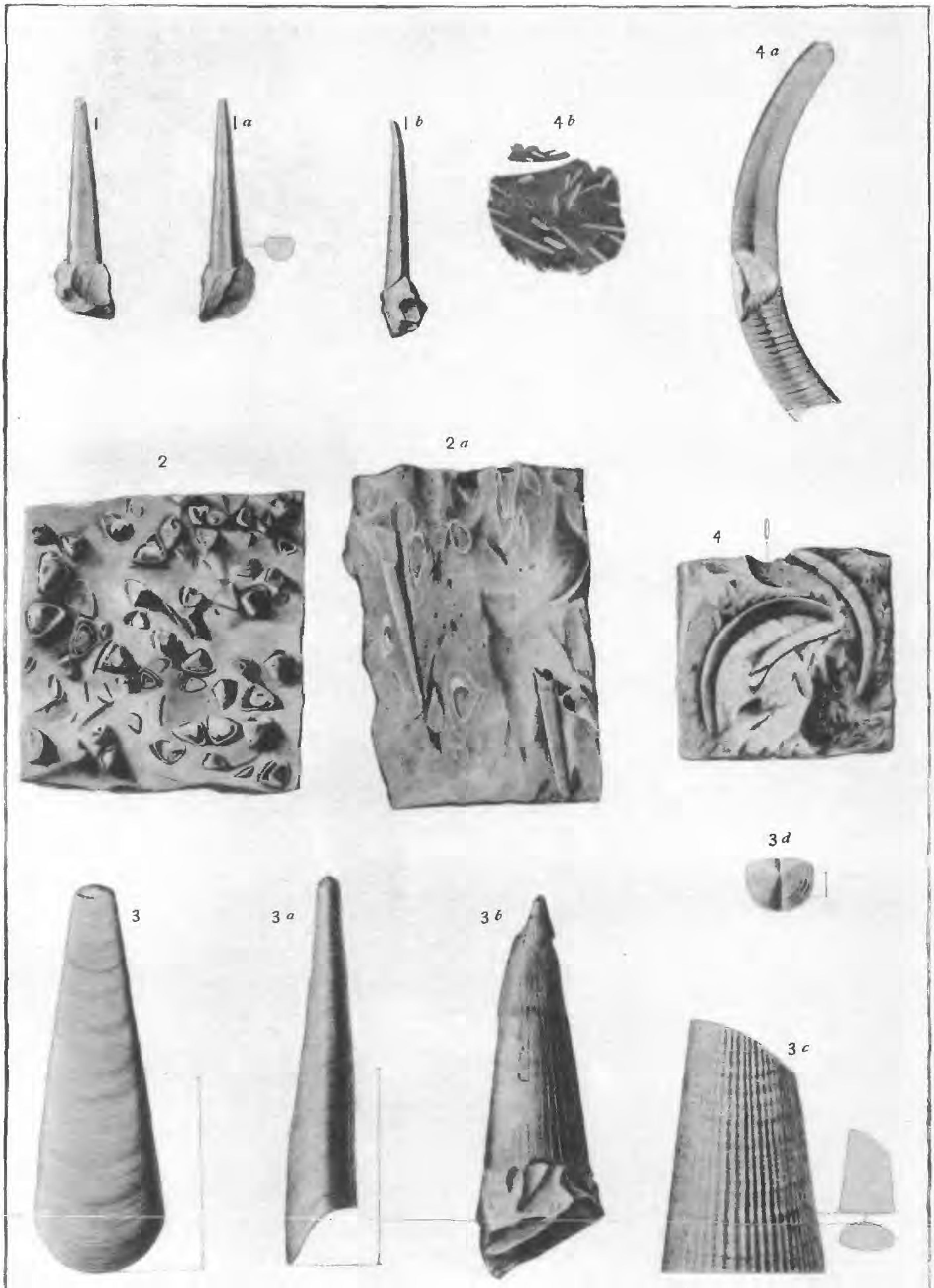
3*d*. Operculum associated with this species.

HELENIA BELLA 616

FIG. 4. A fragment of limestone, with two nearly entire shells. Collection U. S. National Museum.

4*a*. Enlargement of specimens, to show surface striæ,

4*b*. Sections of the shell shown in a thin slice of the rock.



Forbes Co., Boston.

PTEROPODA.

PLATE LXXIX.

PLATE LXXIX.

Page.

HYOLITHELLUS MICANS 624

FIG. 1. A fragment of the shell remaining in a natural mold, enlarged to show the annulations. Collection U. S. National Museum.

1*a*. Enlargement of the terminal portion of a tube. Collection U. S. National Museum.

1*b*. A crushed specimen in shale. Collection U. S. National Museum.

1*c*. Exterior of operculum. Collection U. S. National Museum.

1*d*. Cast of the interior of an operculum. Collection U. S. National Museum.

1*e*. Interior of an operculum. Collection U. S. National Museum. All specimens from Troy, N. Y., except 1*b*, which was found one mile below Schodack Landing.

HYOLITHELLUS MICANS *var.* RUGOSA 624

FIG. 2. Enlargement of fragment, to show the rugose surface. Collection U. S. National Museum.

SALTERELLA CURVATUS 625

FIG. 3, 3*a*. Illustrations of the type specimens. (After Shaler & Foerste.)

SALTERELLA RUGOSA 625

FIG. 4. Enlarged view of a specimen from L'Anse au Loup. Collection U. S. National Museum.

SALTERELLA PULCHELLA 625

FIG. 5. Lateral view of a specimen from a pebble in the Point Levis limestone conglomerate. Collection U. S. National Museum.

5*a*. A specimen from same locality, showing the aperture and one of the inner tubes. Collection U. S. National Museum.

5*b*, 5*c*. Casts of specimens in the "Red Sandrock," east of Highgate Springs, Vt. Collection U. S. National Museum.

5*d*, 5*e*. Specimens from the "Winooski" marble, near Swanton, Vt. These probably belong to a different species. Collection U. S. National Museum.

COLEOLOIDES TYPICALIS 624

FIG. 6. Enlargement to three diameters, to show form of tube. Collection U. S. National Museum.

6*a*. Further enlargement to show the elevated spiral striæ.

VOLBORTHELLA TENUIS 722

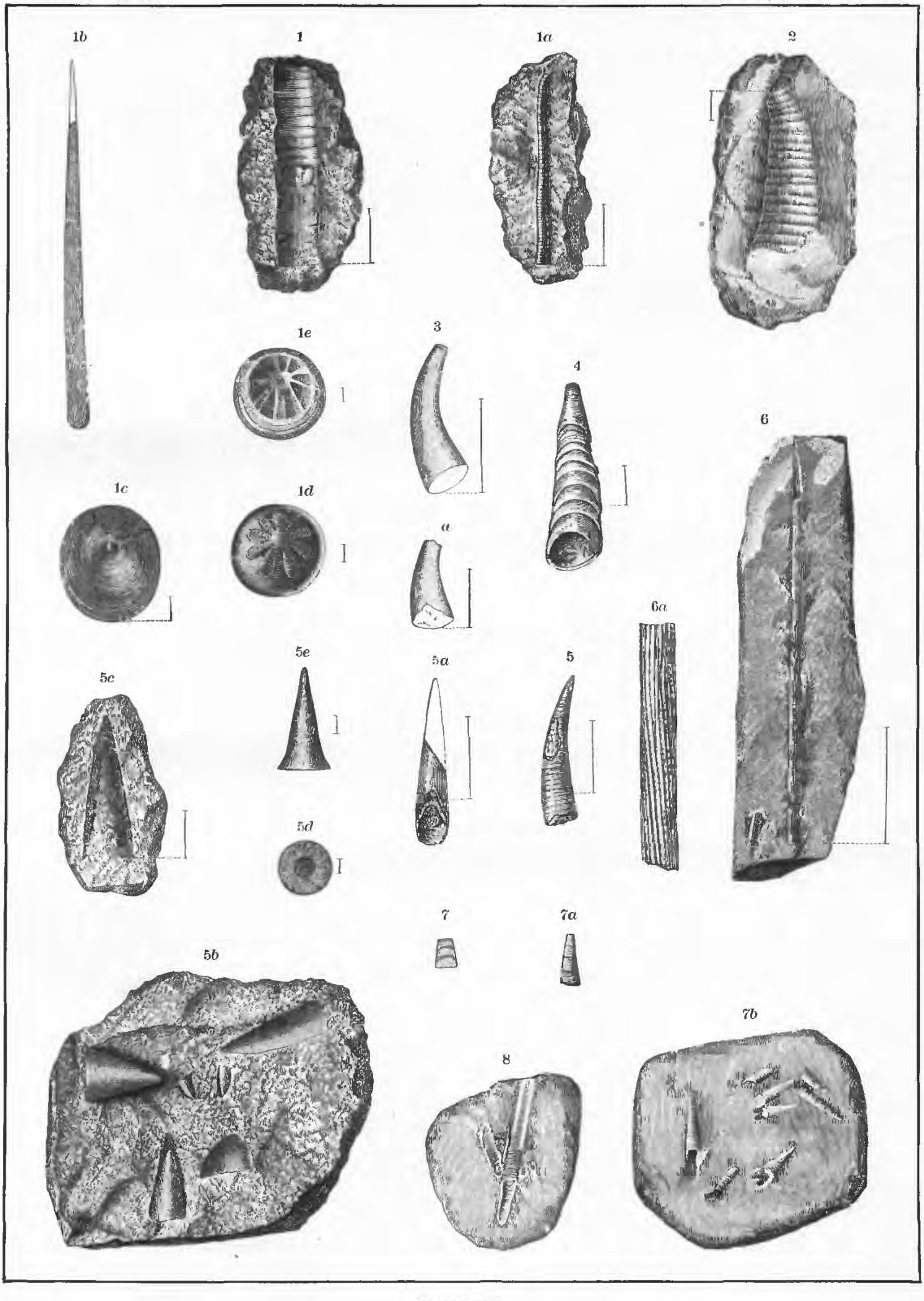
FIG. 7. Longitudinal section of tube. (After Schmidt.)

7*a*. Exterior view of tube. (After Schmidt.)

7*b*. Fragment of rock with several tubes upon it. (After Schmidt.)

PLATYSOLENITES ANTIQUISSIMUS 722

FIG. 8. Large examples on a fragment of sandstone. (After Schmidt.)



PTEROPODA.

PLATE LXXX.

PLATE LXXX.

LEPERDITIA (I.) DERMATOIDES.. 626

FIG. 1. Left (?) valve and outlines of its convexity.

1*a*. Enlargement to show punctate surface and the wrinkled appearance of the test, as seen on some specimens.

ARISTOZOE TROYENSIS.. 628

FIG. 2. Right valve, from Troy, N. Y. Collection U. S. National Museum.

2*a*. Cast of left valve, from Washington County, N. Y. Collection U. S. National Museum.

ARISTOZOE ROTUNDATA.. 627

FIG. 3. Cast of the right valve. A row of vascular markings are quite distinctly shown on the lower portion of the valve.

NOTHOZOE VERMONTANA.. 628

FIG. 4. A nearly circular valve. Collection U. S. National Museum.

4*a*, 4*b*. Right and left valves, embedded in the "granular quartz" rock. Collection U. S. National Museum.

AGNOSTUS DESIDERATUS.. 629

FIG. 5. Head shield, enlarged. Collection U. S. National Museum.

AGNOSTUS, sp. undetermined.. 630

FIG. 6. Head shield.

6*a*. Pygidium associated with the head represented by Fig. 6.

MICRODISCUS PARKERI.. 632

FIG. 7, 7*a*. Head and pygidium, enlarged. Collection U. S. National Museum.

AGNOSTUS ? NOBILIS.. 629

FIG. 8. Copy of Mr. S. W. Ford's original figure. Type specimen lost.

MICRODISCUS CONNEXUS.. 631

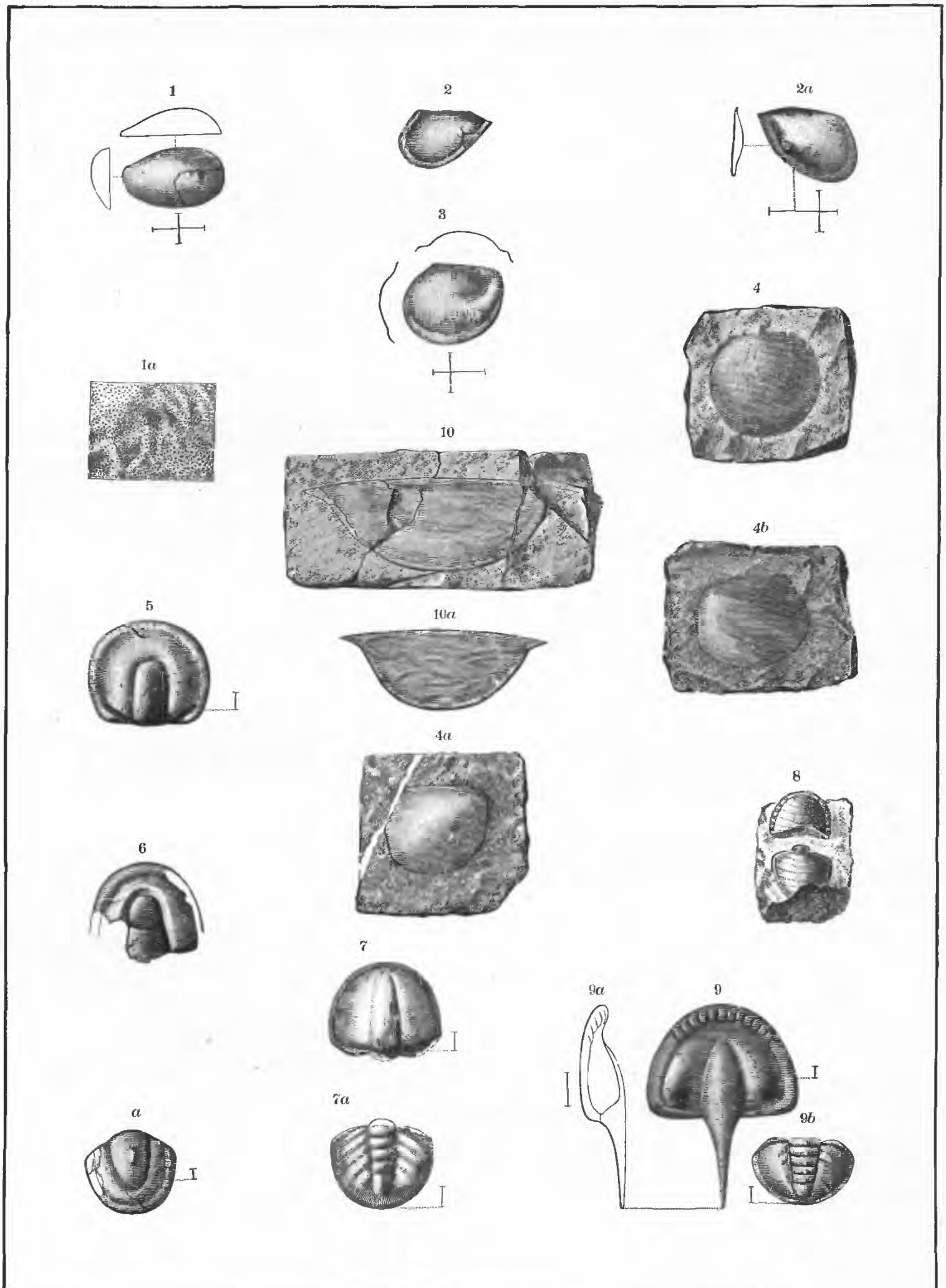
FIG. 9, 9*a*. Summit and side views of head.

9*b*. Associated pygidium.

ISOXYS CHILHOWEANA.. 626

FIG. 10. Cast in clay shale of a portion of one valve and on the left side a portion of the opposite valve. Natural size. Collection U. S. National Museum.

10*a*. A very perfect specimen showing the characters of the carapace as far as known. Collection U. S. National Museum.



CRUSTACEA AND TRILOBITA.

PLATE LXXXI.

PLATE LXXXI.

Page.

MICRODISCUS HELENA 632

FIG. 1. View of head from above, with outline of side view. Collection U.S. National Museum.
1*a*. Pygidium associated with this species.

MICRODISCUS BELLIMARGINATUS 630

FIG. 2. Copy of original figure of the species, by Schaler & Foerste.
2*a*. View of head from above, with outline of side view. Collection U.S. National Museum.
2*b*. Pygidium associated with the head represented by Fig. 2*a*. Collection U.S. National Museum.

MICRODISCUS MEEKI 632

FIG. 3. View of head from above, and side view in outline, drawn from type specimen. Collection S. W. Ford.

MICRODISCUS LOBATUS 632

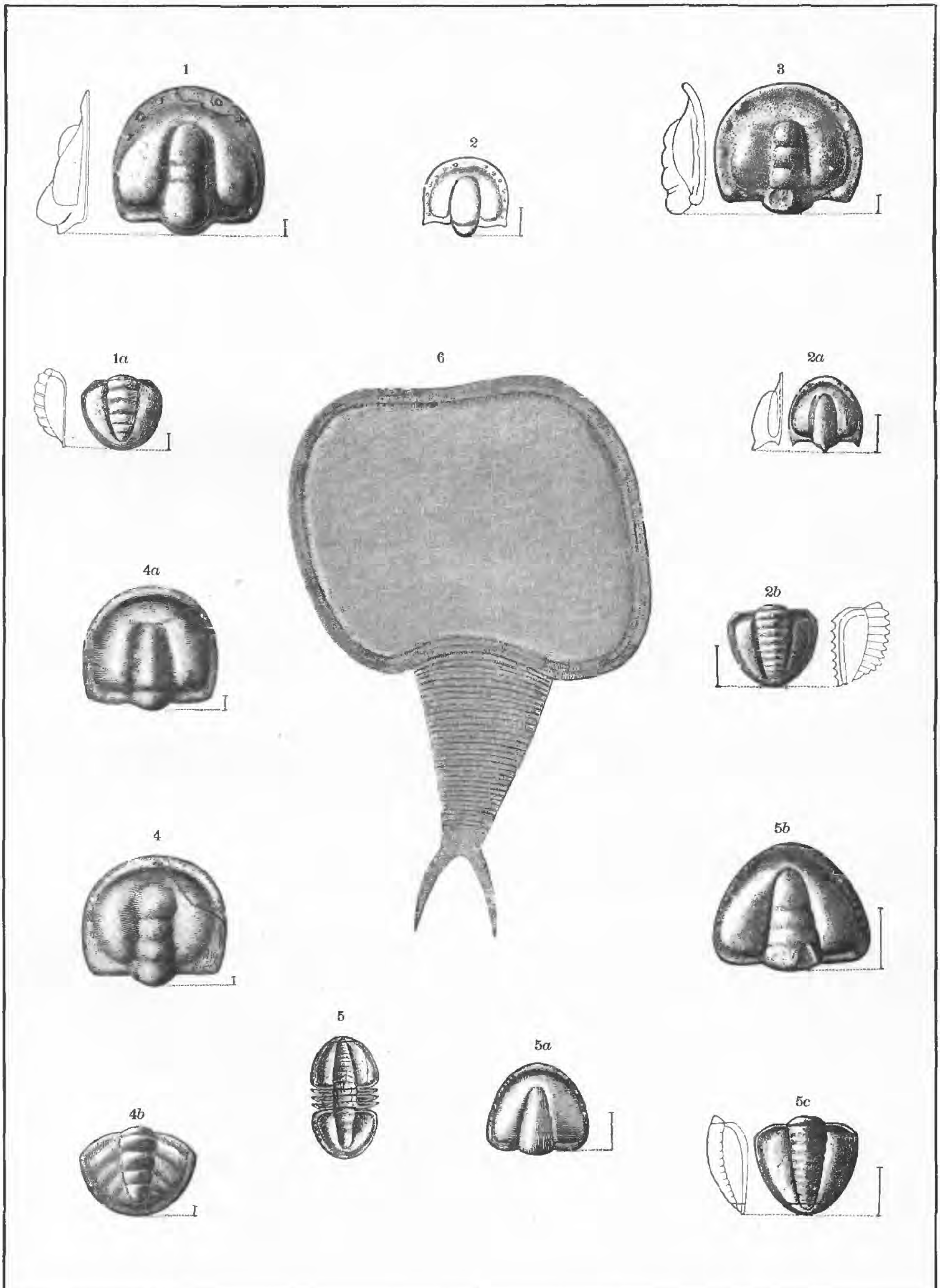
FIG. 4. Head, very much enlarged. Collection U.S. National Museum.
4*a*. Head, showing considerable variation from 1. Collection U.S. National Museum.
4*b*. Pygidium, very much enlarged. Collection U.S. National Museum. Original specimens from Troy, N. Y.

MICRODISCUS SPECIOSUS 632

FIG. 5. Entire specimen from Washington County, N.Y. Collection U.S. National Museum.
5*a*, 5*b*. Two very perfect head shields. Collection U. S. National Museum.
5*c*. Pygidium associated with 5*a*.

PROTOCARIS MARSHI 629

FIG. 6. Figure given in Bulletin 10, U. S. Geological Survey. Pl. X. Description on page 50. Reproduced here in order to show the Lower Cambrian fauna, as known to me, in one series of plates. Collection U.S. National Museum.



CRUSTACEA AND TRILOBITA.

PLATE LXXXII.

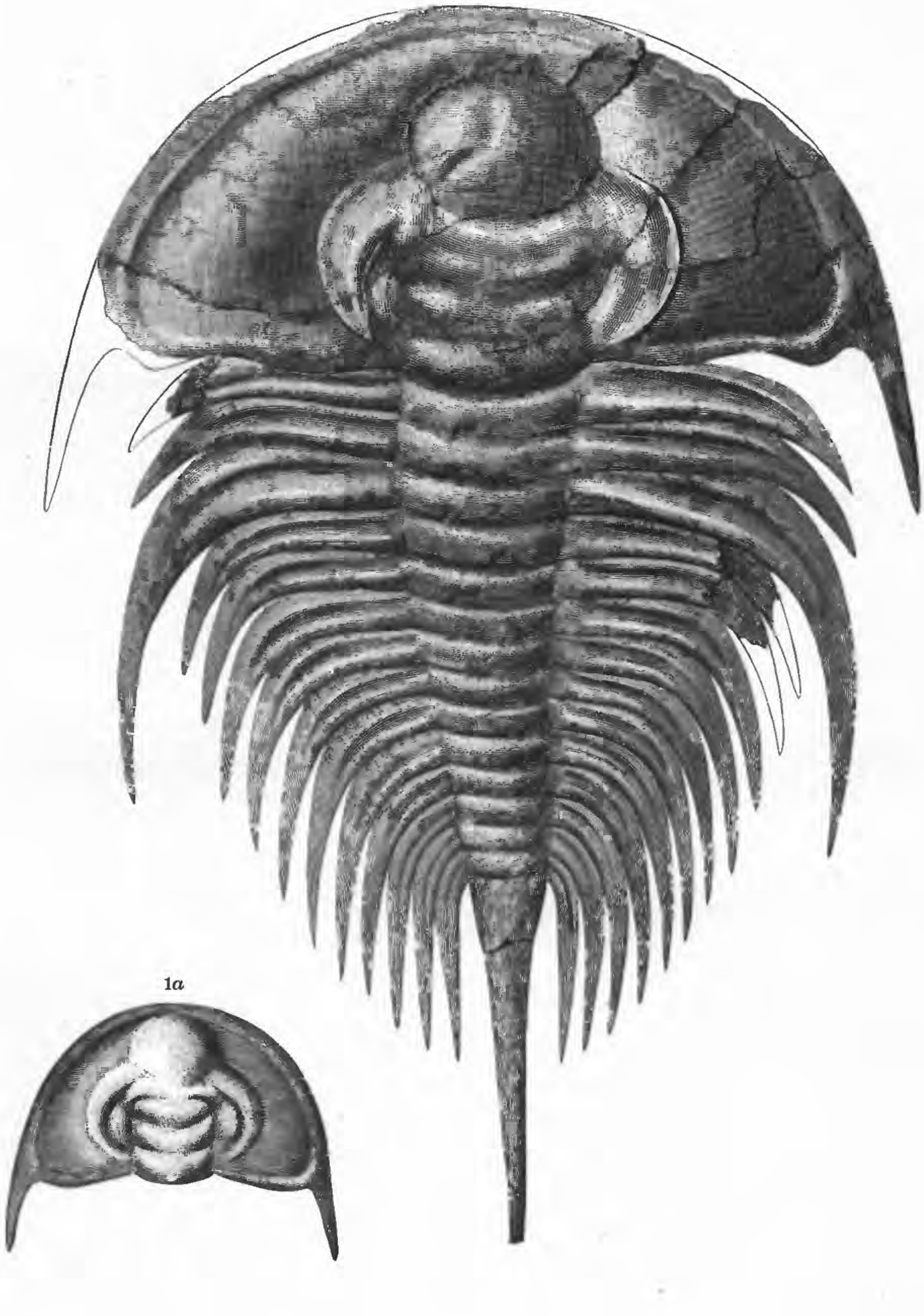
PLATE LXXXII.

	Page.
OLENELLUS THOMPSONI	635

FIG. 1. A large individual with the third segment unusually prolonged. From the type locality at Parker's quarry, Georgia, Vt. Collection U.S. National Museum.

1*a*. A very perfect head, preserving the natural convexity, from the decomposed magnesian limestone east of Swanton. As portions of the specimen were broken away other specimens were used to aid the draughtsman in representing an entire head. Collection U.S. National Museum.

(See Pl. LXXXIII.)



TRILOBITA.

PLATE LXXXIII.

PLATE LXXXIII.

	Page.
OLENELLUS THOMPSONI	635

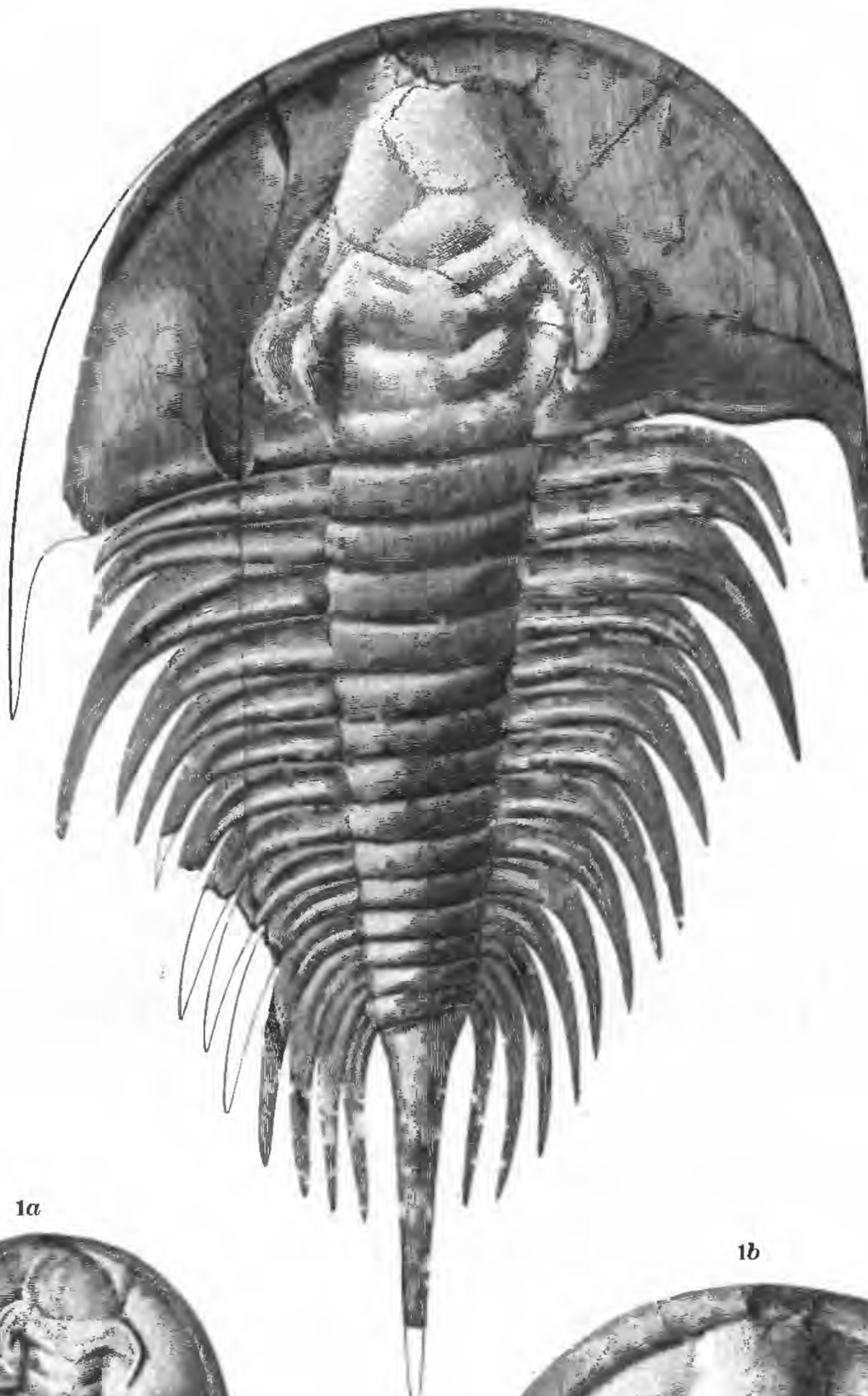
FIG. 1. A nearly perfect specimen from Parker's quarry. As compared with Fig. 1, Pl. LXXXII, this may be considered the narrow form of the species. Collection U. S. National Museum.

1*a*. Entire specimen from fine argillaceous shales at Parker's quarry. Collection U. S. National Museum.

1*b*. Head, with an unusually broad border, from Swanton, Vt. Collection U. S. National Museum.

(See Pl. LXXXII.)

1



1a

1b

TRILOBITA.

PLATE LXXXIV.

PLATE LXXXIV

Page

OLENELLUS GILBERTI 636

FIG 1 Normal form of the species, except the unusual prolongation of the third segment Collection U S National Museum

1*a* Outline of the specimen from which Fig 1 was enlarged Natural size

1*b* 1*c* Top and lateral views of type specimen from Pioche, Nev Collection U S National Museum

1*d* Side of head, showing line of narrow groove on inside of the test at *o x*, corresponding to position of suture in Paradoxides Collection U S National Museum

1*e* A portion of a head referred to this species, showing the same carrying forward of the genal angles that is shown in specimens from the Eureka district and Groom district, Nevada Collection U S National Museum

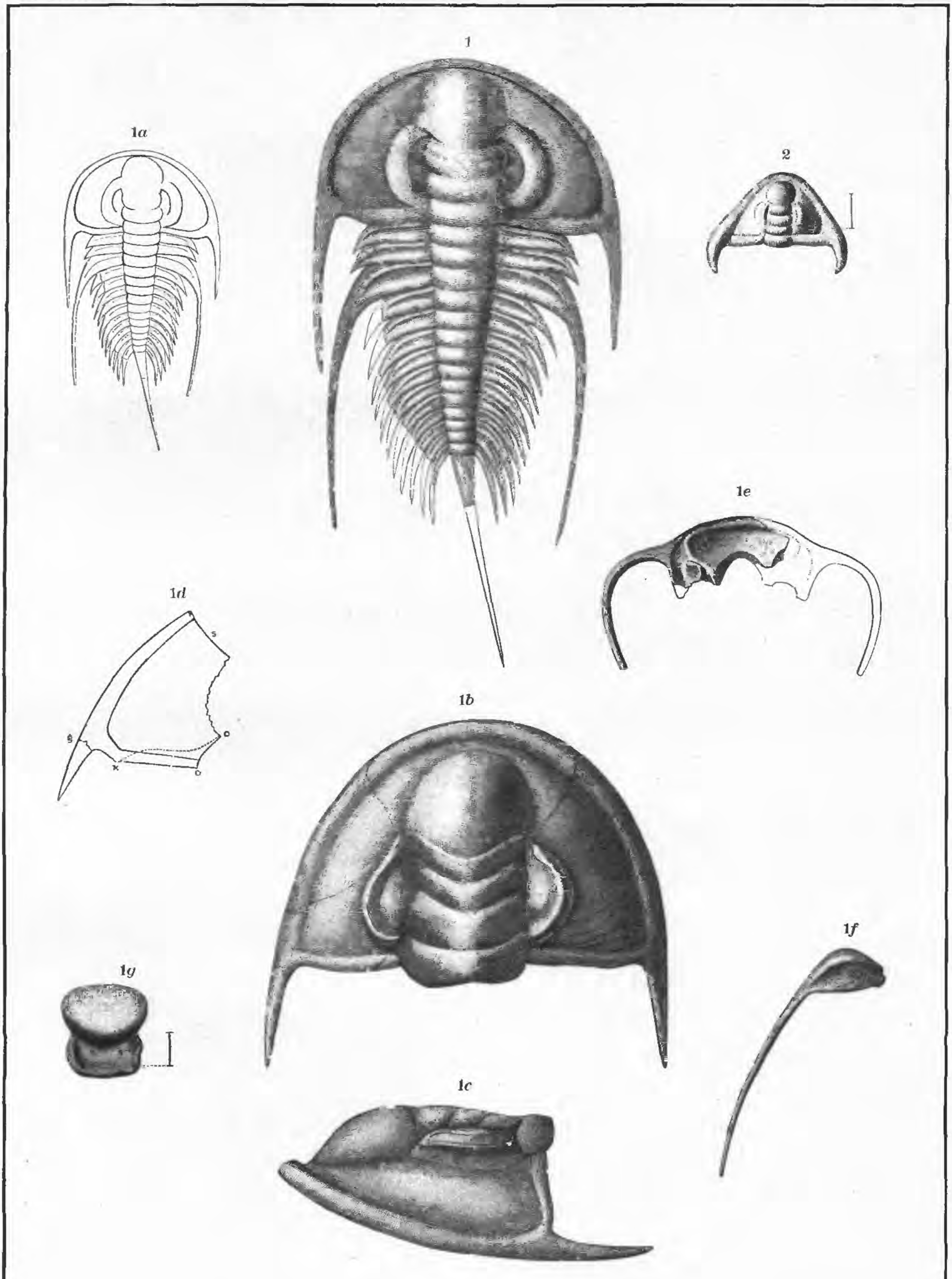
1*f* Prolonged pleura of third (?) segment of this species Associated with 1*g*

1*g* Hypostoma associated with this species in the Eureka district, Nevada Collection U S National Museum

(See Pls LXXXV and LXXXVI)

OLENELLUS IDDINGSI 636

FIG 2 View of the type specimen enlarged to two diameters Collection U S National Museum



TRILOBITA.

PLATE LXXXV.

PLATE LXXXV.

	Page.
OLENELLUS GILBERTI	636

FIG. 1. Specimen broadened by longitudinal compression. The head shows features observed in the series of heads figured on Pl. LXXXVI. The long, slender extremities of the genal spines and the terminations of the third thoracic segments are not often observed. Collection U. S. National Museum.

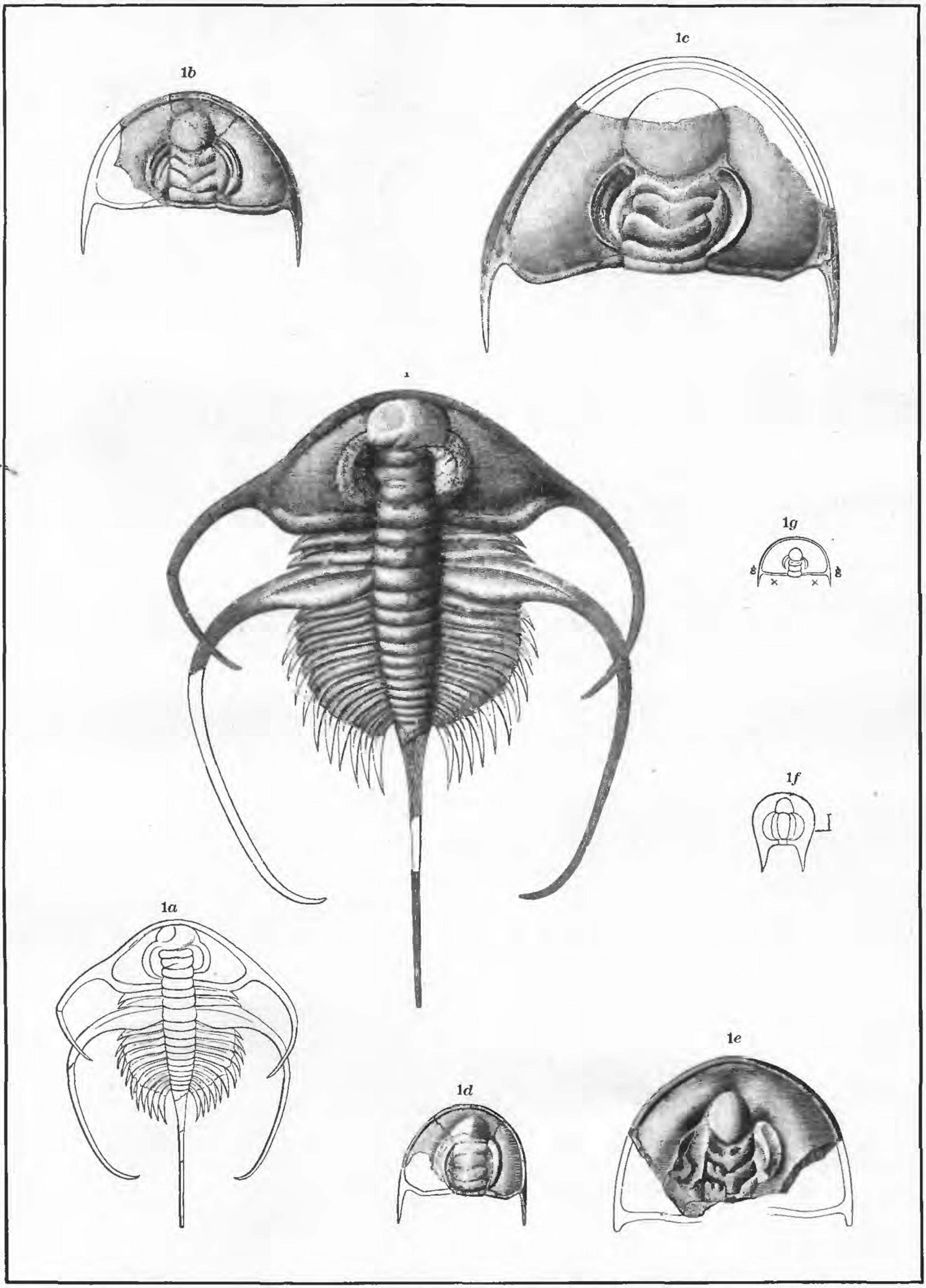
1*a*. Outline of figure from which Fig. 1 was enlarged. Natural size.

1*b*, 1*c*, 1*d*. Figures of the type specimens illustrated by Dr. White, from Pioche, Nev.

1*e*, 1*f*. Specimens from the Eureka district, Nev. Collection U. S. National Museum.

1*g*. A worn specimen of a young individual of this species or *Olenellus iddingsi*. Groom district, Nev. Collection U. S. National Museum.

(See Pls. LXXXIV and LXXXVI.)



TRILOBITA.

PLATE LXXXVI.

PLATE LXXXVI.

Page.

OLENELLUS GILBERTI 636

FIG. 1, 1*c*. Smallest specimen of the head in the collection; eyes distinct from the glabella.

1*a*. A larger specimen than 1, but with the genal angles carried forward, while the eyes are close to the glabella.

1*b*. Genal angles normal, but eyes united to the glabella by an ocular ridge.

1*d*. Head showing the anterior position of the genal spines, *gg*, and the angles of the posterior margin, *xx*, extravagantly developed. The difference in the length of the ocular ridges of the right and left side is also very marked. Natural size.

1*e*. The smallest individual in which the depression indicating posterior course of the false facial suture was observed. The outline of the head is much like that of Fig. 1. Natural size.

1*f*. A specimen from southern Nevada, with the genal spines still further advanced than those of 1*d*.

1*g*. Form intermediate in contour of head between Figs. 1*d* and 1*e*. *gg*, Genal angles and spines; *xx*, angles of the posterior margin. Natural size.

1*h*. The eyes in this specimen are no longer pedunculated or united to the glabella by an ocular ridge, and the genal angles are more posterior. The course of the false facial suture, in front of the eye, is also seen for the first time. Natural size.

1*i*. Example in which the genal angles are in the same position as in the adult individual in species of this genus. The eyes are more embryonic in character than in the preceding example. Natural size.

1*k*. Broader and more common form, showing the same peculiarities as Fig. 1*m*. Natural size.

1*l*. The right and left sides are irregularly developed, the genal spine on the left side being more anterior in position. The course of the false facial suture is traced in accordance with its position, as observed in Fig. 1*h*. Natural size.

1*m*. Narrow form, with the eyes of the adult type, and having the genal angles carried forward, as in the younger individuals, 1*c*, 1*e*, 1*h*. Natural size.

All the originals of the above are in the collection of the U. S. National Museum.

(See Pls. LXXXIV and LXXXV.)

OLENELLUS (H.) KJERULFI 634

FIG. 2. Outline of head showing the position of the genal angles and angles of the posterior margin, *xx*, with the interocular spine; also the ocular ridge (*a*) uniting the glabella and eyes. (After Linnarsson.)

OLENELLUS (M.) ASAPHOIDES 637

FIG. 3. Embryonic form, showing the circular outline, the genal spines in close proximity to the interocular spines. X 35. (After Ford.) Collection S. W. Ford.

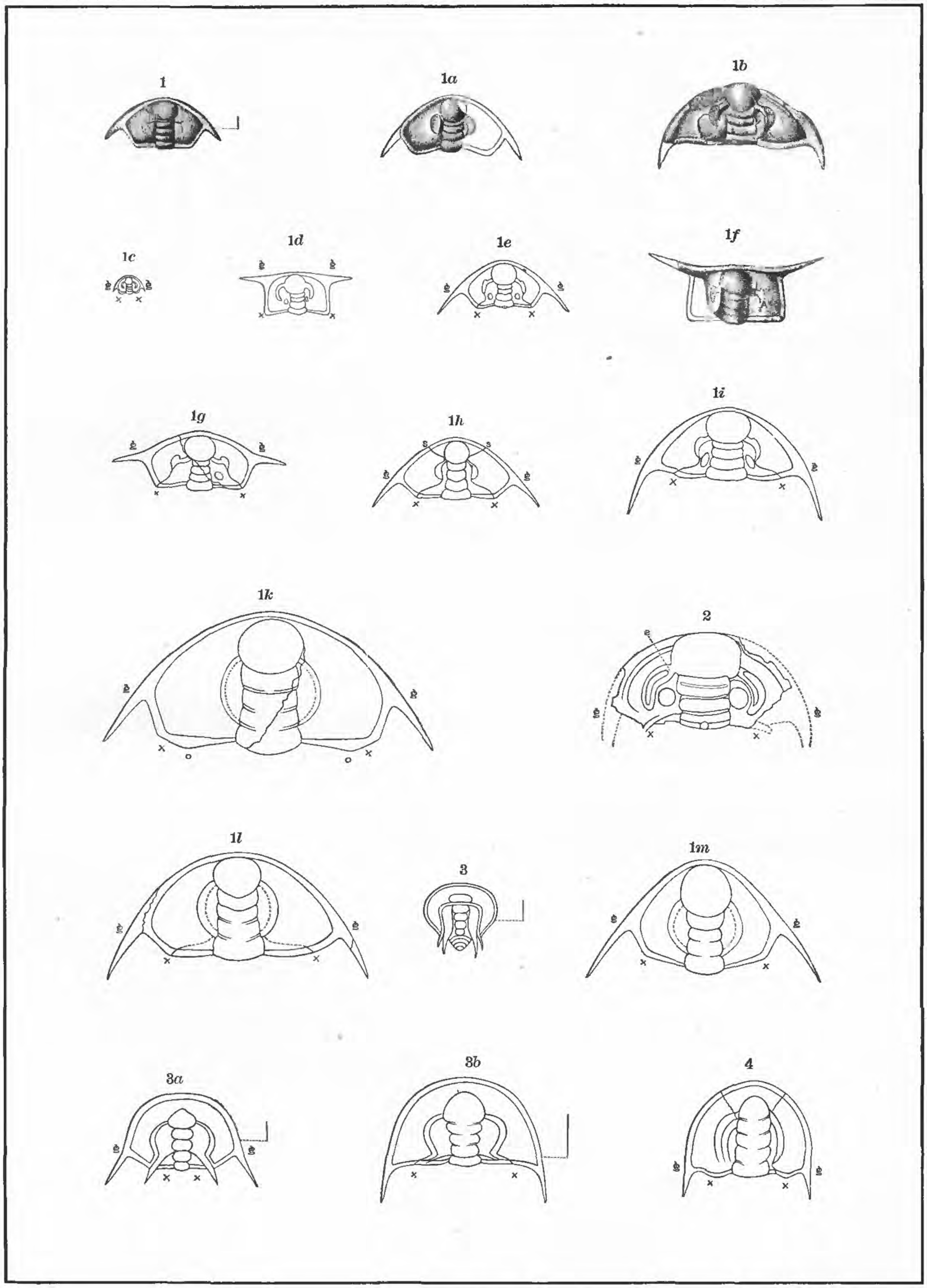
3*a*. Another phase of the development of this species, succeeding, with probably intermediate forms, Fig. 3. The position of the genal spine, *gg*, and the false sutures cutting the posterior margin at the angles *xx*, is comparable to the same in Fig. 1*e*. X 5. (After Ford.) Collection S. W. Ford.

3*b*. Normal adult type of the head of this species. X 2. (After Ford.) Collection S. W. Ford.

(See Pls. LXXXVIII, LXXXIX and XC.)

OLENELLUS GILBERTI 636

FIG. 4. Narrow form of head, that shows the angles in the posterior margin, *xx*, slightly developed. Natural size. (After White.) Collection U. S. National Museum.



TRILOBITA.

PLATE LXXXVII.

PLATE LXXXVII.

	Page.
OLENELLUS (MESONACIS) VERMONTANA	637

FIG. 1. Copy of the original figure of the type specimen of the species. Collection American Museum of Natural History, New York City.

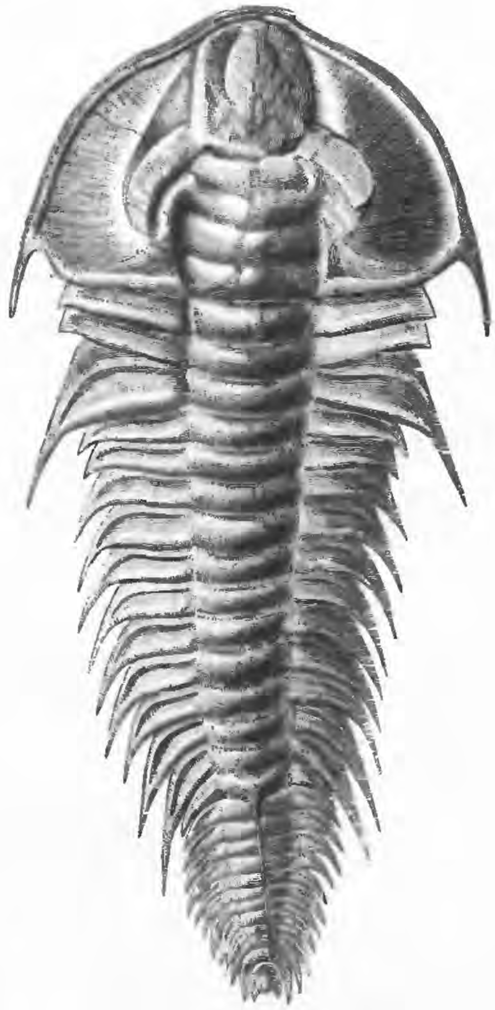
1*a*. A very perfect specimen from the collection of Mr. E. Hurlburt. The matrix is in the U. S. National Museum.

1*b*. Enlargement of the posterior portion of 1*a*. The spine projecting from the fifteenth segment is flattened down on the thorax more than is shown in the figure.

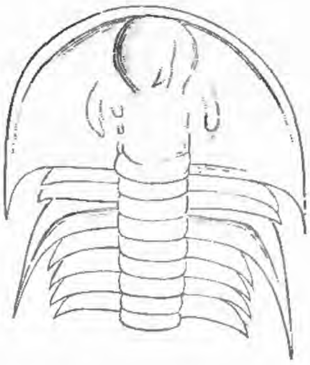
PARADOXIDES RUGULOSUS	738

FIG. 2. Pygidium and four posterior thoracic segments, enlarged after Barrande (Syst. Sil. Bohême, vol. i, Pl. ix, Fig. 31, 1852). It is introduced for comparison with Fig. 1*b*.

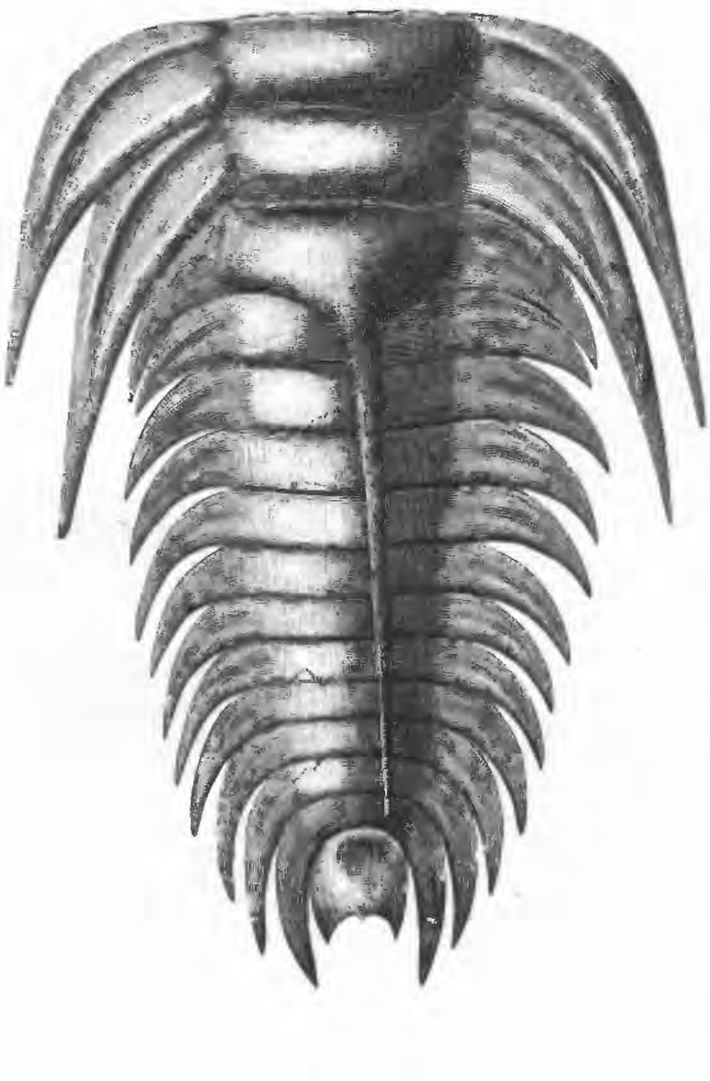
1a



1



1b



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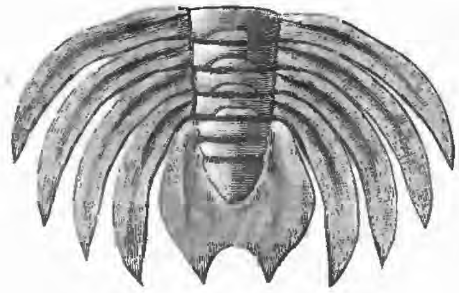


TRILOBITA.

PLATE LXXXVIII.

PLATE LXXXVIII.

Page.

OLENELLUS (MESONACIS) ASAPHOIDES 637

FIG. 1. The youngest stage of development of this species yet observed by the writer. Length, four-fifths of one millimeter. Collection U. S. National Museum.

1*a*. A slightly larger specimen than that represented by 1*b*. It is 1.75^{mm} in length. Collection U. S. National Museum.

1*b*. A young individual, showing embryonic features in the head and the great prolongation of the third thoracic segment. Collection S. W. Ford.

1*c*. A larger specimen than that represented by Fig. 1*b*, in which the third thoracic segment is shorter. Collection S. W. Ford.

1*d*. A small individual in which the third segment of the thorax is the same as the other segments, and the head has the essential characters of the adult with the exception of the slight prolongation of the interocular spine. Collection S. W. Ford.

1*e*. Enlargement of a portion of the surface of the lateral cheek.

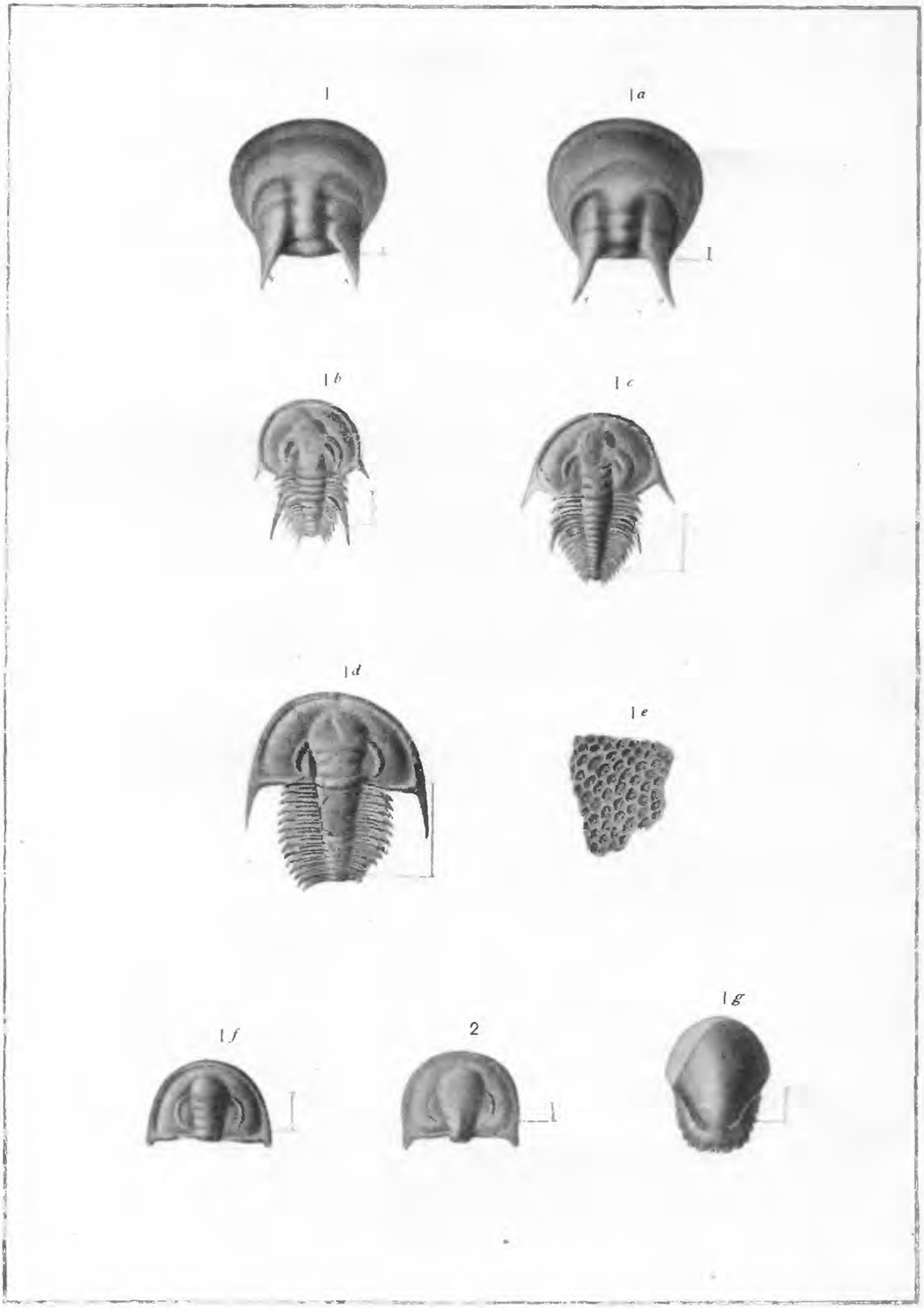
1*f*. Enlargement of a small head, for comparison with Fig. 2.

1*g*. Hypostoma referred to this species. Collection U. S. National Museum.

(See Pls. LXXXVI, LXXXIX and XC.)

OLENELLUS WALCOTTI 636

FIG. 2. Enlargement of the type specimen. The glabella is slightly crushed, so as to make it narrower at the base than when in a natural condition. Compare with Fig. 1*f*. Collection U. S. National Museum.



Forbes Co., Boston.

TRILOBITA

PLATE LXXXIX.

PLATE LXXXIX.

Page.

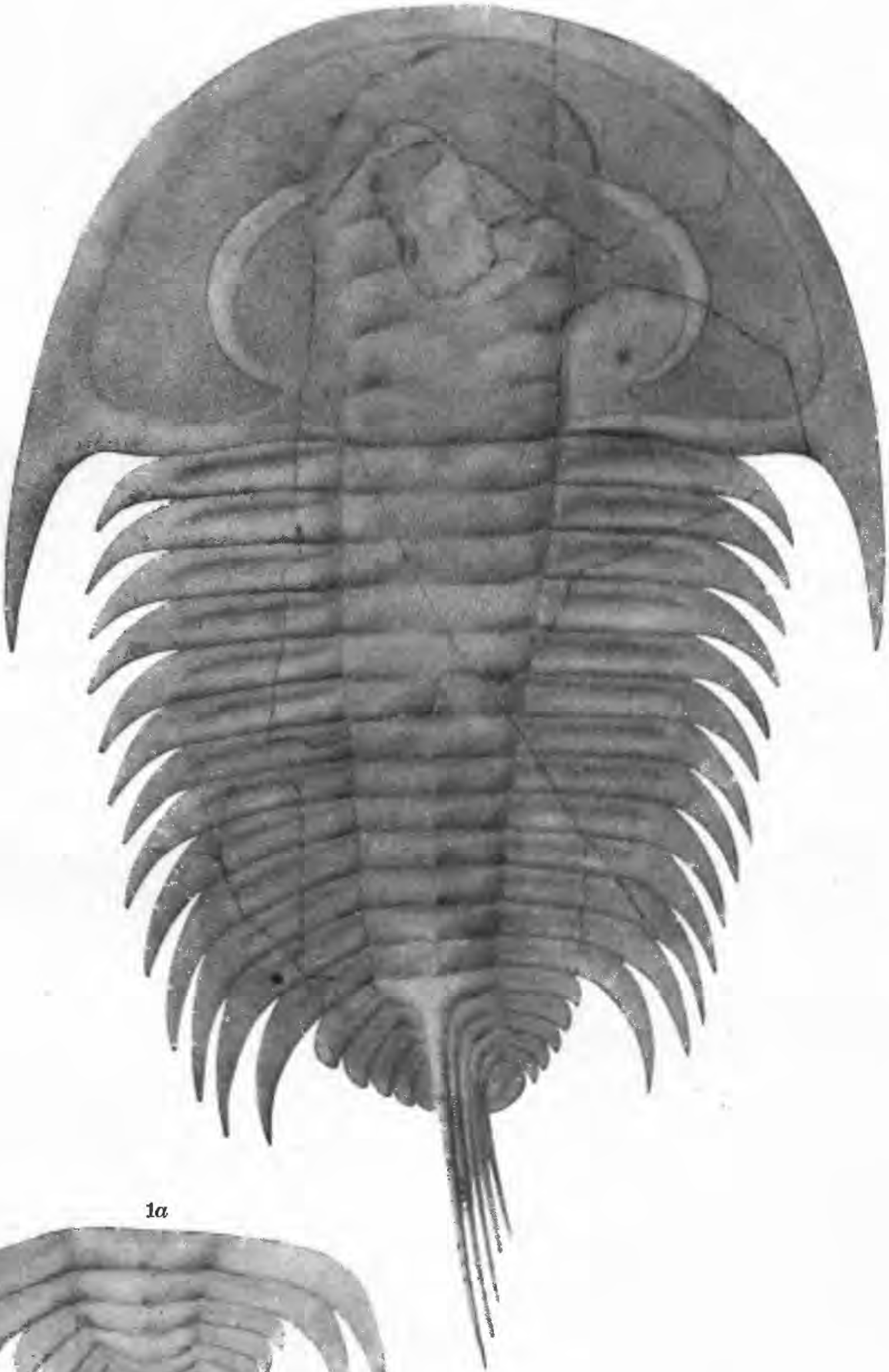
OLENELLUS (MESONACIS) ASAPHOIDES.. 637

FIG. 1. A specimen from the type locality of the species in Washington County, N. Y. The spines on the posterior segments have been restored from another specimen. Collection U. S. National Museum.

1*a*. Pygidium and posterior segments of Fig. 1, without the thoracic spines.

(See Pls. LXXXVI, LXXXVIII and XC.)

1



1a

TRILOBITA.

PLATE XC.

PLATE XC.

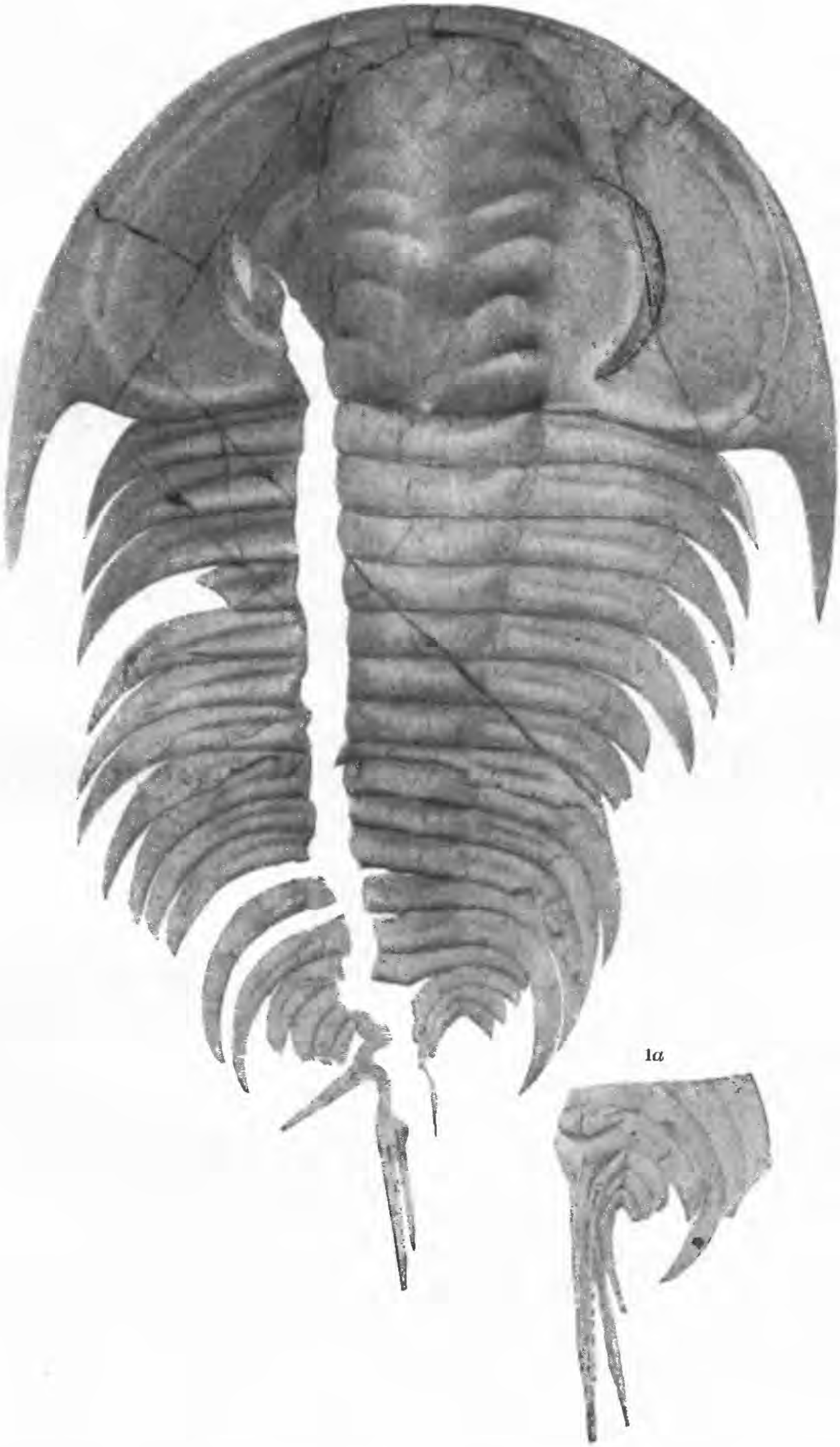
	Page.
OLENELLUS (MESONACIS) ASAPHOIDES	637

FIG. 1. A large individual from the type locality of the species. No attempt at restoration is made in any part. Collection U. S. National Museum.

1*a*. Fragment preserving the posterior segments and spines. Collection U. S. National Museum.

(See Pls. LXXXVI, LXXXVIII and LXXXIX.)

1



1a

TRILOBITA.

PLATE XCI.

PLATE XCI.

Page.

OLENELLUS (HOLMIA) BRÖGGERI 638

FIG. 1. Restoration of this species, based on a large number of partially preserved fragments in the limestone and numerous nearly entire specimens compressed in the shale. The specimens in the limestone show the convexity and those in the shale the general proportions and number of segments.

(See Pl. XCII.)

1

TRILOBITA.

PLATE XCII.

PLATE XCII.

	Page.
OLENELLUS (HOLMIA) BRÖGGERI	638

FIG. 1. An uncompressed head in the decomposed limestone. Collection U. S. National Museum.

1*a*. Outline view of the side of 1.

1*b*. Lateral cheek, showing genal spine. Collection U. S. National Museum.

1*c*. Pygidium and posterior segments. Collection U. S. National Museum.

1*d*. Termination of pleura, enlarged to two diameters. Collection U. S. National Museum.

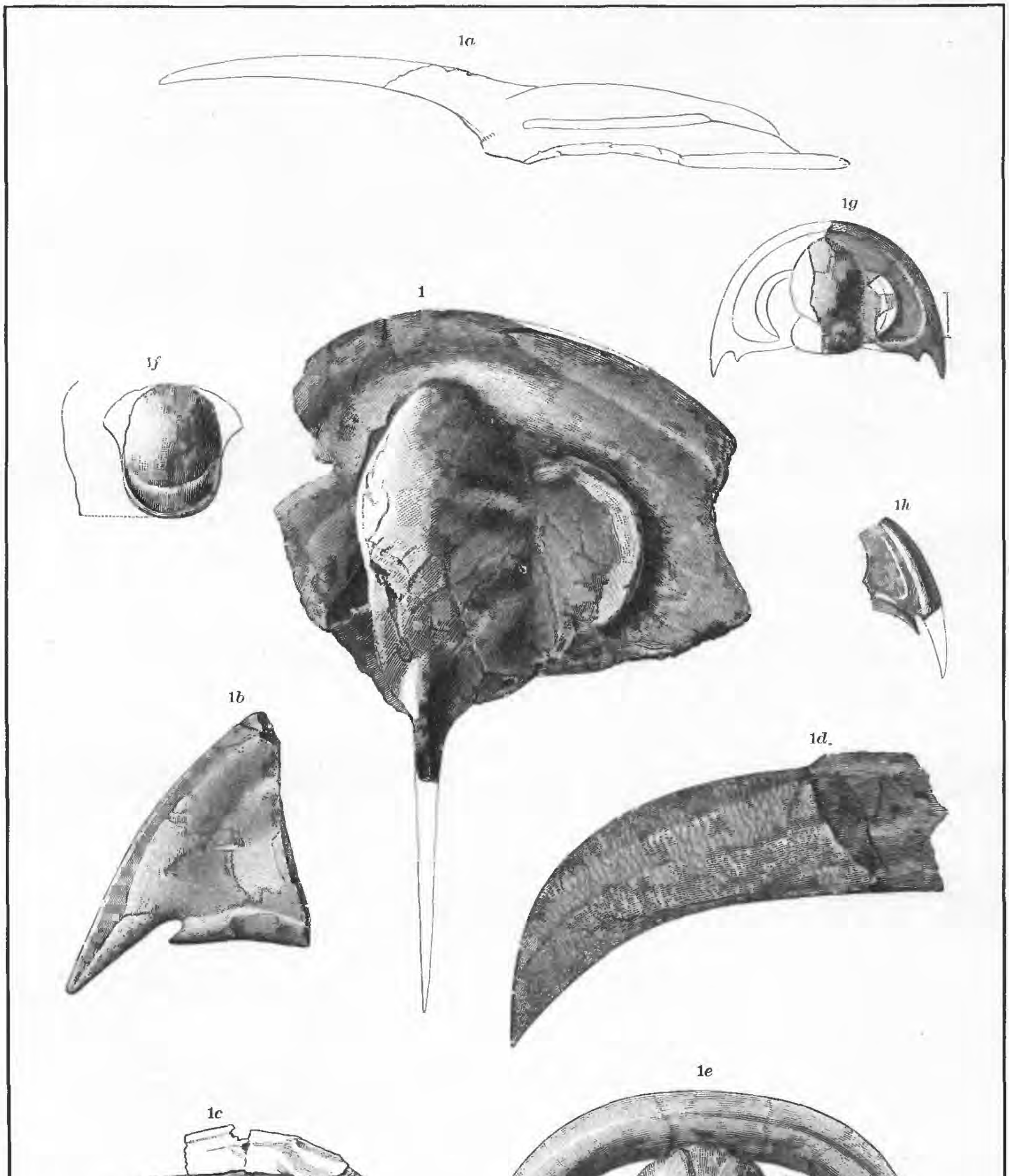
1*e*. Hypostoma attached to the doublure. Collection U. S. National Museum.

1*f*. Hypostoma. Collection U. S. National Museum.

1*g*. A small head. Collection U. S. National Museum.

1*h*. Small lateral cheek, in which the genal spine is unusually short. Collection U. S. National Museum.

(See Pl. XCI.)



TRILOBITA.

PLATE XCIII.

PLATE XCIII.

Page.

OLENELLUS (MESONACIS) MICKWITZIA.. 634

FIG. 1. This figure is taken from Schmidt's work,[1] and represents about all that was known of the species at the date of its publication.

OLENELLUS (HOLMIA) KJERULFI.. 634

FIG. 2. A beautiful illustration of this species. (After Holm.)[2]

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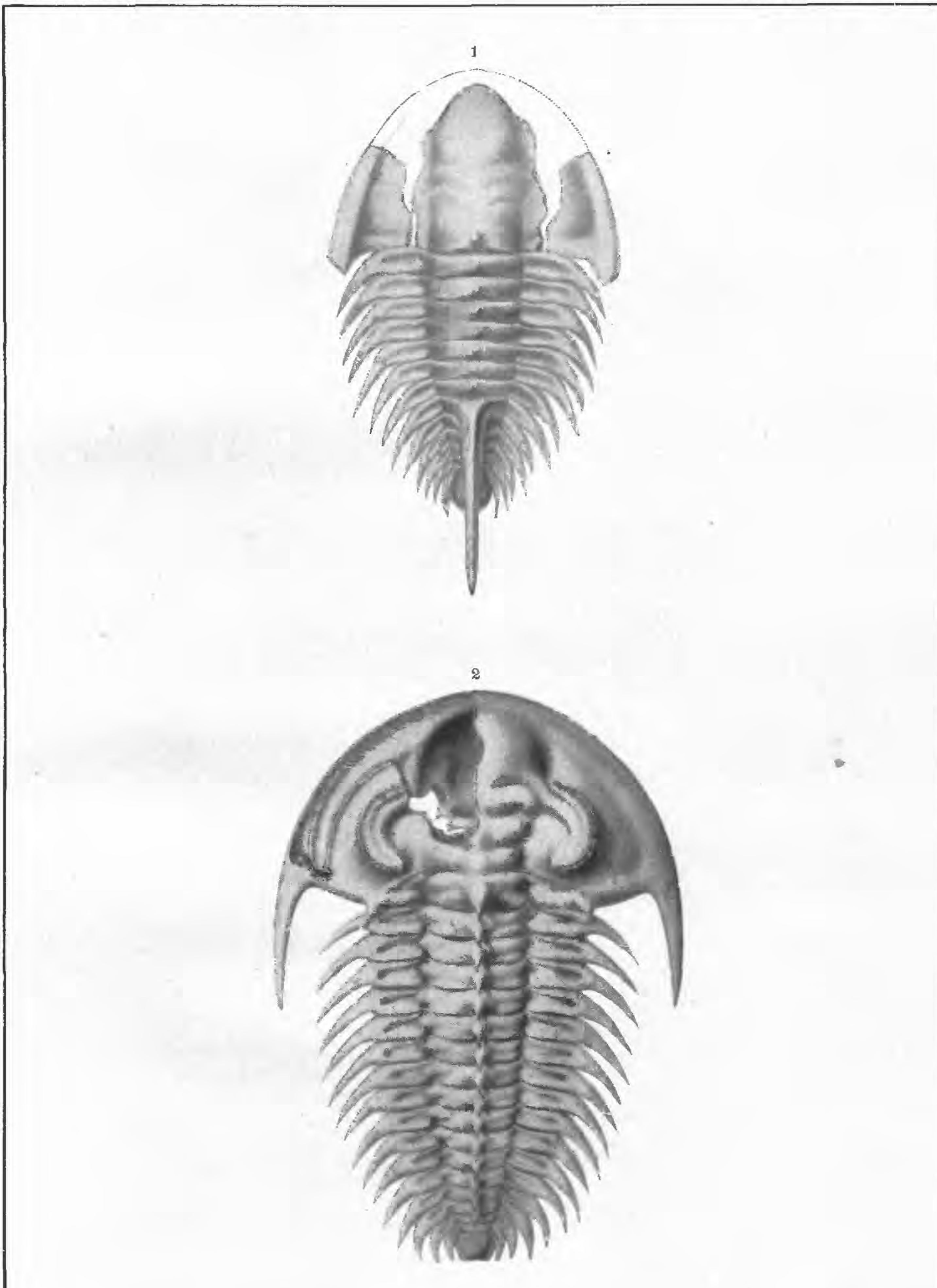
[1] Über eine neuentdeckte untercambrische fauna in Estland; F. Schmidt. Mém. Acad. Imp. Sci. St. Pétersbourg, V, II, vol. 36. No. 2, 1888, pp. 1–27, Pls. i, ii.

[2] Om Olenellus kjerulfi; G. Holm. Geol. Fören. Förhandl., Bd. 9, 1887.



TRILOBITA.

PLATE XCIV.

PLATE XCIV.

Page.

OLENOIDES CURTICEI 752

FIG. 1. This species is from the Middle Cambrian of the Coosa Valley, Georgia. It is introduced to illustrate the characters of the genus Olenoides. Collection U.S. National Museum.

1*a*. View of section of a specimen buried in a flint nodule. Collection U.S. National Museum.

OLENOIDES MARCOUI 642

FIG. 2, 2*a*. Head and pygidium from the arenaceous shales of Parker's quarry. Collection U.S. National Museum.

2*b*. Interior of pygidium. Collection U.S. National Museum.

OLENOIDES FORDI 641

FIG. 3. Head with exception of free cheeks. Washington County, N.Y. Collection U.S. National Museum.

3*a*, 3*b*. Pygidium and free cheek associated with 3. Collection U.S. National Museum.

3*c*. Side outline of 3*a*.

OLENOIDES QUADRICEPS 646

FIG. 4. Original figure of *Dikellocephalus quadriceps* Hall & Whitfield, enlarged to three diameters. Collection U. S. National Museum.

4*a*, 4*b*. Top and side views of associated pygidium. Collection U.S. National Museum.

4*c*. Side view of Fig. 4.

4*d*. Specimen from the Olenellus zone of the Eureka district, Nevada. Collection U.S. National Museum.

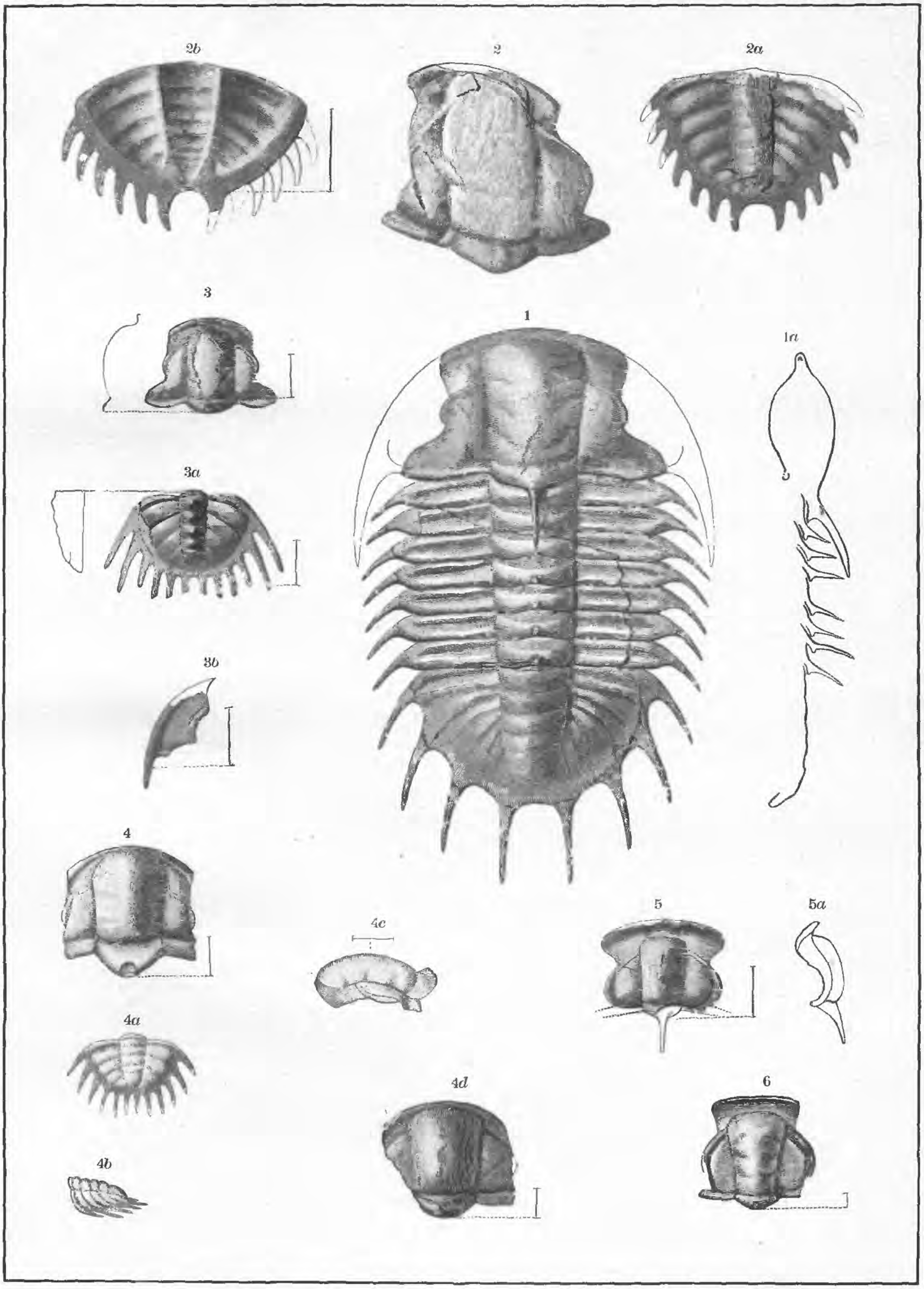
ZACANTHOIDES LEVIS 646

FIG. 5. View of the type specimen. Collection U.S. National Museum.

5*a*. Side view of 5.

ZACANTHOIDES EATONI 646

FIG. 6. View of the type specimen, from Washington County, N.Y. Collection U.S. National Museum.



TRILOBITA.

PLATE XCV.

PLATE XCV.

Page.

Bathynotus holopyga 646

Fig. 1. View of a nearly perfect specimen; the long eye-lobes are crushed down. Natural size. Collection U. S. National Museum.

1*a*. View of the free cheeks and hypostoma in position. Collection U. S. National Museum.

Ptychoparia ? attleborensis 649

Fig. 2. Enlargement of a head of this species from Manuel's Brook, Conception Bay, Newfoundland. Collection U. S. National Museum.

Avalonia manuelensis 646

Fig. 3. A small head, enlarged to the size of the largest head found. Collection U. S. National Museum.

3*a*. Enlargement of the surface markings, from a specimen in the limestone of Topsail Head, Newfoundland. Collection U. S. National Museum.

Oryctocephalus primus 653

Fig. 4. Head with the free cheeks in outline; the latter are raised up and appear broader than when attached to the central parts of the head. Collection U. S. National Museum.

4*a*. Pygidium that is associated in the same piece of rock with the head wherever the latter is found, enlarged to four diameters. Collection U. S. National Museum.

Conocoryphe trilineata 647

Fig. 5. Figure of Dr. Emmons's original specimen, now in the American Museum of Natural History, New York City.

5*a*. An unusually perfect specimen from the typical locality in Washington County, N. Y. Collection U. S. National Museum.

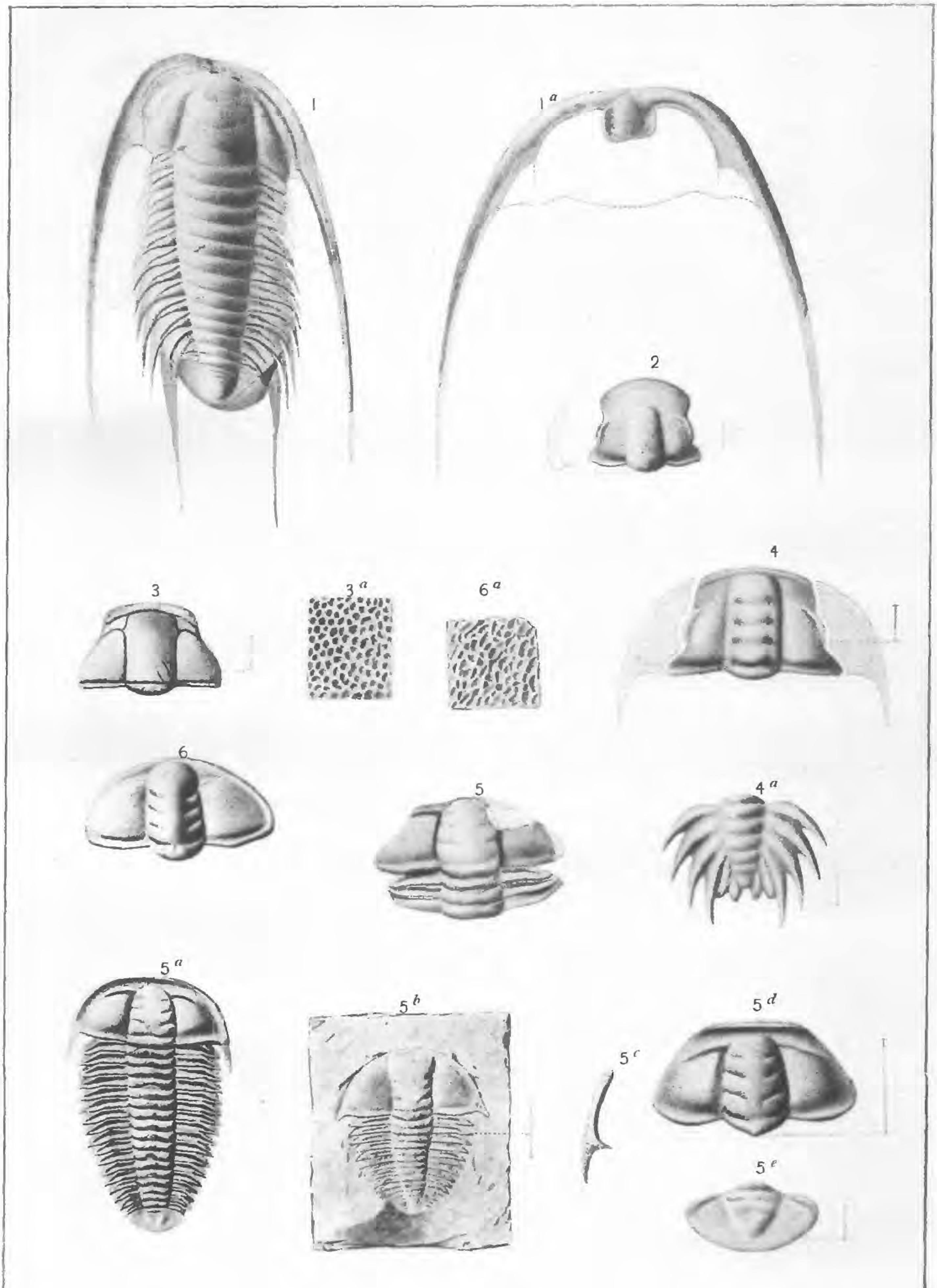
5*b*. A small specimen associated with 5*a*. This specimen has ten thoracic segments and a wide glabella. These characters appertain to the young or embryonic stages of growth. Collection U. S. National Museum.

5*c*, 5*d*, 5*e*. Free cheek, head, and pygidium associated with 5*a*. Collection U. S. National Museum.

Conocoryphe reticulata 649

Fig. 6. A very perfect head from the conglomerate limestone at the northwest side of the village of Salem, N. Y. Collection U. S. National Museum.

6*a*. Enlargement of a portion of the surface of the test of the cheek of 6.



Forbes Co., Boston.

TRILOBITA.

PLATE XCVI.

PLATE XCVI.

Page

PTYCHOPARIA ADAMSI 649

FIG. 1. Head from the "Red Sandrock," east of Highgate Springs, Vermont Collection U. S. National Museum.

1*a*, 1*b*. Narrow and broad form of head from the limestone "lentile," two miles east of Swanton, Vt. Collection U. S. National Museum.

1*c* Nearly entire specimen from Parker's quarry, Vermont. Original in the collection of the Museum of Comparative Zoology, Cambridge, Mass

ANOMOCARE ? PARVUM. 653

FIG. 2. View of type specimen, enlarged Collection U. S National Museum.

PTYCHOPARIA TEUCER. 652

FIG. 3. View of specimen from the "Red Sandrock," east of Highgate Springs, Vermont. Collection U. S. National Museum.

PTYCHOPARIA VULCANUS... 653

FIG 4. Compressed specimen from Parker's quarry Collection U. S. National Museum.

4*a* More perfect specimen from the "Red Sandrock," east of Highgate Springs, Vermont. Collection U S. National Museum

PTYCHOPARIA FITCHI . 650

FIG 5 Central portions of the head without the free cheeks. Collection U. S. National Museum.

PTYCHOPARIA SUBCORONATA . 652

FIG 6. Figure of the type specimen figured by Hall & Whitfield, enlarged to four diameters Collection U. S. National Museum.

CREPICEPHALUS LILIANA 653

FIG 7 Large head, with granulose surface. Collection U. S. National Museum

7*a*. Pygidium, associated with 3 in the same fragment of rock Collection U S National Museum.

7*b*. Cast of a smaller head Collection U S National Museum.

7*c*. Associated free cheek.

PTYCHOPARIA MISER 651

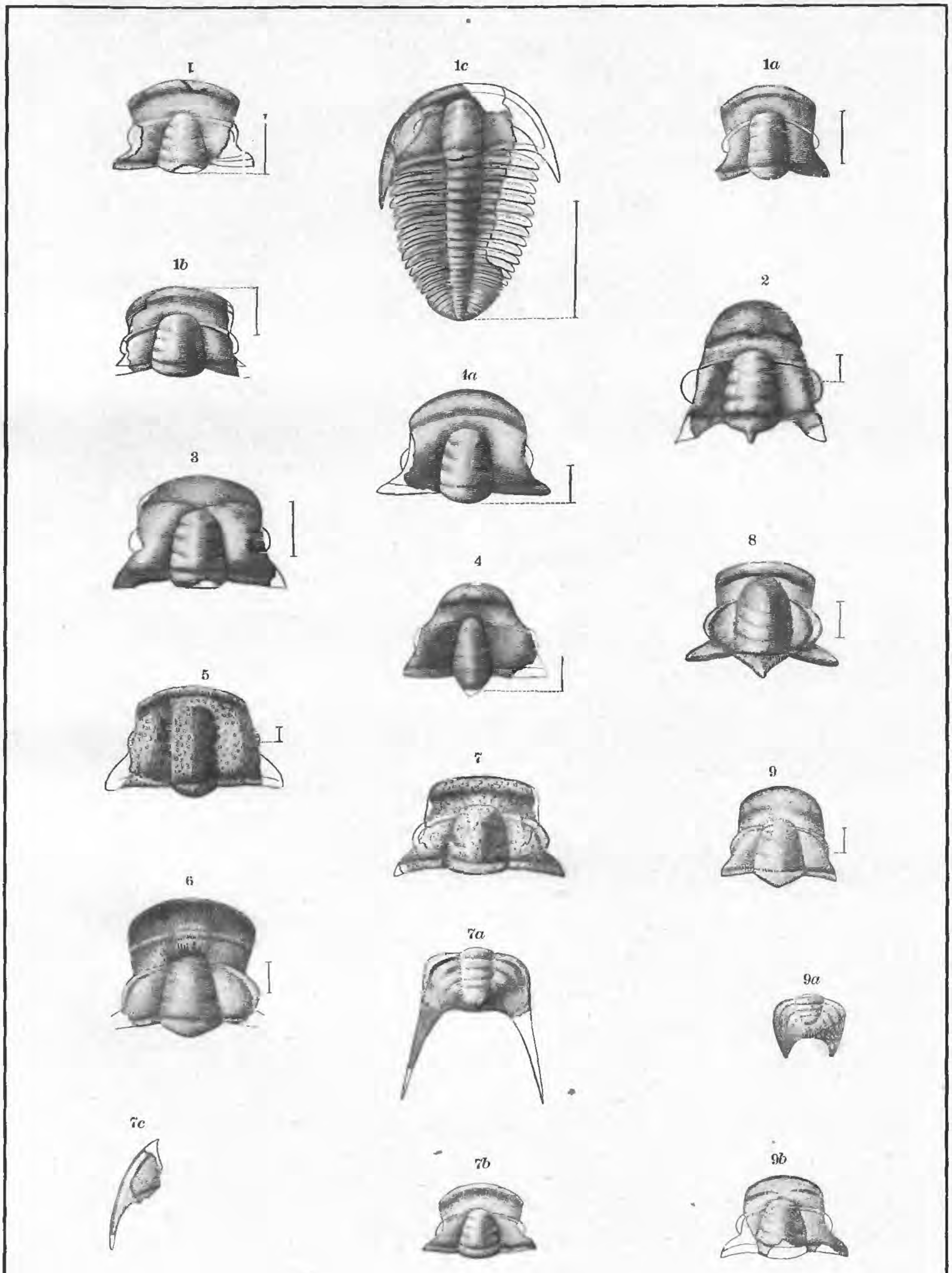
FIG. 8 Figure drawn from the type specimen in the collection of the Geological Survey of Canada.

CREPICEPHALUS AUGUSTA . 653

FIG 9 A much smaller head, showing variation from Fig. 9*b*. Collection U. S National Museum

9*a*. Pygidium, associated with the heads of this species. Collection U S National Museum.

9*b* Head, natural size Collection U. S. National Museum.



TRILOBITA.

PLATE XCVII.

PLATE XCVII

Page

AGRAULOS STRENUUS 653

FIG 1 A head, laterally compressed, from the Brigus Head limestone Collection U S National Museum

1*a* An unusually large, strongly marked head that is referred with doubt to this species Manuel's Brook, Conception Bay Collection U S National Museum

1*b* A head very much like the type of the species Topsail Head limestone Collection U S National Museum

1*c* Free cheek, associated with 1*b* Collection U S National Museum

AGRAULOS STRENUUS var NASUTUS 654

FIG 2 A very perfect head with the exception of the free cheeks Manuel's Brook, Conception Bay, Newfoundland Collection U S National Museum

2*a* Pygidium associated with Fig 2

2*b* Lateral view to show the projecting frontal limb Manuel's Brook, Conception Bay, Newfoundland Collection U S National Museum

2*c* Lateral view to show the unusually thickened frontal limb Manuel's Brook, Conception Bay, Newfoundland Collection U S National Museum

PTYCHOPARIA ? sp undetermined 758

FIG 3 Fragment of head, associated with *Agraulos strenuus* Manuel's Brook, Conception Bay, Newfoundland Collection U S National Museum

ELLIPSOCEPHALUS NORDENSKOLDI 758

FIG 4 A head without the free cheeks, from Andrarum Sweden Collection U S National Museum

ELLIPSOCEPHALUS HOFFI 758

FIG 5 An entire specimen of this species, to illustrate the characters of the genus (After Barrande)

PTYCHOPARIA sp undetermined 758

FIG 6, 6*a* Head and pygidium of an undetermined species from the upper portion of the Olenellus zone, in Washington County, N Y

SOLENOPLEURA HARVEYI 656

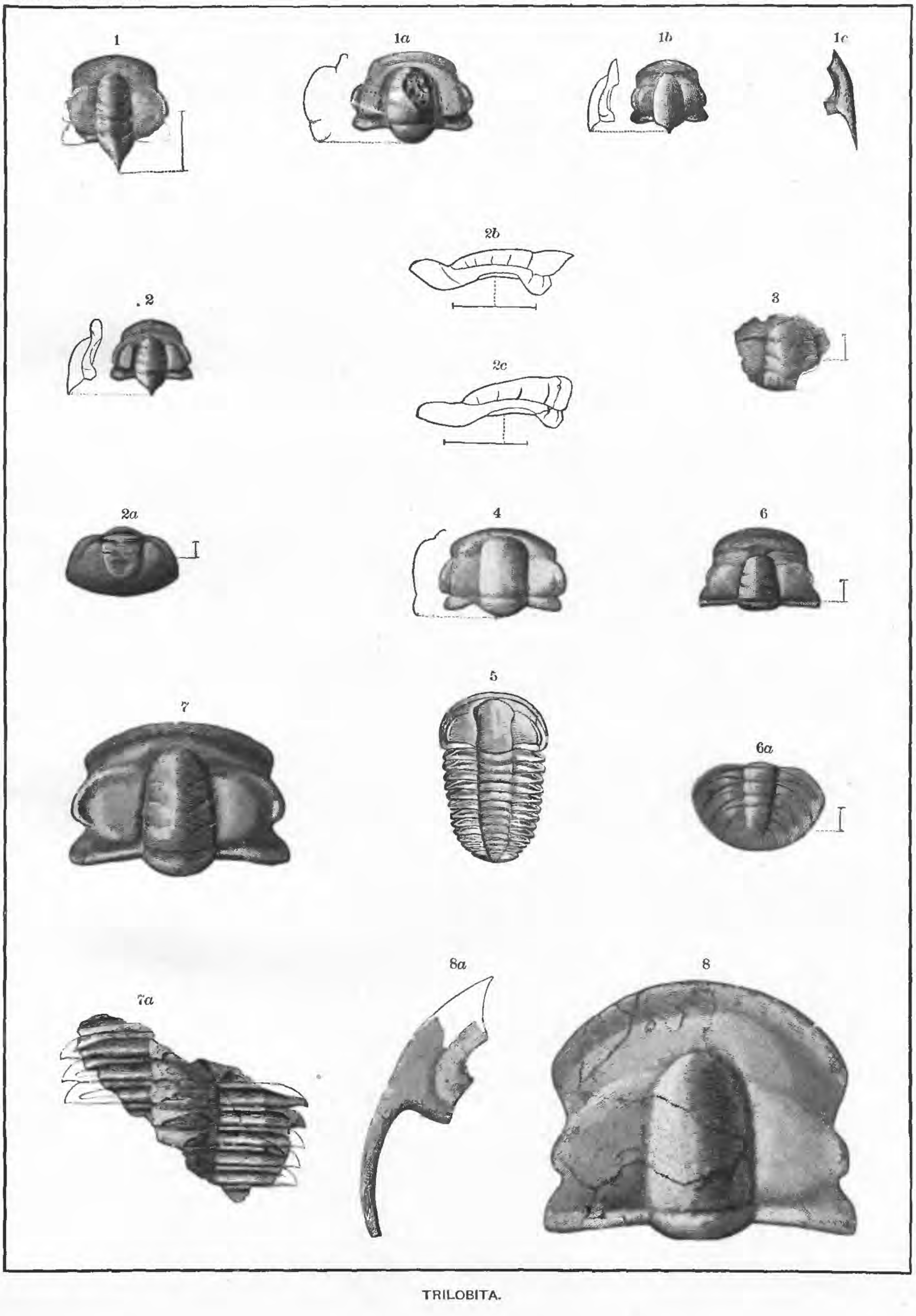
FIG 7 The central portions of the head natural size from Manuel's Brook, Conception Bay Newfoundland Collection U S National Museum

7*a* A portion of the thorax of the species Manuel's Brook, Conception Bay Newfoundland Collection U S National Museum

SOLENOPLEURA HOWLEYI 657

FIG 8 The central portions of the head, natural size, from Manuel's Brook, Conception Bay, Newfoundland Collection U S National Museum

8*a* Free cheek, associated with Fig 8 Collection U S National Museum



TRILOBITA.

PLATE XCVIII.

PLATE XCVIII.

Page

SOLENOPLEURA ? NANA 658

FIG. 1. Enlarged view of specimen from the typical locality at Troy, N. Y. Collection U. S. National Museum.
1*a*. Side outline of 2.
1*b*. Side outline of a head with a granulated surface that has obscure glabellar furrows. Collection U. S. National Museum.
1*c*, 1*d*. Top and side view of pygidium, associated with 1 and 1*b*. Collection U. S. National Museum.
1*e*. A similar pygidium as 1*c*, from Troy, N. Y.
2. A smooth variety that is referred with doubt to this species. Washington County, N. Y. Collection U. S. National Museum.

SOLENOPLEURA ? TUMIDA 658

FIG 3. 3*a*. Top and side views of head without free cheeks. Washington County, N. Y. Collection U. S. National Museum.

PROTYPUS ? CLAVATUS.. 656

FIG. 4. Enlargement to show details of head, with the exception of the free cheeks. Collection U. S. National Museum.

SOLENOPLEURA BOMBIFRONS.. 656

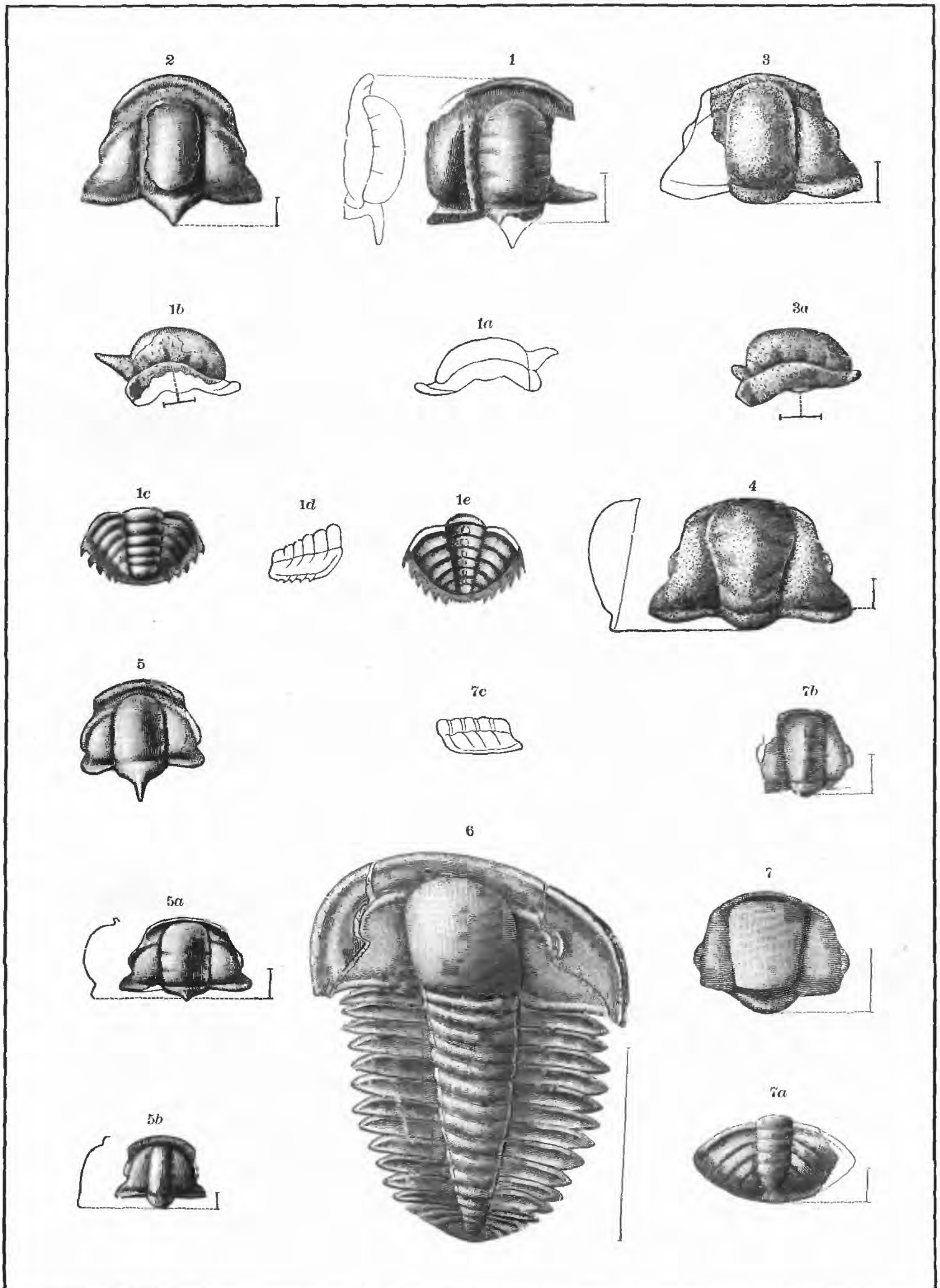
FIG. 5. A very perfect head with the exception of the free cheeks. Manuel's Brook, Conception Bay, Newfoundland. Collection U. S. National Museum.
5*a*. A small head, enlarged, in which faint glabellar furrows are seen. Collection U. S. National Museum.
5*b*. A very small head. Collection U. S. National Museum.

PROTYPUS HITCHCOCKI.. 655

FIG. 6. Figure of the type specimen. (After Whitfield.) Collection U. S. National Museum.

PROTYPUS SENECTUS.. 655

FIG. 7. View of flattened specimen. Collection U. S. National Museum.
7*b*. Specimen laterally compressed. Collection U. S. National Museum.
7*a*, 7*c*. Pygidium, associated with the heads 7 and 7*c*. Collection U. S. National Museum.



TRILOBITA.

ERRATA.

Page 196, in tabular statement at foot of page, for Monograph II read Monograph XII.
Page 520, line 14 from top, for 1862 read 1861.
Page 525, lines 4 and 5 of title to Fig. 44, for Ordovician read Silurian.
Page 526, line 9 from top, and in table, for Ordovician read Silurian.
Page 547, line 4, for p. 566 read p. 564.
Page 552, line 4 from bottom, for upper portion read lower portion.
Page 552, line 2 from bottom, for 700 feet read 50 feet. (Discoveries made in August, 1890.)
Page 557, line 19, for section B read section 2.
Page 557, line 21, for section H read section 9.
Page 557, line 14 from bottom, for p. 552 read p. 550.
Page 557, line 12 from bottom, for p. 551 read p. 549.
Page 557, line 10 from bottom, for p. 552 read p. 550.
Page 557, line 4 from bottom, for p. 553 read p. 551.
Page 557, bottom line, for p. 554 read p. 552.
Page 558, line 2, for p. 561 read p. 559.
Page 558, line 7, for p. 561 read p. 559.
Page 558, line 20, for p. 555 read p. 553.
Page 558, line 20 from bottom, for p. 556 read p. 554.
Page 558, line 6 from bottom, for p. 551, p. 552, p. 552 read p. 549, p. 550, and p. 550, respectively.
Page 558, line 4 from bottom, for p. 553, p. 554 read p. 551 and p. 552, respectively.
Page 558, bottom line, for 556 read 554.
Page 559, line 6 of text, for Pls. XLV and XLVI read Pls. XLV and XLVII
Page 561, line 13 from bottom, for p. 552 read p. 550.
Page 564, line 8, for p. 549 read p. 547.
Page 564, line 3 from bottom, for (Mesonacis) read (Holmia).
Page 565, top line, for (M.) read (H.).
Page 565, line 6, for p, 556 read p. 554.
Page 565, line 19, for (Mesonacis) read (Holmia).
Page 567, line 16, for p. 546 read p. 544.
Page 568, line 5 from bottom, for (M.) read (H.).
Page 571, line 6, for p. 551 and p. 552 read p. 549 and p. 550, respectively.
Page 571, line 4 from bottom, for p. 552 read p. 550.
Page 575, line 10 of table, for Olenellus (Mesonacis) bröggeri read Olenellus (Holmia) bröggeri.
Page 576, line 6 from bottom, for Obutus pulchea read Obolus pulcher.

The name Silurian is now used to include both the Lower Silurian (Ordovician) and the Upper Silurian on the maps of the Geological Survey. Except that it is too late to make the changes in the text on pages 546, 547, 549, 552, 553, 563, and 568, this nomenclature would have been adopted in this paper. (C. D. W.). In the table, p. 547, the name Hudson is to be substituted for Lorraine.

INDEX.

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GENERAL GEOLOGICAL MAP OF THE PENOKEE REGION.
BY R.D. IRVING AND C.R. VAN HISE.
SCALE OF MAP 1 IN = 3 MILES.
SCALE OF SECTIONS 1 INCH = 1 MILE.
CAMBRIAN.
EASTERN SANDSTONE.
€
ALGONKIAN.
KEWEENAWAN.
Ak
PENOKEE SERIES.
UPPER SLATE MEMBER.
Apu
IRON-BEARING MEMBER.
Api
QUARTZ SLATE MEMBER.
Apq
CHERTY LIMESTONE MEMBER.
Apl
GREENSTONE CONGLOMERATES.
Apv
FERRUGINOUS SLATES.
Apf
ERUPTIVES.
Ape
ARCHEAN.
SOUTHERN COMPLEX.
GRANITE & GRANITOID GNEISS.
g
SCHIST & FINE-GRAINED GNEISS.
s
I
II
III
IV
V
VI
N
S
GOGEBIC LAKE
Bessemer
Penokee
English L.
T.44 N.
T.45 N.
T.46 N.
T.47 N.
R.V W.
R.IV W.
R.III W.
R.II W.
R.I W.
R.I E.
R.II E.
R.III E.
R.47 W.
R.46 W.
R.45 W.
R.44 W.
R.43 W.
R.42 W.