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

WASHINGTON, D. C., *December*, 1891.

TWELFTH ANNUAL REPORT

OF THE

UNITED STATES GEOLOGICAL SURVEY

TO THE

SECRETARY OF THE INTERIOR

1890–'91

BY

J. W. POWELL

DIRECTOR

PART I—GEOLOGY

WASHINGTON

GOVERNMENT PRINTING OFFICE

1891

TWELFTH ANNUAL REPORT

OF THE

DIRECTOR

OF THE

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Part I.—GEOLOGY.

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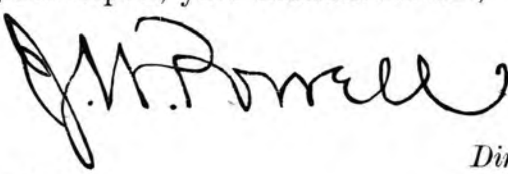
DEPARTMENT OF THE INTERIOR,
U. S. GEOLOGICAL SURVEY,
Washington, D. C., July 2, 1891.

SIR: I have the honor herewith to transmit to you a report of the operations of the Geological Survey for the fiscal year ending June 30, 1891.

Permit me to express my sincere gratitude for the kind encouragement you have given me in the multifarious duties devolving upon me as a subordinate officer of the Department.

I am, with great respect, your obedient servant,



Director.

Hon. JOHN W. NOBLE,
Secretary of the Interior.

TWELFTH ANNUAL REPORT OF THE UNITED STATES GEOLOGICAL SURVEY.

BY J. W. POWELL, DIRECTOR.

PROGRESS OF TOPOGRAPHIC WORK.

During the year topographic work has been carried on by the Survey in twenty-seven States and Territories, and an area of 44,100 square miles has been surveyed and mapped. Of this area 16,843 square miles were mapped upon a scale of 1:62,500, with contour intervals of 5, 10, or 20 feet, and the remainder on a scale of 1:125,000, with contour intervals of 20, 50, or 100 feet. The distribution of the mapped area is shown graphically on Plate I, in the pocket at the end of this volume, and the details of the work are set forth in the accompanying administrative reports by Messrs. Gannett and Thompson.

The present condition of the topographic survey is exhibited in the accompanying table.

Table showing the present condition of topographic surveys and the areas surveyed in 1890-'91, by States and Territories.

States.	Total. area.	Area surveyed to date.	Area surveyed in 1890-'91.	Scale.	Contour interval.
	Sq. miles.	*Sq. miles.*	*Sq. miles.*		*Feet.*
Alabama	52, 250	14, 870	....	1 : 125000	50 and 100
Arizona	113, 020	41, 000	....	1 : 250000	200 and 250
Arkansas	53, 850	13, 000	2, 500	1 : 125000	50
California	158, 360	29, 000	1, 000	1 : 125000 1 : 250000	50, 100, 200
Colorado	103, 925	32, 300	8, 700	1 : 62500 1 : 125000	25, 50, 100
Connecticut	4, 990	4, 990	2, 250	1 : 62500	20
District of Columbia	70	70	....	1 : 62500	20

Table showing the present condition of topographic surveys and the areas surveyed in 1890–'91, etc.—Continued.

States.	Total area.	Area surveyed to date.	Area surveyed in 1890–'91.	Scale.	Contour interval.
	Sq. miles.	*Sq. miles.*	*Sq. miles.*		*Feet.*
Florida	58,680	700	450	1: 62500	10
Georgia	59,475	14,275	400	1:125000	50 and 100
Idaho	....	3,800	1,900	1:125000	50 and 100
Illinois	56,650	1,725	1,125	1: 62500	5 and 10
Iowa	56,025	5,375	900	1: 62500	20
Kansas	82,080	53,200	9,000	1:125000	20 and 50
Kentucky	40,400	11,800	2,030	1:125000	100
Louisiana	48,720	7,000	5,000	1: 62500	5
Maine	33,040	2,457	1,125	1: 62500	20
Maryland	12,210	5,930	2,450	1: 62500 1:125000	20, 50, 100
Massachusetts	8,315	8,315	....	1: 62500	20
Michigan	58,915	231	168	1: 62500	20
Missouri	69,415	26,000	....	1: 62500 1:125000	20 and 50
Montana	146,080	10,800	400	1:125000 1:250000	100 and 200
Nevada	110,700	16,800	2,800	1:125000 1:250000	100, 200, 250
New Hampshire	9,305	1,000	....	1: 62500	20
New Jersey	7,815	7,815	....	1: 62500	10 and 20
New Mexico	122,580	26,850	2,850	1:125000 1:250000	100 and 200
New York	49,170	1,095	450	1: 62500	20
North Carolina	52,250	10,400	....	1:125000	100
Oregon	96,030	11,000	....	1:250000	200
Pennsylvania	42,215	4,737	1,800	1: 62500	20
Rhode Island	1,250	1,250	....	1: 62500	20
South Carolina	30,570	4,350	2,050	1:125000	50 and 100
Tennessee	42,050	15,095	2,480	1:125000	100
Texas	265,780	40,250	8,000	1:125000	50
Utah	84,970	6,000	....	1:250000	250
Vermont	9,565	560	....	1: 62500	20
Virginia	42,450	31,410	1,860	1:125000 1: 62500	20, 50, 100
West Virginia	24,780	20,500	2,150	1:125000	100
Wisconsin	56,040	3,840	1,575	1: 62500	20
Wyoming, including Yellowstone National Park	97,890	4,000	....	1:125000	100

ATLAS SHEETS.

The work of the last year completes 125 atlas sheets, of which 73 are on a scale of 1 : 62,500, and the remainder on a scale of 1 : 125,000. The whole number of atlas sheets completed to the present date by survey and compilation is 613. Of this number, 259 are on the scale of 1 : 62,500, 293 on a scale of 1 : 125,000, and 61 on a scale of 1 : 250,000.

ORGANIZATION.

During most of the field season the organization of the topographic branch remained substantially the same as last year, the work done under the Geological Survey proper being in charge of Mr. Henry Gannett, while the topographic work executed under the Irrigation Survey, as a distinct organization, was in charge of Prof. A. H. Thompson. But a provision of the sundry civil act, passed in the latter days of August, required certain changes in organization. By that act a portion of the work of the Irrigation Survey was discontinued, and appropriation for topographic work under the Geological Survey was divided equally between the country lying east and that lying west of the one hundredth meridian. It seemed advisable to make the organization conform to this division of the appropriation, and accordingly the topographic branch of the Survey was organized in two divisions, whose fields of work were separated by the one hundredth meridian; the eastern division in charge of Mr. Henry Gannett and the western division in charge of Mr. A. H. Thompson. Certain transfers of persons and fields of work were made at the same time. These changes are fully set forth in the administrative reports of Messrs Gannett and Thompson.

SURVEYS EAST OF THE ONE HUNDEDTH MERIDIAN.

Work was prosecuted in Maine by two parties and 5 atlas sheets were completed.

The survey of Connecticut, commenced last year in cooperation with the State authorities and in part at the expense of the State, was finished.

Two sheets were surveyed in the valley of the Hudson in New York and eight sheets in the anthracite coal region of Pennsylvania.

In the southern Appalachian region work was actively prosecuted by six topographic parties and one triangulation party. The areas surveyed are: In Maryland, on the west shore of Chesapeake Bay; in southern Virginia, on the Atlantic plain; in central West Virginia; in eastern Kentucky; in the Cumberland plateau of Tennessee; and the drainage basin of the Savannah River in South Carolina and Georgia. In most of these regions the demand for maps is great, owing to the rapid development of mineral resources.

The work commenced in the iron region of the upper peninsula of Michigan was completed, and a detailed map of this important iron-producing region was finished.

In southern Wisconsin 7 atlas sheets were finished.

The work in Illinois, along the course of the Illinois River, was prosecuted actively, and 7 atlas sheets were surveyed.

Work was prosecuted in Iowa until early in October, and 4 atlas sheets were completed.

In Kansas work was prosecuted by two topographic parties and one triangulation party, and 7 atlas sheets, comprising about 7,000 square miles, were surveyed.

Work was continued in the Ozark Hills of Arkansas, and 2 sheets and parts of a third sheet were finished.

In Texas work was actively prosecuted, finishing 6 sheets, or about 6,000 square miles.

During the winter the survey of the alluvial region of the lower Mississippi, commenced the season before, was continued, and, partly from field-work and partly by compilation, 20 sheets were prepared.

During the winter also work was continued in the phosphate region of Florida, and 1 sheet was completed, together with most of a second sheet.

Work was likewise prosecuted in the Dismal Swamp of Virginia and the country adjacent thereto, and 2 sheets were completed.

SURVEYS WEST OF THE ONE HUNDREDTH MERIDIAN.

In California 2 atlas sheets were completed and 33 reservoir sites surveyed and reported upon.

In Colorado 9 atlas sheets were completed and 46 reservoir sites located, surveyed, and reported upon.

In Idaho 2 atlas sheets were surveyed.

In Kansas work was completed on 2 atlas sheets.

In Montana 400 square miles lying in the Sun River drainage basin were mapped and 28 reservoir sites were surveyed and reported upon.

In Nevada work on 4 atlas sheets was completed and 2 reservoir sites were surveyed and reported upon.

In New Mexico 3 atlas sheets were completed and 39 reservoir sites were surveyed and reported upon.

In North Dakota 734 miles of level lines were run for topographic purposes and for determining the height, above the Missouri River, of the divide between that stream and the James River. A general reconnaissance of the country was also made.

In Texas work was completed on 2 atlas sheets.

ENGRAVING.

The following tables show a summation of the number and distribution of engraved atlas sheets and a description of the individual sheets:

Table showing number, distribution, etc., of the atlas sheets engraved to June 30, 1891.

State.	Wholly within State.	Partly within State.	Scale.	Contour interval.	Approximate area.
				Feet.	*Sq. miles.*
Alabama	13	3	1 : 125000	50 and 100	14, 200
Arizona	13	2	1 : 250000	200 and 250	58, 000
Arkansas	10	....	1 : 125000	50	10, 000
California	13	1	{ 1 : 125000 1 : 250000 }	50, 100, 200	30, 000
Colorado	13	....	{ 1 : 62500 1 : 125000 }	50 and 100	11, 450
Connecticut	7	10	1 : 62500	20	2, 475
Delaware	....	1	1 : 62500	10	50
District of Columbia	....	2	1 : 62500	20	70
Georgia	9	4	1 : 125000	50 and 100	11, 800
Idaho	2	....	1 : 125000	50 and 100	2, 000
Illinois	2	1	1 : 62500	10	650
Iowa	18	....	1 : 62500	20	4, 050
Kansas	39	6	1 : 125000	20 and 50	43, 000

Table showing number, distribution, etc., of the atlas sheets engraved to June 30, 1891—Continued.

State.	Wholly within State.	Partly within State.	Scale.	Contour interval.	Approximate area.
				Feet.	*Sq. miles.*
Kentucky	4	7	1 : 125000	100	8,000
Maine	4	2	1 : 62500	20	1,000
Maryland	1	7	{ 1 : 125000 1 : 62500 }	20, 50, 100	2,000
Massachusetts	29	22	1 : 62500	20	8,315
Missouri	25	9	{ 1 : 125000 1 : 62500 }	20 and 50	26,000
Montana	9	....	1 : 250000	200	31,500
Nevada	5	3	1 : 250000	200 and 250	24,500
New Hampshire	....	11	1 : 62500	20	1,000
New Jersey	32	10	1 : 62500	10 and 20	7,815
New Mexico	7	....	{ 1 : 125000 1 : 250000 }	50, 100, 200	19,000
New York	1	8	1 : 62500	20	1,000
North Carolina	3	13	1 : 125000	100	7,000
Oregon	1	....	1 : 250000	200	3,500
Pennsylvania	6	6	1 : 62500	20	2,000
Rhode Island	7	6	1 : 62500	20	1,250
South Carolina	1	3	1 : 125000	100	1,500
Tennessee	6	14	1 : 125000	100	12,000
Texas	28	....	1 : 125000	50	28,000
Utah	17	1	1 : 250000	250	65,000
Vermont	2	....	1 : 62500	20	450
Virginia	12	25	{ 1 : 62500 1 : 125000 }	20, 50, 100	23,500
West Virginia	7	14	1 : 125000	100	14,500
Wisconsin	4	....	1 : 62500	20	900
Wyoming	4	....	1 : 125000	100	3,600

PROGRESS OF GEOLOGIC WORK.

Progress in geologic work has gone steadily forward along two general lines: First, the mapping of the areal distribution of formations; second, the study in field and office of various problems in rock structure and history. This progress is conditioned by two factors: First, the existence of topographic maps upon which to delineate the areal distribution; and second, the amount of money appropriated for the purpose.

The area available for mapping areal distribution steadily grows with the progress of topographic mapping.

The money appropriated for geologic work this year was 15 per cent more than for the previous year. As a result, some of the existing sections were enlarged and new work was instituted in two directions. The mineral phosphates of Florida have recently assumed commercial importance, and as little is known of their origin, extent, or geologic occurrence, systematic study of them has been entered upon. It is hoped that this study may lead to inferences of value in the exploitation of other deposits of similar character. This new section of work has been placed in charge of Mr. George H. Eldridge. A New Jersey section of work has also been created during the year, and placed in charge of Prof. Raphael Pumpelly. This is a joint service in which the State and the General Government, by their respective surveys, unite to obtain the best results without duplication of work, and at a minimum cost.

General charge of all the geologic work of the Survey has continued under the direction of Mr. G. K. Gilbert, chief geologist, whose own work as well as that of the whole geologic branch of the Survey is fully set forth in the accompanying administrative reports. The Director has thus been relieved of the duty of preparing a detailed statement of the operations of this branch of the Survey, which has afforded him time to set forth more elaborately the operations of the Irrigation Survey. The report on this latter subject will appear as a second part of this report.

PROGRESS OF PALEONTOLOGIC WORK.

The work of this branch of the Survey has been carried forward on the principles set forth in the tenth and eleventh annual reports of the Survey. Briefly stated they are: (1) The identification and correlation of geologic formations by the organic remains contained therein, for the purpose of aiding the geologists in delineating formations and making geologic maps. (2) The study, from a biologic point of view, of the faunas and floras contained in the rocks, for the purpose of obtaining a critical knowledge of the genera and species and of the evolution of life and its relations to environment during geologic time.

In the study of stratified rocks the interdependence of geology and paleontology is such that much of the paleontologist's time is given to a study of strata in the field and to the literature of geology in order more fully to establish the stratigraphic succession and geographic distribution of life in the various geologic formations. It is recognized that stratigraphic geology is the foundation of chronologic paleontology, and that no definite record of the progress of life can be obtained without a knowledge of the succession of faunas and floras in the strata. When this knowledge is once obtained the paleontologist can correlate the various isolated fossiliferous formations the geologists meet with, by reference to a general scheme of the succession of life that has previously been established. This general succession has been determined in its broader outlines, but special studies are still necessary to verify and increase our knowledge of it. The paleontologists also aid the geologists in the field by making special studies of the geologic sections, and determining the horizons of various formations.

To correlate more thoroughly the work of the various divisions of the paleontologic branch, Mr. Charles D. Walcott was instructed to examine and obtain data for a report upon the collections of the Geological Survey in charge of paleontologists not located in Washington. He found the collections well cared for and, in the event of the death or disability of the person in charge, each could be readily identified, packed, and shipped to the Geological Survey at Washington. The methods used in caring for the collections are set forth in his administrative report.

Mr. Walcott has charge of the invertebrate paleontology of the Paleozoic formations. He has been principally engaged in completing the correlation essay on the Lower Paleozoic or Cambrian rocks of North America. In addition to this, attention was given to matters relating to the paleontologic branch of the Survey and to the study of the Silurian section northwest of Canyon City, Colorado, with relation to the stratigraphic position of the oldest vertebrate fossil remains yet discovered. By their associated invertebrate faunas the fish remains were found to be of middle Lower Silurian age, and much more ancient than any vertebrate life hitherto known.

Prof. H. S. Williams, who is attached to this division, completed his correlation essay on the Devonian and Carboniferous rocks, and conducted studies, both in field and office, on the relations of the Upper Paleozoic rocks in the Mississippi Valley, in Arkansas, and in Missouri.

The work of Prof. Alpheus Hyatt on the Lower Mesozoic was materially advanced by his field studies on the Pacific coast, in cooperation with the geologic division in charge of Mr. J. S. Diller, by the revision and description of the Triassic fossils from Idaho, and by the preparation of geologic sections made by him in New Mexico in 1889. This work has largely increased the data for the classification of the formations of the Jura-Trias period.

Dr. C. A. White, in charge of the Division of Upper Mesozoic Paleontology, completed in February his correlation essay on the Cretaceous formations of North America. The preparation by him of a bibliography of North American invertebrate paleontology, together with a catalogue of all the published species, is now so far advanced that its publication next year may be expected. On completing the correlation essay, his attention was directed toward accumulating data for two memoirs on the Upper Cretaceous formations.

Dr. W. B. Clark has completed and transmitted for publication his correlation essay on the older Cenozoic or Eocene rocks of the United States.

Dr. W. H. Dall, in charge of the work on Cenozoic invertebrates, has completed his essay on the correlation of the newer Cenozoic or Neocene group. He has also continued his studies of the collections of Cenozoic age and their related later faunas that have been collected by the members of the Survey or presented by private individuals. His special field work was in northern California, in connection with Mr. J. S. Diller, who was engaged in mapping the areal geology. He also studied in the field several questions relating to Floridian geology, especially in the southern portion of that peninsula.

The importance of field work was so great in the Division of Vertebrate Paleontology, in charge of Prof. O. C. Marsh, that he personally visited the region under exploration, especially the localities where the most interesting discoveries had been made in the Laramie beds. Although it was planned to devote the resources of the division mainly to laboratory work, nevertheless a large amount of valuable material was obtained in the field. This material will be of great value in studies connected with the monographs now in preparation on the vertebrates. Study of the material in the laboratory was continued and work on the monograph on the Sauropoda so far advanced that its early publication is anticipated. A large series of typical vertebrate fossils has been selected from the collection stored at New Haven, and will soon be placed on exhibition in the collections of the National Museum.

Work on the vertebrate fossils from the newer formations of Florida was continued by Prof. Joseph Leidy, of Philadelphia, Pennsylvania, and but for his sudden illness and death it would soon have been completed.

The Division of Paleobotany, in charge of Prof. Lester F. Ward, has advanced the bibliographic work on the subject and assembled a vast amount of data, valuable for correlating American formations by their contained plant remains. Field work, for the purpose of obtaining collections of fossil plants from various geologic groups, was vigorously prosecuted in the Cretaceous series of Montana, in the Devonian of New York, in the Cretaceous of Gay Head, Massachusetts, and in the Jura-Trias of the Connecticut Valley. The special work in the laboratory was the preparation of a paper on the plant-bearing deposits of the Atlantic States. This, in connection with the monograph now in preparation on the flora of the Laramie group, the editing of the monograph by Prof. Lesquereux on the Dakota group, and general routine work, occupied the time of the entire force of the division throughout the year.

The work of the Division of Fossil Insects, in charge of Prof. Samuel H. Scudder, was almost wholly confined to the office and laboratory. An important collection, gathered in previous years, has been to a large extent worked over and the material prepared for study. Also, three works were published, as follows: The Tertiary Insects of North America, Bibliography of Fossil Insects, and An Alphabetical Index to the Known Fossil Insects of the World. In addition to this, progress was made in preparing a monograph on one of the divisions of the Coleoptera.

Details of the work of the various paleontologic divisions, including the progress of various special researches, journeys, and collections made in the field; special reports on local collections made to field geologists, and the distribution of work among assistants, are set forth at length in the administrative reports of the chiefs of paleontologic divisions.

PROGRESS IN ACCESSORY WORK.

CHEMISTRY AND PHYSICS.

This division has continued under the efficient direction of Prof. F. W. Clarke. The scientific corps, consisting of seven chemists and two physicists, remained unchanged. The energies of the division were largely spent in the ordinary routine of chemical work. Two hundred and sixty-two complete quantitative analyses were made, mostly of rocks and minerals collected by the geologists. A much larger number of specimens received from various sources were reported upon qualitatively. The chemical constitution of the micas, chlorites, and vermiculites has been studied jointly by Prof. Clarke and Dr. Schneider, and a bulletin giving results prepared.

The occurrence of nitrogen in a mineral found chiefly in Archean granite was determined last year by Dr. W. F. Hillebrand. This year he has extended his investigations and confirmed his earlier conclusions. Dr. Thomas M. Chatard has entered upon a special study of the mineral phosphates, beginning with those in Florida, where he spent a month in making collections. Near the close of the year Dr. William Hallock visited Wheeling, West Virginia, and obtained a series of valuable measures of earth temperatures, a dry well 4,500 feet deep affording an exceptional opportunity for such researches. Further details will be found in the report of Prof. Clarke.

STATISTICS OF MINERAL PRODUCTS.

With the present fiscal year began the regular decennial census of the United States. It was found advantageous, as set forth in the last annual report, to combine the work of the Census relating to mineral industries with that of the division of Mining Statistics of the Geological Survey. This joint work has been successfully carried on under the direction of Dr. David T. Day. The work of the division was during the year enlarged to several times its ordinary dimensions with a correspondingly increased volume of results. The expense was borne jointly by the Geological Survey and the Census

The following is a tabulated statement of the mineral products of the United States for the calendar year 1890:

Metallic products of the United States in 1890.

	Quantity.	Value.
Pig iron, spot value....long tons..	9,202,703	$151,200,410
Silver, coining value....troy ounces..	54,500,000	70,464,645
Copper, value at New York City....pounds..	265,115,133	30,848,797
Gold, coining value....troy ounces..	1,588,880	32,845,000
Lead, value at New York City....short tons..	161,754	14,266,703
Zinc, value at New York City....do....	63,683	6,266,407
Quicksilver, value at San Francisco....flasks..	22,926	1,108,090
Nickel, value at Philadelphia....pounds[1]..	323,488	194,093
Aluminum, value at Philadelphia....do[2]....	72,543	72,543
Antimony, value at San Francisco....short tons..	....	30,000
Platinum, value (crude) at New York...troy ounces..	600	2,500
Total....	....	307,299,188

Non-metallic mineral products of the United States in 1890 (spot values).

Bituminous coal....short tons[3]..	106,921,083	$109,431,221
Pennsylvania anthracite....do....	46,468,641	61,445,683
Building stone....	....	54,000,000
Lime....barrels..	....	25,000,000

[1] Including nickel from Canadian matte.
[2] Including aluminum alloys.
[3] Including brown coal and lignite and anthracite mined elsewhere than in Pennsylvania.

Non-metallic mineral products of the United States, etc.—Continued.

	Quantity.	Value.
Natural gas	....	$12,000,000
Petroleum ....barrels..	47,000,000	30,000,000
Cement ....do....	8,000,000	6,000,000
Salt ....do....	8,683,943	4,707,869
Limestone for iron flux ....long tons..	7,000,000	4,000,000
Phosphate rock ....do....	575,000	2,800,000
Mineral waters ....gallons sold..	14,000,000	2,000,000
Zinc white ....short tons..	....	1,600,000
Gypsum ....do....	275,000	800,000
Potters' clay ....long tons..	300,000	650,000
Borax ....pounds..	8,000,000	500,000
Mineral paints ....long tons..	35,000	475,000
Grindstones	....	450,000
Fibrous talc ....short tons..	34,809	323,746
Asphaltum ....do....	60,000	200,000
Manganese ore ....long tons..	25,000	250,000
Soapstone ....short tons..	15,000	250,000
Flint ....long tons..	12,000	50,000
Pyrites ....do....	87,856	235,611
Precious stones, gold-quartz, jewelry, etc	....	200,000
Marls ....short tons..	125,000	50,000
Crude barytes ....long tons..	20,000	110,000
Bromine ....pounds..	100,000	30,000
Corundum ....short tons..	2,000	100,000
Mica ....pounds..	60,000	75,000
Feldspar ....long tons..	7,000	40,000
Graphite, crude ....pounds..	....	75,000
Fluorspar ....short tons..	8,250	55,328
Slate ground as pigment ....long tons..	2,000	20,000
Sulphur ....short tons..	260	7,800
Ozokerite, refined ....pounds..	100,000	5,000
Chrome iron ore ....long tons..	11,000	50,000
Novaculite ....pounds..	2,500,000	35,000
Millstones	....	30,000
Cobalt oxide ....pounds..	10,000	25,000
Infusorial earth ....short tons..	5,000	25,000
Rutile ....pounds..	1,000	3,000
Total	....	318,105,258

Résumé of the values of the metallic and non-metallic mineral substances produced in the United States in 1890.

Metals	$307,299,188
Mineral substances named in the foregoing table	318,105,258
Estimated value of mineral products unspecified	10,000,000
Grand total	635,404,446

WORK IN THE DIVISION OF ILLUSTRATIONS.

This division has remained in charge of Mr. De Lancey W. Gill, who has maintained a high degree of efficiency. The average number of persons employed was 8 and the number of drawings produced 1,520. These have been prepared for annual reports, bulletins, and monographs. Interesting details respecting this division will be found in Mr. Gill's report.

ENGRAVING AND PRINTING.

This division was created in February, 1890. Before that time the engraving and printing of maps was done by contract. Since that date a part has been done by contract and an increasing part by this division, which has steadily grown both in size and efficiency. It now numbers 12 persons and has the necessary machinery and appliances for rapid and economic map-engraving and printing. The chief engraver, Mr. S. J. Kübel, whose report is printed in this volume, has shown a comprehensive knowledge of his art, good executive ability, and zeal. As a result, the division is well organized and efficient. As now constituted it can economically and skillfully make all the necessary corrections and revisions of the engraved plates, can do all the experimental engraving work, engrave some new sheets, and do all the map printing. This map printing will steadily increase as the number of plates and the demand for maps increase. The Survey now has the engraved copper plates of 473 sheets of the topographic atlas of the United States. The total number of maps printed during the year was 27,000.

The engraving of maps, both by contract and by the Division of Engraving and Printing, has gone forward rapidly throughout the year. At the date of my last report 344 sheets had been engraved. During the fiscal year just ended 129 sheets were engraved, making the total number to date 473. Of these, 28 were engraved in the office and 101 by contract.

On June 30, 1890, contracts for engraving sheets of the general atlas of the United States were pending as follows:

Sinclair & Co., Philadelphia, 100 sheets at	$3.40
H. C. Evans & Co., Washington, 30 sheets at	2.30
Bien & Co., New York, 48 sheets at	2.76
Bien & Co., New York, 20 sheets at	2.76
Bien & Co., New York, 9-sheet map of U. S	48.50

Excepting the second contract with Bien & Co., all the foregoing are completed.

During the year the following contracts for engraving 140 atlas sheets at an average cost of $282 have been awarded:

Evans & Bartle, Washington, 24 sheets at $285	$6,840
Evans & Bartle, Washington, 38 sheets at $250	9,500
Evans & Bartle, Washington, 23 sheets at $300	6,900
Bien & Co., New York, 25 sheets at $325	8,125
Harris & Sons, Baltimore, 30 sheets at $270	8,100
Harris & Sons., Baltimore, map of Connecticut	3,485
Total	42,950

PUBLICATIONS.

During the year there was excellent progress in making public the results obtained by the Survey. This branch of work had fallen in arrears, but is now fully up to date. For this the Survey is greatly indebted to the efficient cooperation of the Public Printer, Hon. F. W. Palmer. Papers aggregating nearly 11,000 pages were published during the year. The details are set forth in the accompanying report of Mr. W. A. Croffut.

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. The accessions during the year amount to 2,120 books, 3,260 pamphlets, and 2,337 maps, and these were acquired in part by purchase and in part by exchange. The library now consists of 29,635 books, 37,957 pamphlets, and 22,337 maps. The extent to which the library is used may be judged by the fact that not less than 12,720 books and pamphlets were drawn out for use during the year. The sale and exchange of the Survey's publications, as well as the transmission of documents published for gratuitous distribution and the extensive correspondence connected therewith, have been carried on in the library. In all, 8,116 publications have been sent out in exchange, 34,689 distributed gratuitously, and 4,187 sold. The total number of parcels handled is 53,078.

DISBURSEMENTS.

The accounts of the Survey have been, as ever since its organization, in the hands of Mr. John D. McChesney, chief disbursing clerk, who has prepared the following statement:

FINANCIAL STATEMENT.

Amounts appropriated for and expended by the United States Geological Survey for the fiscal year ending June 30, 1891.

	General expenses.	Office salaries.	Geological maps.	Total appropriation.
Appropriation fiscal year ending June 30, 1891, acts approved July 11, 1890, and August 30, 1890	$613,900.00	$35,540.00	$70,000.00	$719,440.00
Amounts expended, classified as follows:				
A. Services	400,751.96	34,721.00		
B. Traveling expenses	40,270.38			
C. Transportation of property	4,527.47			
D. Field subsistence	32,536.59			
E. Field supplies and expenses	50,980.93			
F. Field material	8,030.09			
G. Instruments	4,255.71			
H. Laboratory material	3,125.69			
I. Photographic material	2,997.21			
K. Books and maps	5,221.10			
L. Stationery and drawing material	1,811.62			
M. Illustrations for report	143.00			
N. Office rents	3,440.51			
O. Office furniture	754.25			
P. Office supplies and repairs	2,319.54			
Q. Storage	955.33			
R. Correspondence	29.70			
S. Engraving maps			19,643.75	
T. Bonded railroad accounts: Freight $388.05; Transportation of assistants 1,711.45	2,099.50			
Total expenditures	564,250.58	34,721.00	19,643.75	618,615.33
Balance unexpended June 30, 1891	49,649.42	819.00	50,356.25	100,824.67
Probable amount required to meet outstanding liabilities, including contracts for engraving geological maps	49,649.42		50,356.25	100,005.67

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

ACKNOWLEDGMENTS.

For the successful prosecution of its work the Survey is greatly indebted to the Secretary of the Smithsonian Institution, the Superintendent of the Coast and Geodetic Survey, and the Chief Signal Officer, for their hearty cooperation. The work of the Geological Survey is in many ways related to that under the supervision of these officers, and through their kindness important assistance has been rendered to the Survey from day to day throughout the year.

The laborious duties connected with the administration of a large bureau can not be successfully performed without intelligent, faithful, and zealous cooperation on the part of various assistants. On no one officer is the Director compelled to rely to a greater and more varied extent than upon his chief clerk. For a period of some twenty years it has been the Director's good fortune to have the efficient, zealous, and faithful cooperation and support of Mr. James C. Pilling. From the present Director's appointment down to April 30, 1891, the office of chief clerk in the Geological Survey has been filled by Mr Pilling. In addition to his multifarious duties in this position Mr. Pilling has been engaged in scientific work, collecting, arranging, and publishing material relating to the Indian languages of North America; but failing health has made it necessary for him to relinquish a portion of his work, and he has determined to devote himself exclusively to the scientific part. On the 1st of May he was succeeded in the office of chief clerk by Col. H. C. Rizer. As a member of the Bureau of Ethnology Mr. Pilling will continue to prosecute his bibliographic and linguistic researches, and in the interest of science and of scientific workers it is hoped that he may be spared yet many years to continue his useful work.

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, 1891.

ADMINISTRATIVE REPORTS.

REPORT OF MR. HENRY GANNETT.

U. S. GEOLOGICAL SURVEY,
EASTERN DIVISION OF TOPOGRAPHY,
Washington, D. C., July 1, 1891.

SIR: I have the honor to submit the following report upon the operations of the Eastern Division of Topography during the last year:

In accordance with the precedent set by my last annual report I include in this report the work of this division executed during May and June of the preceding fiscal year, and omit from consideration its operations during May and June, 1891, in order to avoid a division of the field season.

During the year the work of this division has been carried on in twenty States, namely: Maine, Connecticut, New York, Pennsylvania, Maryland, Virginia, West Virginia, South Carolina, Georgia, Kentucky, Tennessee, Florida, Michigan, Wisconsin, Illinois, Iowa, Kansas, Arkansas, Louisiana, and Texas.

The area surveyed is 44,100 square miles. Of this area 16,843 square miles were surveyed upon a scale of 1 : 62,500, with contour intervals of 5, 10, or 20 feet, and 27,257 square miles upon the scale of 1 : 125,000, with contour intervals of 20, 50, or 100 feet. The area surveyed upon the larger scale is 50 per cent greater than that of the preceding year, while that upon the smaller scale is less in nearly the same proportion, showing a decided advance in the direction of enlarging the scale.

The number of atlas sheets completed by the season's work was 101, of which 73 were upon the scale of 1 : 62,500, and but 28 upon the scale of 1 : 125,000.

The area surveyed by this division is distributed as shown in the following table and upon the map which constitutes Plate I:

State.	Scale of field work.	Scale of publication.	Contour interval.	Area surveyed.
			Feet.	*Sq. miles.*
Maine	1 : 45, 000	1 : 62500	20	1, 125
Connecticut	1 : 45, 000	...do	20	2, 250
New York	1 : 45, 000	...do	20	450
Pennsylvania	1 : 45, 000	...do	20	1, 800
Maryland	1 : 63, 360	...do	20	2, 450
Virginia	1 : 63, 360	1 : 125000	50	2, 197
West Virginia	1 : 63, 360	...do	100	2, 150
Georgia	1 : 63, 360	...do	50	400
South Carolina	1 : 63, 360	...do	50	2, 050
Tennessee	1 : 63, 360	...do	100	2, 480
Kentucky	1 : 63, 360	...do	100	2, 030
Florida	1 : 63, 360	1 : 62500	10	450
Michigan	1 : 31, 680	...do	20	168
Wisconsin	1 : 31, 680	...do	20	1, 575
Illinois	1 : 31, 680	...do	10	1, 125
Iowa	1 : 31, 680	...do	20	900
Kansas	1 : 63, 360	1 : 125000	20	7, 000
Arkansas	1 : 63, 360	...do	50	2, 500
Texas	1 : 63, 360	...do	20 and 50	6, 000
Louisiana	1 : 63, 360	1 : 62500	5	5, 000

ORGANIZATION.

During the early part of the season the organization of the Topographic branch was substantially the same as during the year preceding. It comprised four sections, named, respectively, Northeastern, Southeastern, Northern, Central, and Southern Central.

The Northeastern Section included all work done in the States north of the Mason and Dixon line and east of Ohio; the Southeastern Section, all work done south of the Mason and Dixon line and the Ohio River and east of the Mississippi and the eastern boundary of Louisiana; the Northern Central Section, all work done in the States of the Mississippi Valley north of the southern boundary of Kansas and east of the one hundredth meridian; the Southern Central Section, all work done in the States of Arkansas, Texas, and Louisiana.

This form of organization was maintained until the 1st of October. Shortly before that date the sundry civil bill was passed by Congress. Among its provisions affecting the Geological Survey was one providing that out of the total appropriation for topographic work ($325,000) to be executed under the Geological Survey, one-half, or $162,500, should be expended for surveys east and one-half for surveys west of the one hundredth meridian. This was a considerable reduction from the amount theretofore appropriated, and it required an immediate reduction of force and change of plans.

Accordingly, as will be noted hereafter in greater detail, the work in Texas and part of that in Kansas was moved west of the one hundredth meridian, and that in Iowa was transferred to western North Dakota. These changes involved the transfer of a number of men from the Eastern to the Western Division of Topography, and left in the Southern Central Section only the Arkansas work.

Under these circumstances it seemed advisable to consolidate the Northern Central and Southern Central Sections into one, under the name of the Central Section, and this was accordingly done.

During the field season an average of 125 men were in the employ of this division, of whom 90 were topographers, assistant topographers, draftsmen, mechanicians, and field assistants; the remainder consisting of cooks, drivers, and laborers. During the winter there were employed in the office an average of 75 men.

NORTHEASTERN SECTION.

During the early part of the season this section remained in charge of Mr. Marcus Baker. On October 1, Mr. Baker was made General Assistant of the Director, and Mr. H. M. Wilson was placed in charge of this division. It has surveyed 5,625 square miles, completing 25 atlas sheets, all on a publication scale of 1:62,500 and with a contour interval of 20 feet. The field of work was in southwestern Maine, eastern Connecticut, southeastern New York, and the anthracite coal region in northeastern Pennsylvania.

The parties of this section took the field during the months of May and June. Work in Maine was resumed in May by Mr. W. H. Lovell, with three assistants. His field of work included the lower valley of the Kennebec and the coast of Casco Bay. Work was prosecuted actively throughout the season and was closed late in November, five atlas sheets, comprising 1,125 square miles, having been completed.

The work in Connecticut was continued at the joint expense of the U. S. Geological Survey and the State of Connecticut, Mr. J. H. Jennings being in charge of the work. Four topographic parties were sent to the field in May, in charge respectively of Messrs. Jennings, Gulliver, Atkinson, and Clark, each with one or more assistants. A fifth party, under Mr. G. L. Johnson, was assigned the duty of revising the three sheets partially surveyed during the preceding season by E. W. F. Natter.

Early in the season Mr. Gulliver received a sunstroke, from which he recovered only partially, and the portion of the work assigned to him suffered greatly in consequence. Early in November Mr. G. E. Hyde, who had spent the early part of the season in the iron region of Michigan, was assigned to work in this area, but was unable to complete it. With this exception the work continued through the season with excellent results, and when the parties left the field late in November or early in December the entire State of Connecticut was completed, with the exception of one sheet (the Norwich sheet) in the southeastern part, which was one of the two assigned to Mr. Gulliver's party. During last spring this sheet was completed, and I am able to report that the survey of Connecticut is finished.

The work in New York was placed in charge of Mr. Frank Sutton, with Mr. Robert Muldrow as an assistant. This party commenced work the first of June and left the field late in November. The field of work lay in the lower valley of the Hudson. The Tarrytown sheet was completed, and the West Point sheet also, with the exception of a narrow strip on the western bank of the Hudson River.

The work in Pennsylvania was placed in charge of R. D. Cummin, and was carried on by four topographic parties, under Messrs. Cummin, Kramer, Lambert, and Smith. These parties took the field in May and completed their work in the latter part of November or early in December, and surveyed during the season eight atlas sheets, all lying within the anthracite coal region in the northeastern part of Pennsylvania.

SOUTHEASTERN SECTION.

This section remained in charge of Mr. Gilbert Thompson. During the season an area of 14,137 square miles was surveyed, and twenty-five atlas sheets completed, thirteen of which are on a scale of 1:125,000, and twelve on a scale of 1:62,500. Work has been prosecuted in Maryland, Virginia, West Virginia, Kentucky, Tennessee, South Carolina, Georgia, and Florida. In addition to the new work in these areas, considerable revision has been made, especially in the valley of East Tennessee.

A party under Mr. C. M. Yeates was occupied during the season in extending the triangulation in eastern Kentucky for the control of the topographic work in that region. He took the field with a small party in June. His field of work was a most difficult one, consisting of the broken country in the lower slopes of the Cumberland Plateau, and he experienced great difficulty in planning and executing the required triangulation. He finally succeeded in carrying it through, and connected with the astronomical station at Richmond, Kentucky, previously established by the U. S. Coast and Geodetic Survey. The discrepancy found in this connection was in latitude 2.3″ and longitude 0.5″. Assuming that the astronomical position of Richmond is correct—i. e., that there is no station error—this discrepancy may be regarded as representing the accumulation of error in 225 miles of triangulation over what is probably the most difficult section of country in the United States, and the result cannot but be regarded as very satisfactory.

The party operating in Maryland was put in charge of Mr. A. E. Murlin, topographer, and the area intrusted to him to survey lies upon the western shore of Chesapeake Bay, extending from the mouth of the Potomac northward to the head of the bay and westward to the Mount Vernon and Frederick sheets. It included the Baltimore and East Washington sheets, already surveyed. This area was to be surveyed for publication upon a scale of 1:62,500, with contour intervals of 20 feet.

Mr. Murlin, with two assistants, took the field earlyin June and prosecuted the work actively until the middle of December, when he had completed the area assigned him. The output of the party was 2,450 square miles, completing twelve atlas sheets.

The Virginia party was placed in charge of Mr. Chas. E. Cooke, who had two assistants. To him was intrusted the work of completing the Appomattox sheet and the entire survey of the Lynchburg sheet. The party took the field about the middle of June, and worked industriously throughout the season, but was nevertheless forced to remain in the field until the 1st of January to complete the area assigned it. This area, which finishes two atlas sheets, includes 1,860 square miles.

The West Virginia party remained, as heretofore, under Mr. L. C. Fletcher, to whom, with three assistants was assigned the work of completing the Charleston and Huntington atlas sheets in the western part of the State, a region consisting of the lower slopes of the Cumberland plateau, which are extremely broken and covered with forests.

Mr. Fletcher began work about the middle of June and prosecuted it with his usual energy and good judgment, completing the area assigned him, and disbanding November 1. The area surveyed during the season was 2,150 square miles, completing the two atlas sheets above mentioned.

The Kentucky party remained, as heretofore, in charge of Mr. E. C. Barnard, to whom, with three assistants, was intrusted the work of surveying the Beattyville and Richmond atlas sheets, and as much of the Harrodsburg sheet as possible. These sheets include the lower slopes of the Cumberland plateau, which presented difficulties similar to those encountered by Mr. Fletcher in West Virginia and a portion of the bluegrass country.

This party took the field June 10, and worked steadily till the latter part of November, when the Beattyville and Richmond sheets were completed, together with half of the Harrodsburg sheet, the total area surveyed being 2,030 square miles.

Mr. Merrill Hackett has remained in charge of the party engaged in surveying the drainage basin of the Savannah River, in South Carolina. This party, consisting of Mr. Hackett and two assistants, took the field in the latter part of June, charged with the completion of the Abbeville sheet and the survey of the Elberton and McCormick sheets, lying mainly in South Carolina, north of Augusta, Georgia. This region consists of a rolling country, with little relief.

Work was prosecuted till the middle of December, when the above-named sheets were completed. The area surveyed by this party was 2,450 square miles, completing three atlas sheets. Besides executing the topographic surveys, Mr. Hackett's party were obliged to control their work by means of primary traverse lines.

The work done in Tennessee during the last season was located in the southeastern part of the State, along its southern boundary, and extending westward from the Sequatchie Valley. Mr. Louis Nell was placed in charge of the party, and at the opening of the season was assigned three assistants, one of whom it was found necessary to withdraw for special work shortly after the commencement of the season.

This party took the field early in July, and completed work and disbanded on November 19, having surveyed 2,480 square miles, completing the Sewanee and Pikeville sheets and about half of the McMinnville sheet. Besides executing the topographic survey of this area, they ran 111 miles of primary traverse for its control.

In addition to the new work above described, considerable revision was carried on. Mr. Longstreet was engaged throughout the season in revising the Maynardville, Morristown, and Mount Guyot sheets, and Mr. Chas. G. Van Hook was detached in July from Mr. Nell's party, and was engaged during the remainder of the season in the resurvey of the Knoxville atlas sheet.

During the winter, work was actively prosecuted in the phosphate regions of Florida. Two parties were organized, one under Mr. C. M. Yeates for running primary traverse lines and establishing bench-marks, and one under Mr. Hersey Munroe for the mapping of topographic details.

Mr. Yeates's party took the field about the beginning of the calendar year, and ran a line from Cedar Keys, on the west coast, to Gainesville, thence southward to Ocala, following the railroad, and thence by common road westward to the coast at Homosassa. His traverse lines were accompanied by a level line for the purpose of establishing bench-marks for the topographers.

Mr. Munroe commenced work upon the Dunnellon sheet west of Ocala early in December, with four assistants. Work was prosecuted by this party until the 1st of May, resulting in the completion of the Dunnellon sheet and the survey of about three-fourths of the Ocala sheet, the scale of work being suitable for publication upon a scale of 1:62,500 with a contour interval of 10 feet.

During the winter and spring, field work has been prosecuted in the Dismal Swamp and the country adjacent on the north and east by Mr. W. R. Atkinson, in the area commenced three years previous. Work was pushed from the 1st of January until the end of May, and resulted in the survey of 337 square miles, completing the Norfolk and Virginia Beach sheets, the scale of publication being 1:125,000, and the contour interval 5 feet.

NORTHERN CENTRAL SECTION.

This section has remained in charge of Mr. J. H. Renshawe. Work has been prosecuted in the iron region upon the upper peninsula of Michigan, in southern Wisconsin, in Illinois, and in Kansas, and during the winter in southern Louisiana. The area surveyed was 15,768 square miles, completing 43 atlas sheets, 36 of which are upon the scale of 1:62,500 and 7 upon the scale of 1:125,000.

The topographic survey of the Marquette iron region upon the upper peninsula of Michigan, which was commenced during the preceding year, was completed and the survey of the Gogebic region carried out. This work was done by Mr. G. E. Hyde and one assistant, who commenced work in May and completed both areas in October.

As the work in these regions has been confined closely to the iron region, without any reference to the completion of atlas sheets, the area surveyed is irregular in form, and no sheets have been finished. The entire area surveyed by Mr. Hyde in this region was 168 square miles.

The work in Wisconsin, as heretofore, was in charge of Mr. Van H. Manning, who with two assistants prosecuted the survey from May until November. Seven sheets were surveyed, comprising approximately 1,575 square miles, lying in the southeastern part of the State.

The work in Illinois, as during the preceding season, was in charge of Mr. D. C. Harrison, with one assistant. They commenced work in May, and prosecuted it actively until the latter part of November, completing two sheets, which had been partially surveyed during the preceding season, and surveying entirely five others, lying along the course of the Illinois River southwest of Chicago. The entire area surveyed by Mr. Harrison is estimated at 1,125 square miles.

As heretofore, the work in Iowa was carried on by Mr. W. J. Peters. Mr. Peters, with one assistant, commenced work early in May and prosecuted it admirably and effectively until the first of October, when, owing to the allotment of the appropriation by Congress, and the consequent reduction in the amount available for eastern work, it became necessary to transfer him with his assistant to the Western Division of topography. Up to that time Mr. Peters had surveyed four sheets in eastern Iowa, having an area of 900 square miles.

The work in Kansas was carried on under a form of organization similar to that of the season before. The work was in general charge of Mr. H. L. Baldwin, who personally conducted the triangulation for its control. There were two topographic parties in charge respectively of R. M. Towson and W. H. Herron. To Mr. Baldwin fell the work of extending the northern belt of triangulation from its former termination in longitude 97 to the one hundredth meridian, and the connection of his triangulation stations with section corners of the General Land Office.

To Mr. Herron, with two assistants, was assigned the survey of the three sheets lying along the southern boundary of the State, and limited on the west by the one-hundredth meridian, while to Mr. Towson was assigned the survey of five sheets in the northern portion of the State. These parties took the field early in May. Mr. Towson's party continued through the season in the field allotted to it, and completed the five required sheets. Mr. Herron had an extremely difficult field for survey, consisting of a broken canyon country with few settlements and roads, and his progress was therefore necessarily slow. The 1st of October found his party with two sheets completed and level lines run over the third sheet, but no topography sketched upon it. At that date it became necessary to transfer this party to the Western Division.

The triangulation party under Mr. Baldwin had practically completed on October 1 the belt of triangulation which it was called upon to execute, and at that date this party was also transferred to the Western Division.

The area surveyed by the Kansas party was 7,000 square miles, completing seven atlas sheets, all surveyed for publication upon a scale of 1 : 125,000, with a contour interval of 20 feet.

SOUTHERN CENTRAL SECTIONS.

This section was in charge of Mr. R. U. Goode until October 1. Work was prosecuted in Arkansas and Texas. The area surveyed was 8,500 square miles, completing eight atlas sheets, all upon a scale of 1 : 125,000.

The organization of the Arkansas parties remained as during the preceding year, and consisted of a triangulation party under Mr. G. T. Hawkins, and a topographic party under Mr. H. B. Blair. The triangulation party took the field on the 1st of May, and was engaged throughout the season in working northward and westward along the northern border of the State and running primary traverse lines in southwestern Missouri looking toward the survey of the three sheets in the southwestern corner of that State. He left the field toward the end of November.

The topographic party, consisting of H. B. Blair with three assistants, commenced work about the 1st of July, and continued in the field until the latter part of December. Two sheets were surveyed completely in the northern part of the State, while the third, the Little Rock sheet, was nearly completed.

The organization in Texas was increased over that of last season by the addition of a party under Mr. A. E. Wilson for executing primary leveling and furnishing bench-marks to the topographers. Besides this leveling party there was, as before, one party for carrying on triangulation and two parties for mapping topographic details. The former was in charge of Mr. C. F. Urquhart, the latter in charge of Messrs. H. S. Wallace and R. O. Gordon.

These parties left for the field in the latter part of April and commenced work in the early part of May. They surveyed, first, the two sheets lying between the meridians of 97° and 97° 30′ and the parallels of 31° and 32°; then moving their parties westward, they surveyed four sheets lying between the meridians of 99° 30′ and 100° and the parallels of 31° and 33°. The triangulation and leveling parties all this time kept in advance of the topographic parties and furnished them positions and elevations for their use. The area last mentioned was completed on or about October 1, when all these parties were transferred to the western section and their field work moved west of the one hundredth meridian. At this date what was left the Southern Central Division was consolidated with the Northern Central Division, and subsequent work belongs to the latter organization.

During the winter work was actively prosecuted in southern Louisiana. This was placed in charge of Mr. H. L. Baldwin, and to him were assigned eight assistants. They left for the field early in January, and were organized into four parties of two men each for economic prosecution of the work. Provision was made for housing the parties upon flatboats, as it appeared to be impracticable to maintain them at houses, as was the practice the winter before.

Work was continued until the middle of April. The area surveyed lay south of the territory surveyed last season, and included the area between the meridians of 89° 45′ and 91° and from the parallel of 29° 45′ southward to the coast. Besides this, the unfinished portions of two sheets of the previous season's area were completed. In this region great assistance was afforded by the work of the U. S. Coast and Geodetic Survey, which has completed or nearly completed the coast line with the topography inland for some distance up the bayous and rivers.

From this season's work twenty atlas sheets will be finished, embracing an area of about 5,000 square miles, all on a scale of 1 : 62,500, and with a contour interval of 5 feet.

ASTRONOMIC AND COMPUTING SECTION.

Upon the resignation of Mr. R. S. Woodward, formerly in charge of this section, Mr. S. S. Gannett was transferred to fill his place. Besides determining the position of Rapid City, South Dakota, by astronomic observation, Mr. Gannett has been occupied in the reduction of observations of triangulation in Kansas, Arkansas, and Texas, and in the computation of primary traverses and in the preparation of tables for field use by the topographers.

In accordance with a request made by this office, the U. S. Coast and Geodetic Survey has made astronomic determinations of position at Jacksonville, Texas; Gainesville, Florida; and Augusta, Georgia—these positions being needed for the location of topographic work.

DRAFTING DIVISION.

This division, in charge of Mr. Harry King, was engaged during the early part of the year in the preparation of map illustrations for reports, and in the proof-reading of engraved atlas sheets. In March of the present year this section was dissolved, Mr. King's two assistants being transferred to the Division of Illustration, and Mr. King being made proof-reader of maps.

INSTRUMENTS.

The instrument shop, as heretofore, has been in charge of Mr. Edward Kübel, with four assistants. As heretofore, the work done in the shop has been practically limited to the repair and adjustment of the instruments in the possession of the Survey. This work taxes the resources of the shop to its utmost limit, and practically no new instruments have been made during the year.

ENGRAVING.

In my last report it was stated that there were pending at that time a contract with Messrs. Sinclair & Co., of Philadelphia, for engraving 100 sheets; one with H. C. Evans, of Baltimore, for 30 sheets; one with Messrs. Bien & Co., of New York, for 20 sheets, for 48 sheets, and for the 9-sheet map of the United States. With the exception of that with Messrs. Bien for 48 sheets, all these contracts have been completed, the plates furnished this office, and small editions of the maps printed.

Since that date the following contracts have been made: With Evans & Bartle, 24 sheets, 44 sheets, 23 sheets; with Bien & Co., 25 sheets; with Messrs. Geo. S. Harris & Sons, 30 sheets, and the map of the State of Connecticut in 4 sheets.

These six contracts are all pending in various stages of completion. Besides the sheets engraved under contract, the engraving division of this office has engraved 28 sheets.

Appended to this report will be found a list of the atlas sheets engraved up to July 1, 1891.

Very respectfully,

HENRY GANNETT,
Chief Topographer.

Hon. J. W. POWELL,
Director.

Atlas sheets engraved to June 30, 1891.

Locality.	Name of sheet.	Designation of sheet. Lat.		Long.		Area covered.	Scale.	Contour interval.
		°	′	°	′			Feet.
Maine	Portland	43	30	70	15	1/16 degree	1 : 62,500	20
	Newfield	43	30	70	45	...do	...do	20
	Biddeford	43	15	70	15	...do	...do	20
	Kennebunk	43	15	70	30	...do	...do	20
Maine and New Hampshire.	York	43	00	70	30	...do	...do	20
	Dover	43	00	70	45	...do	...do	20
New Hampshire and Vermont.	Brattleboro	42	45	72	30	...do	...do	20
Vermont	Wilmington	42	45	72	45	...do	...do	20
Massachusetts and New Hampshire.	Newburyport	42	45	70	45	...do	...do	20
	Haverhill	42	45	71	00	...do	...do	20
	Lawrence	42	30	71	00	...do	...do	20
	Lowell	42	30	71	15	...do	...do	20
	Groton	42	30	71	30	...do	...do	20
	Fitchburg	42	30	71	45	...do	...do	20
	Winchendon	42	30	72	00	...do	...do	20

Atlas sheets engraved to June 30, 1891—Continued.

Locality.	Name of sheet.	Designation of sheet.		Area covered.	Scale.	Contour interval.
		Lat.	Long.			
		° ′	° ′			Feet.
Massachusetts, New Hampshire, and Vermont.	Warwick	42 30	72 15	$\frac{1}{16}$ degree	1 : 62,500	20
Massachusetts and Vermont.	Greenfield	42 30	72 30	...do	...do	20
	Hawley	42 30	72 45	...do	...do	20
	Greylock	42 30	73 00	...do	...do	40
Massachusetts, Vermont, and New York.	Berlin	42 30	73 15	...do	...do	20
Massachusetts and New York.	Pittsfield	42 15	73 15	...do	...do	20
Massachusetts	Gloucester	42 30	70 30	...do	...do	20
	Salem	42 30	70 45	...do	...do	20
	Boston Bay	42 15	70 45	...do	...do	20
	Boston	42 15	71 00	...do	...do	20
	Framingham	42 15	71 15	...do	...do	20
	Marlborough	42 15	71 30	...do	...do	20
	Worcester	42 15	71 45	...do	...do	20
	Barre	42 15	72 00	...do	...do	20
	Belchertown	42 15	72 15	...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
	Dedham	42 00	71 00	...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
	Marthas Vineyard	41 15	70 72	...do	...do	20
	Gay Head	41 15	70 42	...do	...do	20
Massachusetts and Connecticut.	Webster	42 00	71 45	...do	...do	20
	Brookfield	42 00	72 00	...do	...do	20
	Palmer	42 00	72 15	...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
Massachusetts, Connecticut, and New York.	Sheffield	42 00	73 15	...do	...do	20
Massachusetts and Rhode Island.	Franklin	42 00	71 15	...do	...do	20
	Blackstone	42 00	71 30	...do	...do	20
	Providence	41 45	71 15	...do	...do	20
	Fall River	41 30	71 00	...do	...do	20
Rhode Island	Burrillville	41 45	71 30	...do	...do	20
	Narragansett Bay	41 30	71 15	...do	...do	20

Atlas sheets engraved to June 30, 1891—Continued.

Locality.	Name of sheet.	Designation of sheet.		Area covered.	Scale.	Contour interval.
		Lat.	Long.			
		° ′	° ′			*Feet.*
Rhode Island	Kent	41 30	71 30	1/16 degree	1 : 62,500	20
	Sakonnet	41 15	71 00	....do	..do	20
	Newport	41 15	71 15	....do	..do	20
	Charlestown	41 15	71 30	....do	..do	20
	Block Island	41 00	71 30	....do	..do	20
Rhode Island and Connecticut.	Putnam	41 45	71 45	....do	..do	20
	Moosup	41 30	71 45	....do	..do	20
Rhode Island, Connecticut, and New York.	Stonington	41 15	71 45	....do	..do	20
Connecticut	Meriden	41 30	72 45	....do	..do	20
	Waterbury	41 30	73 00	....do	..do	20
	New Milford	41 30	73 15	....do	..do	20
	New Haven	41 15	72 45	....do	..do	20
	Derby	41 15	73 00	....do	..do	20
	Bridgeport	41 00	73 00	....do	..do	20
	Norwalk	41 00	73 15	....do	..do	20
New York and Connecticut.	Stamford	41 00	73 30	....do	..do	20
New York	Brooklyn	40 30	73 45	....do	..do	20
New York and New Jersey.	Harlem	40 45	73 45	....do	..do	20
	Staten Island	40 30	74 00	....do	..do	20
	Ramapo	41 00	74 00	....do	..do	20
	Greenwood Lake	41 00	74 15	....do	..do	20
New Jersey	Franklin	41 00	74 30	....do	..do	20
	Paterson	41 00	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
	Somerville	40 30	74 30	....do	..do	20
	High Bridge	40 30	74 45	....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
	Whitings	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
	Mullicas	39 30	74 30	....do	..do	10
	Hammonton	39 30	74 45	....do	..do	10
	Glassboro	39 30	75 00	....do	..do	10
	Salem	39 30	75 15	....do	..do	10
	Atlantic City	39 15	74 15	....do	..do	10
	Great Egg Harbor	39 15	74 30	....do	..do	10
	Tuckahoe	39 15	74 45	....do	..do	10
	Bridgeton	39 15	75 00	....do	..do	10
	Sea Isle	39 00	74 30	....do	..do	10

Atlas sheets engraved to June 30, 1891—Continued.

Locality.	Name of sheet.	Designation of sheet.				Area covered.	Scale.	Contour interval.
		Lat.		Long.				
		°	′	°	′			Feet.
New Jersey	Dennisville	39	00	74	45	$\frac{1}{16}$ degree	1 : 62,500	10
	Maurice Cove	39	00	75	00	do	do	10
	Cape May	38	45	74	45	do	do	10
New Jersey and Pennsylvania.	Wallpack	41	00	74	45	do	do	20
	Delaware Water Gap.	40	45	75	00	do	do	20
	Easton	40	30	75	00	do	do	20
	Lambertville	40	15	74	45	do	do	20
	Burlington	40	00	74	45	do	do	20
	Philadelphia	39	45	75	00	do	do	20
Pennsylvania	Scranton	41	15	75	30	do	do	20
	Hazleton	40	45	75	45	do	do	20
	Catawissa	40	45	76	15	do	do	20
	Lykens	40	30	76	30	do	do	20
	Doylestown	40	15	75	00	do	do	20
	Quakertown	40	15	75	15	do	do	20
	Lebanon	40	15	76	15	do	do	20
	Germantown	40	00	75	00	do	do	20
New Jersey and Delaware	Bayside	39	15	75	15	do	do	10
Maryland	Baltimore	39	10	76	30	do	do	20
Maryland and District of Columbia.	East Washington	38	45	76	45	do	do	20
Maryland, District of Columbia, and Virginia.	West Washington	38	45	77	00	do	do	20
	Mount Vernon	38	30	77	00	$\frac{1}{4}$ degree	1 : 125,000	50
Maryland, Virginia, and West Virginia.	Harper's Ferry	39	00	77	30	do	do	100
	Romney	39	00	78	30	do	do	100
Maryland and West Virginia.	Piedmont	39	00	79	00	do	do	100
Maryland and Virginia	Frederick	39	00	77	00	do	do	50
	Fredericksburg	38	00	77	00	do	do	50
Virginia	Warrenton	38	30	77	30	do	do	50
	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	00	do	do	100
	Goochland	37	30	77	30	do	do	50
	Palmyra	37	30	78	00	do	do	50
	Buckingham	37	30	78	30	do	do	100
	Lexington	37	30	79	00	do	do	100
	Natural Bridge	37	30	79	30	do	do	100
	Farmville	37	00	78	00	do	do	50
	Roanoke	37	00	79	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
	Beverly	38	30	79	30	do	do	100
	Staunton	38	00	79	00	do	do	100
	Monterey	38	00	79	30	do	do	100
	Lewisburg	37	30	80	00	do	do	100
	Christiansburg	37	00	80	00	do	do	100
	Dublin	37	00	80	30	do	do	100
	Pocahontas	37	00	81	00	do	do	100

Atlas sheets engraved to June 30, 1891—Continued.

Locality.	Name of sheet.	Designation of sheet.				Area covered.	Scale.	Contour interval.
		Lat.		Long.				
		°	'	°	'			*Feet.*
Virginia and West Virginia.	Tazewell	37	00	81	30	¼ degree	1 : 125, 000	100
West Virginia	St. George	39	00	79	30	...do	...do	100
	Huntersville	38	00	80	00	...do	...do	100
	Nicholas	38	00	80	30	...do	...do	100
	Kanawha Falls	38	00	81	00	...do	...do	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
	Salyersville	37	30	83	00	...do	...do	100
	Hazard	37	00	83	00	...do	...do	100
	Manchester	37	00	83	30	...do	...do	100
Kentucky and Virginia	Whitesburg	37	00	82	30	...do	...do	100
	Grundy	37	00	82	00	...do	...do	100
Virginia and North Carolina.	Hillsville	36	30	80	30	...do	...do	100
	Wytheville	36	30	81	00	...do	...do	100
Virginia, North Carolina, and Tennessee.	Abingdon	36	30	81	30	...do	...do	100
Virginia and Tennessee	Bristol	36	30	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
Kentucky and Tennessee.	Williamsburg	36	30	84	00	...do	...do	100
North Carolina	Wilkesboro	36	00	81	00	...do	...do	100
	Morganton	35	30	81	30	...do	...do	100
	Cowee	35	00	83	00	...do	...do	100
North Carolina and Tennessee.	Roan Mountain	36	00	82	00	...do	...do	100
	Cranberry	36	00	81	30	...do	...do	100
	Greeneville	36	00	82	30	...do	...do	100
	Mount Mitchell	35	30	82	00	...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
North Carolina and South Carolina.	Saluda	35	00	82	00	...do	...do	100
	Pisgah	35	00	82	30	...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
	Carnesville	34	00	83	00	...do	...do	100

Atlas sheets engraved to June 30, 1891—Continued.

Locality.	Name of sheet.	Designation of sheet. Lat.		Designation of sheet. Long.		Area covered.	Scale.	Contour interval.
		°	′	°	′			Feet.
Georgia	Gainesville	34	00	83	30	¼ degree	1 : 125,000	100
	Suwanee	34	00	84	00	do	do	100
	Cartersville	34	00	84	30	do	do	100
	Atlanta	33	30	84	00	do	do	100
	Marietta	33	30	84	30	do	do	50
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
	Scottsboro	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
	Springville	33	30	86	00	do	do	100
	Birmingham	33	30	86	30	do	do	100
	Ashland	33	00	85	30	do	do	100
	Talladega	33	00	86	00	do	do	100
	Bessemer	33	00	86	30	do	do	100
	Clanton	32	30	86	30	do	do	50
Wisconsin	Sun Prairie	43	00	89	00	$\frac{1}{16}$ degree	1 : 62,500	20
	Waterloo	43	00	88	45	do	do	20
	Madison	43	00	89	15	do	do	20
	Koshkonong	42	45	88	45	do	do	20
	Stoughton	42	45	89	00	do	do	20
	Evansville	42	45	89	15	do	do	20
Illinois	Desplaines	41	45	87	45	do	do	10
	Riverside	41	30	87	45	do	do	10
Iowa	Maquoketa	42	00	90	30	do	do	20
	Baldwin	42	00	90	45	do	do	20
	Monticello	42	00	91	00	do	do	20
	Anamosa	42	00	91	15	do	do	20
	Marion	42	00	91	30	do	do	20
	Shellsburg	42	00	91	45	do	do	20
	De Witt	41	45	90	30	do	do	20
	Wheatland	41	45	90	45	do	do	20
	Tipton	41	45	91	00	do	do	20
	Mechanicsville	41	45	91	15	do	do	20
	Cedar Rapids	41	45	91	30	do	do	20
	Amana	41	45	91	45	do	do	20
	West Liberty	41	30	91	15	do	do	20
	Iowa City	41	30	91	30	do	do	20
	Oxford	41	30	91	45	do	do	20
	Davenport	41	30	90	30	do	do	20
	Durant	41	30	90	45	do	do	20
	Wilton Junction	41	30	91	00	do	do	20
Missouri and Illinois	Louisiana	39	00	91	00	¼ degree	1 : 125,000	50
	St. Louis, East	38	30	90	00	$\frac{1}{16}$ degree	1 : 62,500	20
Missouri	St. Louis, West	38	30	90	15	do	do	20
	Mexico	39	00	91	30	¼ degree	1 : 125,000	50
	Moberly	39	00	92	00	do	do	50

Atlas sheets engraved to June 30, 1891—Continued.

Locality.	Name of sheet.	Designation of sheet.		Area covered.	Scale.	Contour interval.
		Lat.	Long.			
		° ′	° ′			Feet.
Missouri	Glasgow	39 00	92 30	¼ degree	1 : 125, 000	50
	Marshall	39 00	93 00	...do	...do	50
	Lexington	39 00	93 30	...do	...do	50
	Independence	39 00	94 00	...do	...do	50
	Hermann	38 30	91 00	...do	...do	50
	Fulton	38 30	91 30	...do	...do	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
	Kansas City	39 00	94 30	...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
	Abilene	38 30	97 00	...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
	Newton	38 00	97 00	...do	...do	50
	Hutchinson	38 00	97 30	...do	...do	20
	Lyons	38 00	98 00	...do	...do	20
	Great Bend	38 00	98 30	...do	...do	20
	Larned	38 00	99 00	...do	...do	20
	Ness City	38 00	99 30	...do	...do	20
	Iola	37 30	95 00	...do	...do	50
	Fredonia	37 30	95 30	...do	...do	50

Atlas sheets engraved to June 30, 1891—Continued.

Locality.	Name of sheet.	Designation of sheet.				Area covered.	Scale.	Contour interval.
		Lat.		Long.				
		°	′	°	′			Feet.
Kansas	Eureka	37	30	96	00	¼ degree	1 : 125,000	50
	Eldorado	37	30	96	30	...do	...do	50
	Wichita	37	30	97	00	...do	...do	50
	Cheney	37	30	97	30	...do	...do	20
	Kingman	37	30	98	00	...do	...do	20
	Pratt	37	30	98	30	...do	...do	20
	Kinsley	37	30	99	00	...do	...do	20
	Spearville	37	30	99	30	...do	...do	20
	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
	Wellington	37	00	97	00	...do	...do	50
	Caldwell	37	00	97	30	...do	...do	20
	Anthony	37	00	98	00	...do	...do	20
Arkansas	Mountain View	36	30	92	00	...do	...do	50
	Marshall	35	30	92	30	...do	...do	50
	Morrillton	35	00	92	30	...do	...do	50
	Dardanelle	35	00	93	00	...do	...do	50
	Magazine Mountain.	35	00	93	30	...do	...do	50
	Fort Smith	35	00	94	00	...do	...do	50
	Benton	34	30	92	30	...do	...do	50
	Hot Springs	34	30	93	00	...do	...do	50
	Mount Ida	34	30	93	30	...do	...do	50
	Poteau Mountain	34	30	94	00	...do	...do	50
	Aplin	35	00	93	00	Degree	1 : 62,500	20
	Greenwood	35	00	94	15	...do	...do	20
	Atkins	35	00	92	45	...do	...do	20
	Washburn	35	00	94	00	...do	...do	20
	Petit Jean	35	00	92	45	...do	...do	20
	Danville	35	00	93	15	...do	...do	20
	Russellville	35	15	93	00	...do	...do	20
	Clarksville	35	15	93	15	...do	...do	20
	Coal Hill	35	15	93	30	...do	...do	20
	Van Buren	35	15	94	15	...do	...do	20
	Arbuckle	35	15	94	00	...do	...do	20
	Ozark	35	15	93	45	...do	...do	20
	Oak Mountain	35	15	92	45	...do	...do	20
Texas	Dallas	32	30	96	30	¼ degree	1 : 125,000	20
	Fort Worth	32	30	97	00	...do	...do	20
	Weatherford	32	30	97	30	...do	...do	50
	Palo Pinto	32	30	98	00	...do	...do	50
	Breckenridge	32	30	98	30	...do	...do	50
	Albany	32	30	99	00	...do	...do	50
	Anson	32	30	99	30	...do	...do	50
	Cleburne	32	00	97	00	...do	...do	50
	Granbury	32	00	97	30	...do	...do	50
	Stephenville	32	00	98	00	...do	...do	50
	Eastland	32	00	98	30	...do	...do	50
	Meridian	31	30	97	30	...do	...do	50
	Hamilton	31	30	98	00	...do	...do	50

Atlas sheets engraved to June 30, 1891.

Locality.	Name of sheet.	Designation of sheet.				Area covered.	Scale.	Contour interval.
		Lat.		Long.				
		°	′	°	′			*Feet.*
Texas	Brownwood	31	30	98	30	¼ degree	1 : 125, 000	50
	Coleman	31	30	99	00	do	do	50
	Gatesville	31	00	97	30	do	do	50
	Lampasas	31	00	98	00	do	do	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
	Burnet	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
	Fredericksburg	30	00	98	30	do	do	50
	Kerrville	30	00	99	00	do	do	50
Montana	Fort Benton	47	00	110	00	1 degree	1 : 250, 000	200
	Great Falls	47	00	111	00	do	do	200
	Big Snowy Mountain.	46	00	109	00	do	do	200
	Little Belt Mountain.	46	00	110	00	do	do	200
	Fort Logan	46	00	111	00	do	do	200
	Helena	46	00	112	00	do	do	200
	Livingston	45	00	110	00	do	do	200
	Three Forks	45	00	111	00	do	do	200
	Dillon	45	00	112	00	do	do	200
Yellowstone National Park.	Canyon	44	30	110	00	¼ degree	1 : 125, 000	100
	Gallatin	44	30	110	30	do	do	100
	Lake	44	00	110	00	do	do	100
	Shoshone	44	00	110	30	do	do	100
Idaho	Camas Prairie	43	00	115	00	do	do	100
	Mount Home	43	00	115	30	do	do	100
Oregon	Klamath	42	00	121	00	1 degree	1 : 250, 000	200
	Ashland	42	00	122	00	do	do	200
Colorado	East Denver	39	30	104	30	¼ degree	1 : 125, 000	50
	Crested Butte	38	45	106	45	1/16 degree	1 : 62, 500	100
	Anthracite	38	45	107	00	do	do	100
	Arroya	38	30	103	00	¼ degree	1 : 125, 000	100
	Sanborn	38	30	103	30	do	do	100
	Big Springs	38	30	104	00	do	do	100
	Las Animas	38	00	103	00	do	do	100
	Catlin	38	00	103	30	do	do	100
	Nepesta	38	00	104	00	do	do	100
	Pueblo	38	00	104	30	do	do	100
	Higbee	37	30	103	00	do	do	100
	Timpas	37	30	103	30	do	do	100
	Apishapa	37	30	104	00	do	do	100
Colorado and Utah	Ashley	40	00	109	00	1 degree	1 : 250, 000	250
	East Tavaputs	39	00	109	00	do	do	250
	La Sal	38	00	109	00	do	do	250
	Abajo	37	00	109	00	do	do	250

Atlas sheets engraved to June 30, 1891.

Locality.	Name of sheet.	Designation of sheet.				Area covered.	Scale.	Contour interval.
		Lat.		Long.				
		°	′	°	′			*Feet.*
Utah	Uinta	40	00	110	00	1 degree	1 : 250, 000	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	112	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
	Carson	39	00	119	30	¼ degree	1 : 125, 000	200
California	Alturas	41	00	120	00	1 degree	1 : 250, 000	200
	Modoc Lava Bed	41	00	121	00	do	do	200
	Shasta	41	00	122	00	do	do	200
	Honey Lake	40	00	120	00	do	do	200
	Lassen Peak	40	00	121	00	do	do	200
	Red Bluff	40	00	122	00	do	do	200
	Downieville	39	30	120	30	¼ degree	1 : 125, 000	50
	Bidwell Bar	39	30	121	00	do	do	50
	Chico	39	30	121	30	do	do	100
	Colfax	39	00	120	30	do	do	100
	Nevada City	39	00	121	00	do	do	100
	Marysville	39	00	121	30	do	do	100
	Placerville	38	30	120	30	do	do	100
	Sacramento	38	30	121	00	do	do	100
	Jackson	38	00	120	30	do	do	100
New Mexico	Largo	36	00	107	00	1 degree	1 : 250, 000	200
	Chaco	36	00	108	00	do	do	200
	Santa Clara	35	30	106	00	¼ degree	1 : 125, 000	100
	Jemez	35	30	106	30	do	do	100
	Albuquerque	35	00	106	30	do	do	50
	Mount Taylor	35	00	107	00	1 degree	1 : 250, 000	200
	Wingate	35	00	108	00	do	do	200
New Mexico and Arizona	Canyon 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

Atlas sheets engraved to June 30, 1891—Continued.

Locality.	Name of sheet.	Designation of sheet.		Area covered.	Scale.	Contour interval.
		Lat.	Long.			
		° ′	° ′			*Feet.*
Arizona	Diamond Creek	35 00	113 00	1 degree	1 : 250, 000	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 Mohave	35 00	114 00	...do	...do	250

REPORT OF MR. A. H. THOMPSON.

U. S. GEOLOGICAL SURVEY,
WESTERN DIVISION OF TOPOGRAPHY,
Washington, D. C., June 30, 1891.

SIR: I have the honor to submit the following report of the work of the Topographic Division West of the one hundredth meridian for the last year.

On account of the commencement of field work before the end of the fiscal year and the impossibility of separating the amount of work actually done before July 1, 1891, from that of the succeeding year, my report of work includes only that done between July 1, 1890, and May 1, 1891.

Work was prosecuted during this period in California, Colorado, Idaho, Kansas, Montana, Nevada, North Dakota, South Dakota, Texas, and New Mexico, and in the office at Washington, D. C., in accordance with plans submitted to and approved by you.

GENERAL ORGANIZATION.

For convenience of supervision and administrative management, five sections for the prosecution of work were organized at the beginning of the year. Upon the passage of the sundry civil bill, August 30, 1890, and in accordance with the provisions of that act requiring that one-half of the gross appropriations for topographic work be spent west of the one hundredth meridian, two additional sections were formed, making seven sections in all. Of these the States of California and Nevada constituted the first, Colorado the second, Idaho the the third, Kansas and Texas the fourth, Montana the fifth, North Dakota the sixth, and New Mexico the seventh. The work in South Dakota was of such a nature that no section was organized.

Mr. E. M. Douglas, topographer, was assigned to the charge of the California-Nevada section, assisted by Messrs. A. F. Dunnington,

R. H. McKee, R. H. Chapman, topographers; H. E. C. Feusier and P. V. S. Bartlett, assistant topographers, in charge of parties.

Mr. Willard D. Johnson, topographer, was assigned to the charge of the Colorado section, assisted by Messrs. C. H. Fitch, Jno. W. Hays, R. C. McKinney, W. S. Post, and R. B. Marshall, topographers; A. C. Barclay, R. A. Farmer, S. P. Johnson, assistant topographers in charge of parties, and Messrs. S. A. Foot, Perry Fuller, L. B. Kendall, C. H. Stone, assistant topographers.

Mr. W. T. Griswold, topographer, was assigned to the charge of the Idaho section, assisted by Mr. E. T. Perkins, jr., in charge of party.

Mr. R. U. Goode, geographer, was assigned to the charge of the Kansas-Texas section, assisted by Messrs. H. L. Baldwin, H. S. Wallace, R. O. Gordon, C. F. Urquhart, W. H. Herron, topographers in charge of parties, and Messrs. Geo. H. Lamar, E. McLean Long, R. B. Cameron, and A. E. Wilson, assistant topographers.

Mr. Frank Tweedy, topographer, was assigned to the charge of the section of Montana, assisted by Mr. Jeremiah Ahern, in charge of party, and Mr. Frank E. Gove, assistant topographer.

Mr. Morris Bien, topographer, was given charge of the North Dakota section, assisted by Mr. Wm. J. Peters, topographer in charge of party, and Messrs W. B. Corse and C. T. Ried, assistant topographers.

Mr. A. P. Davis was assigned to the charge of the New Mexico section, assisted by Messrs. F. J. Knight, J. B. Lippincott, and C. C. Bassett, topographers in charge of parties.

Mr. S. S. Gannett, assisted by Mr. A. F. Dunnington and working in cooperation with Prof. H. S. Pritchett of Washington University, St. Louis, Missouri, had charge of the field work in South Dakota.

ORGANIZATION FOR FIELD WORK.

In the California-Nevada section one triangulation and four topographic parties were organized; in the Colorado section one level and seven topographic parties; in the Idaho section one triangulation and two topographic parties; in the Kansas-Texas section two triangulation, one level, and three topographic parties; in the Montana section one triangulation-topographic and one topographic party; in the North Dakota section two leveling and topographic parties; and in New Mexico section one triangulation and two topographic parties.

The field work of these parties being as heretofore in a sparsely settled region, it was usually necessary to subsist them in camps. The arrangements for this purpose were nearly the same in all localities, each party employing, in addition to the regularly appointed assistants, one or two persons as traverse or rod men, one laborer, one cook, and one teamster, using as means of transportation one large four-mule team and wagon for camp equipage and supplies. and buckboards or saddle animals for persons engaged in map work.

ATLAS SHEETS.

In all sections the work proceeded by atlas-sheet areas according to the general system adopted by the U. S. Geological Survey, and was bounded as far as practicable by the half or quarter degree lines of latitude and longitude. The field work was usually done on twice the scale intended for publication, the relief being represented by contour lines having equal vertical intervals, but differing on different sheets and sometimes on the same sheet.

The following table shows the locality, the scale of field work, the contour interval, and area surveyed during the year.

Locality.	Scale field work.	Contour interval.	Square miles surveyed.	Remarks.
		Feet.		
California	1 inch=1 mile	100-50	1,000	
Colorado	1 inch=1 mile	100-50-25	8,700	
Idaho	1 inch=1 mile	100-50	1,900	
Kansas	1 inch=1 mile	50	1,900	
Montana	1 inch=1 mile	50-100	400	
Nevada	1 inch=1 mile	50-100	2,800	
New Mexico	1 inch=1 mile	25-50-100	2,850	
North Dakota				730-mile levels.
South Dakota				Astronomical station, Rapid City.
Texas	1 inch=1 mile	50	1,925	
	Total		21,475	

In addition to topographic map work, the sections of California, Nevada, Colorado, Montana, and New Mexico located, surveyed, and reported for segregation from the public domain 147 reservoir sites lying within those areas.

The following table shows the States and Territories within which reservoir sites were located and surveyed, the number in each, and the date upon which their segregation was asked, and the total area which was recommended for segregation.

Locality.	Number reservoirs.	Date of segregation.	Area segregated.
			Acres.
California	33	Feb. 27, 1891	21,192
Colorado	45	....do	56,814
Montana	28	....do	30,113
Nevada	2	....do	2,040
New Mexico	39	....do	55,773
Total	147		165,932

FIELD WORK.

CALIFORNIA-NEVADA SECTION.

The organization and outfitting of parties for this work was completed at Ione, California, and Reno, Nevada, early in July, and they were directed to proceed to the survey of areas known as the Sierra Valley and Big Tree sheets in California; the Reno, Wadsworth, Wabuska and Wellington sheets in Nevada, all lying between longitude 119° and 120° west, and latitude 38° and 40° north.

The triangulation party was placed under charge of Mr. H. E. C. Feusier, and directed to select and locate a sufficient number of points on each atlas sheet to furnish the topographers with the data necessary for the control of their work.

Mr. A. F. Dunnington, with his party, was directed to complete the survey of the Sierra Valley sheet in California, the Wadsworth and the northern part of the Wabuska sheets in Nevada. To Mr. McKee was assigned the Big Tree sheet in California; to Mr. Chapman the completion of the Reno and Wellington sheets in Nevada, and to Mr. Bartlett the Wabuska sheet, in the same State. Mr. Douglas was employed during the entire field season in supervision and inspection of work and in attending to administrative details relating to the disbandment of the Irrigation Survey and the prosecution of his own work.

In addition to the topographic work assigned these parties, they were also directed to survey and report upon the reservoir sites suitable for the storage of water for purposes of irrigation. Each party, with the exception of Mr. Dunnington's, was engaged during the latter part of the season upon this work. Thirty-three such sites were located with reference to the U. S. Land Survey, the necessary height of dam decided upon, the area embraced by the reservoir at the given height of the dam, the approximate content in acre-feet, and the amount of land described in terms of the U. S. Land Survey necessary to segregate for each reservoir site determined.

By November 15 work in this section was closed, the parties disbanded, camp equipage and field material stored, and the animals placed in winter quarters. Mr. Douglas, with his assistants, was then directed to proceed to Washington, District of Columbia, for office work.

COLORADO SECTION.

The organization and outfitting of parties assigned to the work of this section was completed under the direction of Mr. W. D. Johnson, at Pueblo, Colorado, early in July. The parties were then directed to proceed to the survey of the uncompleted portion of the drainage basin of the Arkansas River, lying east of the work of the preceding year, but within the boundaries of the State of Colorado, an area of 8,700 square miles, and including within its limits the half-degree atlas sheets designated as Mesa de Maya, Mount Carrizo, Vilas, Albany, Granada, Lamar, Cheyenne Wells, Kit Carson, Limon, Kiowa, and Hugo. All of these were full atlas sheets except the last two named.

In addition, revision work was to be done on the Springfield and Two Buttes sheets previously surveyed.

For this work seven plane-table parties and one level party were organized under Messrs. Hays, McKinney, Post, Marshall, Barclay, Farmer, S. P. Johnson, and Holman, respectively.

To Mr. Hays was assigned the work on the Vilas sheet, to Mr. McKinney the Kit Carson and part of the Lamar sheet, to Mr. Post the Limon and such portions as were to be worked ofthe Kiowa and Hugo sheets, to Mr. Marshall the Albany sheet and the revision of portions of the Springfield and Two Buttes sheets, to Mr. Barclay the Mesa de Maya and portions of the Mount Carrizo sheets, to Mr. Farmer the Mount Carrizo and the revision of the portions of the Springfield and Two Buttes sheets not assigned, to Mr. Marshall and to Mr. S. P. Johnson the Cheyenne Wells and portions of the Lamar and Granada sheets; Mr. Holman's work, being linear in character, necessarily extended over a portion of several atlas sheets.

As the season progressed, these parties and assignment of areas were somewhat changed to meet the varying conditions of the work, and Messrs. Fuller and Foot were given small parties and assigned to separate areas. Mr. Fitch was detailed, before field work commenced, for special duty in California with the General Land Office, and remained on that service during the entire season. Mr. Kendall was also detached during the months of September, October, and November for service with the Idaho and Montana sections.

During the month of October and the first half of November all topographic work was suspended and the entire force engaged in the location and survey of previously selected reservoir sites, for the storage of waters for irrigation purposes. Forty-five such sites were located and surveyed with reference to the U. S. Land Survey, the site and necessary height of dam decided upon, the area included within the reservoir at the given height of dam ascertained, the approximate content in acre-feet calculated, and the subdivisions of the U. S. Land Survey necessary to segregate for each reservoir site determined.

Mr. Johnson was engaged during the entire season in supervision and inspection of work and in attending matters of detail relating to the disbandment of the Irrigation Survey.

The work assigned this section was completed by the different parties between December 15, 1890, and January 15, 1891, when the parties were disbanded, the camp equipage and field material stored, and the animals placed in winter quarters. Mr. Johnson and his assistants were then directed to proceed to Washington, District of Columbia, for office work.

IDAHO SECTION.

The work of this section was commenced early in July under the direction of Mr. W. T. Griswold at Boisé City, but no permanent parties were organized until the 1st of September, the time being employed in expanding the triangulation over the atlas sheets designed to survey and in receiving and storing the camp equipage and field material of the parties who had been engaged in the Irrigation Survey.

On September 1 one triangulation and two topographic parties were organized and outfitted under charge of Mr. Griswold, Mr. Perkins, and Field Assistant W. P. Trowbridge, respectively.

The party under Mr. Griswold extended the triangulation and control work over two half-degree atlas sheets lying west and north of the previously surveyed areas and known as the Boisé City and Bisuka sheets, an area of 1,850 square miles. To the party under charge of Mr. Perkins, temporarily under Mr. L. B. Kendall, detailed from the Colorado section, during Mr. Perkins's absence on account of sickness, was assigned the survey of the Boisé City sheet, while to the party under Mr. Trowbridge was assigned the work on the Bisuka sheet.

All the parties of this section completed the work assigned them by November 15, and were then directed to proceed to Washington, District of Columbia, for office work.

KANSAS-TEXAS SECTION.

This section was formed after the passage of the sundry civil bill, August 30, 1890, and in accordance with its provisions, by the transfer of parties working in Texas and Kansas to areas west of the one hundredth meridian.

In Texas one triangulation, one level, and two topographic parties, and in Kansas one triangulation and one topographic party were thus transferred and placed under charge of Mr. R. U. Goode, geographer, forming the Kansas-Texas section.

To the triangulation party in Kansas under charge of Mr. H. L. Baldwin was assigned the work of extending the belt of control triangulation westward up the valley of the Arkansas River, and to the topographic party under Mr. W. H. Herron, assisted by Mr. Geo. H. Lamar, was assigned the survey of the half-degree atlas sheets known as the Dodge City and Meade sheets. In Texas to the party under Mr. Urquhart was assigned the extension of the triangulation over four half-degree atlas sheets lying immediately west of the one hundredth meridian, and between latitudes 31° and 33′ north; to the level party under Mr. Wilson the survey of level lines over the same area, and to the topographic parties of Mr. Gordon and Mr. Wallace, assisted by Mr. Cameron and Mr. Long, the topographic mapping of the San Angelo and Hayrick sheets respectively. Mr. Goode was engaged in supervising and inspecting the work of the various parties and in such administrative duties as were rendered necessary by the transfer of these parties.

The work assigned was successfully completed by November 15, the parties were disbanded, the camp equipage and field material stored, and the animals placed in winter quarters, and Mr. Goode and his assistants were instructed to proceed to Washington, District of Columbia, for office work.

MONTANA SECTION.

To this section was first assigned the topographic survey of the drainage basin of Sun River. For this purpose Mr. Tweedy organized one triangulation and topographic party under himself, assisted by Mr. F. E. Gove, and one topographic party under Mr. Ahern, but after some 400 square miles had been surveyed both the parties were directed to locate and survey the reservoir sites for the storage of water for irrigation purposes which had been previously designated in Montana.

Twenty-eight such sites were located and surveyed with reference to the United States Land Survey, the sight and necessary height of dam decided upon, the area within the reservoir at the given height ascertained, the approximate content in acre-feet calculated and the subdivisions of the United States Land Survey necessary to segregate for each reservoir site determined.

This work was completed by November 15, when Mr. Tweedy was directed to disband his parties, store his camp equipage and field material, place his animals in winter quarters, and report with his assistants in Washington, District of Columbia, for office work.

NEW MEXICO SECTION.

The organization and outfitting of parties for work in this section were completed under the direction of Mr. A. P. Davis early in July. To the party under Mr. F. J. Knight was assigned the extension of the triangulation over the area included between longitudes 105° and 105° 30′ west and latitudes 35° and 35° 30′ north, comprising three atlas sheets, known as the Lamy, Galisteo, and Corazon sheets. To the party under Mr. Lippincott was assigned the survey of the Lamy and Corazon sheets, and to the party under Mr. Bassett the Galisteo sheet. These sheets were completed about November 1, when the parties of Mr. Lippincott and Mr. Bassett were directed to locate and survey the reservoir sites which had been previously designated for the storage of water for irrigation purposes.

Thirty-nine sites were located with reference to the United States land surveys, the site and necessary height of dam decided upon, the area within the reservoir at the given height of dam ascertained, the approximate content in acre-feet calculated, and the subdivisions of the United States land survey necessary to be segregated for each reservoir site determined.

This work was completed December 15, when Mr. Davis was directed to disband his parties, with the exception of a small force under Field Assistant Joseph Jacobs, store his camp equipage and field material, place his animals in winter quarters, and report with his assistants at Washington, District of Columbia, for office work.

The small party under Mr. Jacobs was directed to proceed to southern New Mexico and revise the work previously done on the Las Cruces and La Union sheets. Mr. Jacobs completed this revision April 15, 1891, and under direction then proceeded to El Paso, Texas, and commenced work in that vicinity, where he is at present engaged.

NORTH DAKOTA SECTION.

This section was formed after the passage of the sundry civil bill, August 30, 1890, by the transfer of Mr. William J. Peters, topographer, and Mr. C. T. Reid, assistant topographer, from the division of topography east of the one hundredth meridian, and the assignment of Mr. W. B. Corse to duty with it, and placed under charge of Mr. Morris Bien.

To this section were assigned the running of transit and level lines to ascertain the height of the lowest passes in the divide between the Missouri River and the Mouse and James Rivers and the establishment of bench-marks for use in the topographic survey of that region. To do this work Mr. Bien organized two level and transit parties at Minot, North Dakota, and taking the field August 15 prosecuted his work until compelled by weather to close, about December 1, 1890.

In all, 730 miles of level lines were run, with the result of showing that the lowest point on the divide between the rivers named was some 200 feet higher than low water in the Missouri River at the western boundary of the State of North Dakota. A large number of bench-marks for future topographic work were established and very interesting features connected with the ancient lake beds of the region discovered.

SOUTH DAKOTA SECTION.

As preliminary to future topographic work in South Dakota, it was decided to determine the latitude and longitude of a station at Rapid City.

Mr. S. S. Gannett was detailed to make the necessary astronomical observations. In this work he was assisted by Mr. A. F. Dunnington, who was detached from the California-Nevada section for this purpose. For the purpose of determining longitude it was decided to exchange time signals with St. Louis, and the services of Prof. H. S. Pritchett, of the Washington University, were procured to conduct the necessary observations and exchanges at that place. Mr. Gannett commenced work at Rapid City on October 23, and by November 20 had completed the necessary observations and exchanges with St. Louis, giving, when all reductions were made, the following:

Longitude, pier Rapid City, 103° 12′ 59·283″ west.

Latitude, pier Rapid City, 44° 04′ 45·24″.

Upon the completion of this work Mr. Gannett and his assistant, Mr. Dunnington, returned to Washington, District of Columbia, for office work.

METHODS OF FIELD WORK.

The field work of all the sections was conducted on essentially the same methods, though the manner of its execution varied with local conditions. It consisted in the determination of linear distances and of altitudes and in the conventional representation of topographic forms and cultural features.

In the California-Nevada and Colorado sections the linear distances were derived from and controlled by the triangulations expanded from the stations of the transcontinental triangulation of the U. S. Coast and Geodetic Survey in those States; in Idaho, Montana, New Mexico, and Texas, from stations in systems of triangulation expanded from bases measured by the U. S. Geological Survey; and in Kansas from land survey measurements controlled and corrected by the triangulation of the U. S. Geological Survey.

Plane-table traverses, using the compass for directions and some form of odometer for distances, were employed for intermediate locations in addition to triangulation and plane-table work from stations, and thus the whole area of every atlas sheet was covered by a network of carefully determined linear lines.

The altitudes of points in the area surveyed were determined by horizontal or angular leveling or by the use of aneroid or mercurial barometers. In all cases a number of accurately determined bench-marks were located on each atlas sheet, and to these all subordinate points were referred. The representation of topographic features was secured by sketching from stations occupied in both plane-table and traverse work. This sketching was done in contours having a prescribed vertical interval.

OFFICE WORK.

Immediately on the disbandment of the field parties, all persons belonging to the permanent force were directed to report at the office of the U. S. Geological Survey in Washington, District of Columbia, for office work. This force was organized by the same sections as the field work, giving to each person who had charge of a field section charge of the office work of that section, and assigning to each person the construction of the maps of the area of which he had done the field work, thus securing in the drawing of the maps all knowledge gained by personal observation in the field. On May 1, 1891, the final drawings of maps of the areas surveyed by each of the sections were completed ready for the engraver.

The following table shows the locality of each full atlas sheet, the scale upon which the final drawing was made, the scale of publication, and the contour interval.

Locality.	Name of sheet.	Scale of drawing.	Publication scale.	Contour interval.
				Feet.
California	Sierraville	1 inch = 1 mile	1 : 125,000	100
Colorado	Mesa de Maya	...do	...do	25-50-100
	Mount Carrizo	...do	...do	25-50-100
	Springfield	...do	...do	25-50
	Vilas	...do	...do	25-50
	Albany	...do	...do	25
	Two Buttes	...do	...do	25-50
	Lamar	...do	...do	25
	Granada	...do	...do	25
	Cheyenne Wells	...do	...do	25
	Kit Carson	...do	...do	25
	Limon	...do	...do	25
Idaho	Boisé	...do	...do	50-100
	Bisuka	...do	...do	50-100
Kansas	Dodge City	1 : 125,000	...do	20
	Meade	...do	...do	20
Nevada	Reno	...do	...do	100
	Wadsworth	...do	...do	100
	Wabuska	1 inch = 1 mile	...do	100
	Wellington	...do	...do	100
New Mexico	Lamy	...do	...do	50-100
	Galisteo	...do	...do	50-100
	San Pedro	1 : 125,000	...do	50-100
	Corazon	1 inch = 1 mile	...do	50-100
Texas	San Angelo	1 : 125,000	...do	50
	Hayrick	...do	...do	50

In addition to the preparation of the maps designated, plats generally on the scale of 2 inches equal 1 mile were made of all the reservoir sites surveyed. These plats showed the location selected for the dam, the boundary line of the water surface of the reservoir at the selected height of dam, its location on the subdivisions of the United States land surveys, and the areas designated by the township, range, sections, and subdivisions of sections necessary to be segregated to reserve the site. These plats were accompanied by short descriptions of each reservoir site, giving the county within which it was situated, the stream upon which it was located, the area of drainage basin which would supply it, the general altitude of the basin, character of topography, water-supply, bench-marks, approximate contents, etc., and where the irrigable lands which the reservoir should serve were located. With these plats were also prepared schedules describing, in terms of the United States Land Survey, the areas necessary to be segregated for each reservoir and the present condition of the title to these land so far as shown by the records of the General Land Office.

Upon the completion of the final drawing of the atlas sheets surveyed during the year and the preparation of the plats, descriptions, and schedules of reservoirs, the permanent force of each section, with the exception of Mr. Fred J. Knight, who was retained in the office at Washington, District of Columbia, to prepare a map of the drainage basin of the Arkansas River in Colorado, was directed to proceed to the field and organize parties for work during the ensuing year in accordance with plans submitted to and approved by you. This duty is now being performed.

DISBURSEMENTS.

The disbursements of money for the work of the Topographic Division west of the one hundredth meridian from July 1 to December 31, 1890, were under the direction of Mr. H. C. Rizer. His duties were performed at the field office established at Topeka, Kansas, and at the office of the U. S. Geological Survey in Washington, District of Columbia. Since January 1, 1891, the disbursements have been made by Mr. Jas. W. Spencer from the office of the U. S. Geological Survey at Washington, District of Columbia.

I am, very respectfully, your obedient servant,

A. H. THOMPSON,
Geographer in Charge Topographic Division
West of One Hundreth Meridian.

Hon. J. W. POWELL,
Director.

REPORT OF MR. G. K. GILBERT.

U. S. GEOLOGICAL SURVEY,
GEOLOGIC BRANCH,
Washington, D. C., June 30, 1891.

SIR: I have the honor to submit the following report on the work of the Geologic Branch for the fiscal year ending to-day.

The general organization of the branch has remained unchanged, but as the appropriation of money for this fiscal year was greater than for the preceding year the work was somewhat enlarged. The enlargement consisted in the expansion of the work of several divisions already constituted and in the establishment of two new divisions, the Florida and the New Jersey.

The land of Florida is reduced by erosion very nearly to the level of the sea. Its streams lie but little below the general level of the land, and their low banks afford no great geologic sections in which the student may readily read the rock structure. The dip of the strata is low and opportunities for its direct measurement are rare. The land is largely mantled by deposits of sand, which conceal the rocky skeleton from view. By reason of these peculiarities the study of Floridian geology is difficult and the ordinary stratigraphic methods of work are inapplicable. It has been necessary to begin by collecting fossils at numerous points and determining through these the general distribution of formations differing in age. This preliminary work has been accomplished chiefly by paleontologists, and Mr. W. H. Dall, who has contributed largely to it, has recently collated and systematically arranged all existing knowledge in a memoir soon to be published. This memoir, classifying the known formations of the State and giving their general distribution, affords to the geologic surveyor the preliminary data necessary for the mapping of their boundaries and makes the present time opportune for the institution of systematic areal work. The propriety of selecting Florida as the field of work for a new division was further indicated by the rapid development of its resources in mineral phosphates, the exploitation of which has within two years become a leading industry of the State. In the organization of the corps for this work Mr. George H. Eldridge, previously a member of the Colorado Division, was placed in charge, and Mr. Lawrence C. Johnson, heretofore a member of the Potomac Division, was named as his principal assistant.

Work in New Jersey was initiated in cooperation with the State survey. The State has for many years maintained a geological survey and the general facts of its geology are well known. Through the cooperation of the State survey with the U. S. Geological Survey a topographic map of the entire State has been completed. Upon this base it is proposed to map in detail all the formations of the State, and it has been arranged that this work, like the topographic work, shall be carried on in cooperation by the two organizations. Initially attention is directed chiefly to two classes of rocks—the superficial deposits, which rest upon all other formations and constitute a large portion of the surface of the State, and the crystalline schists, which contain the ores of iron and zinc, and occupy a compact area in the northwestern part of the State.

The State survey undertakes the mapping of the superficial formations, the national survey undertakes the mapping of the crystalline schists and associated Paleozoic formations, and the results of the two works will be made to contribute at the same time to the geologic atlas of the State and to the geologic atlas of the United States. In the organization of the corps for the work by the U. S. Geological Survey, Prof. Raphael Pumpelly, geologist in charge of the Archean Division, was given general supervision, and immediate charge was assigned to Prof. J. E. Wolff.

WORK OF THE GEOLOGIC DIVISIONS.

The Atlantic Coast Division, under Prof. N. S. Shaler, has been chiefly occupied in the field revision of the the surface geology of Massachusetts and in the office preparation of the resulting atlas sheets and explanatory texts. The outline plan for the publication of the sheets of the geologic atlas of the United States set forth in the Eleventh Annual Report of the Director requires for its practical application that it shall be elaborated with respect to details, and this elaboration was undertaken in a practical way by carefully preparing for publication a series of atlas sheets representing the work of various divisions and geologic phenomena of diverse kinds. To this experimental work Prof. Shaler has contributed largely, and the revision and amendments it has entailed have diminished the output of his division below his expectation. He has, however, reported, in form believed to be final, twenty-two sheets, exhibiting the surface geology of portions of Massachusetts. He has likewise prepared a popular treatise on soils, which appears as one of the accompanying papers of this volume.

The work of the Archean Division, under the direction of Prof. Raphael Pumpelly, consists in the mapping of the metamorphic and crystalline rocks of a district comprised chiefly in New England. The discrimination, tracing, and especially the correlation of these rocks are matters of great difficulty, and have been the occasion in the past of uncertainty and controversy. The general problem was attacked in a district in western Massachusetts believed to be peculiarly favorable for its solution, and after some years of patient and laborious investigation the structure of that district was unraveled. Subsequent work has consisted largely in extending to contiguous areas the knowledge thus gained, and upon one atlas sheet after another the formations have been delineated. An independent investigation instituted in central Massachusetts by Prof. B. K. Emerson led to allied conclusions, and the two works were brought into entire harmony by the cooperation of the investigators. During the year the map area has been extended eastward in Massachusetts, westward for a short distance into the State of New York, and northward in southwestern and central Vermont.

The New Jersey Division, likewise in charge of Prof. Pumpelly, was established in January, and first attention was given to the collation of the literature embodying results of earlier labors. A corps of assistants was organized and reconnaissances were made as early as practicable in the spring. In the latter part of May systematic field work was begun by several parties and this is still in progress.

The Potomac Division, in charge of Mr. W. J. McGee, was originally instituted for the investigation of the formations constituting the coastal plain in the vicinity of the Potomac River. When these formations had been locally classified it was found advantageous to trace them coastwise in both directions, and the work of the division has thus been extended far beyond its original field. This year formations differentiated on the Potomac have been correlated by continuity of physical characters with formations previously recognized and described in the Mississippi Valley. In the main the final delineation of these formations upon maps is impracticable, because they traverse regions to which the topographic work of the Survey has not been carried, but they are being platted on general maps of small scale; and about the borders of Chesapeake Bay and its affluents detailed areal work is in progress.

This year, as last, the chief work of the Appalachian Division, under Mr. Bailey Willis, has consisted in areal geology. It has continued the mapping of the geologic formations on sheets of the atlas in northwestern Georgia, eastern Tennessee, southwestern Virginia, and eastern

West Virginia. Important conclusions as to geologic structure, flowing from the work in Georgia and Alabama, and also from that in the vicinity of Harper's Ferry, West Virginia, have been published, and progress has been made in the elucidation of the structure of Chilhowee Mountain and vicinity, a district of exceptional interest as well as complexity.

The Florida Division was organized in January, with Mr. George H. Eldridge in charge, and field work was immediately commenced. Attention was first directed to the geologic relations of the phosphatic deposits, and the mapping of the formation from which they are primarily derived was then undertaken. Mr. Eldridge also made a general reconnaissance of the peninsula as a means of determining the nature of the problems to be attacked and the best methods of planning the work. Late in the spring all but one of the field parties were withdrawn and office study was begun in Washington.

The work of the Lake Superior Division, in charge of Prof. C. R. Van Hise, is upon the metamorphic and crystalline rocks of the vicinity of Lake Superior. Owing to the inherent difficulty of classifying these rocks, and to the fact that the region they underlie is chiefly covered by dense forest, the division has heretofore given principal attention to localities and districts which promise to aid the work of classification. The areal work accomplished has in chief part been either of somewhat general nature, warranting publication only on a scale smaller than that of the geologic atlas, or else closely associated with mining development, and thus restricted to small areas demanding for publication a scale larger than that of the geologic atlas. For these reasons, and also because the topographic work of the Survey has not made great progress in this district, the systematic areal survey of the geology has but recently been begun. For the last two years, however, it has been actively prosecuted. This year its field has been in the Marquette iron district and in the country lying between that and the Penokee mining district. Progress is necessarily slower than in regions where observation is not impeded by the forest, or where geologic structure is indicated by sympathetic topographic forms; but the great mineral wealth associated with these formations justifies the thorough determination of their distribution.

A large part of the work of the Division of Glacial Geology, under the direction of Dr. T. C. Chamberlin, has consisted in the correlation and mapping of the moraines marking the temporary positions of the great northern ice sheet at various stages of its advance and retreat, and they so grade one into another that their discrimination would be difficult if they were platted only on the large scale atlas sheets of the Survey. It is therefore considered advantageous to do this work in advance of the more detailed map work, and perform it in a comprehensive way for a large area without reference to the progress of the topographic survey. The data are platted on maps of relatively small scale. The division has otherwise been engaged in general studies designed to aid in the classification of Pleistocene formations.

The investigation of the zinc deposits of southwestern Missouri was continued by Dr. W. P. Jenney. A season of field work having been completed, the collections of ores and rock were brought to Washington, and several months were devoted to office study. As a result of his investigations in field and office Dr. Jenney was led to entertain a theory as to the origin of the deposits and their laws of distribution differing in important respects from those previously advanced. The bearing of his preliminary conclusion on the conduct of mining operations is of such importance that it was deemed proper to compare it in the most thorough manner with the accessible phenomena before publishing a report, and additional field work was planned to this end. He returned to Missouri in January, and has continued the field study of the mining district since that time, except that an excursion was made to western Arkansas for the purpose of examining deposits of argentiferous lead and zinc believed to belong to the same structural belt as the deposits of southwestern Missouri, and, therefore, to be competent to afford accessory data bearing on the origin of the Missouri deposits.

In Montana Dr. A. C. Peale has continued the mapping of the geologic formations of the district covered by the Three Forks atlas sheet. The area of that district is about 4,000 square miles, of which 3,000 had been previously mapped. It was hoped that the work would be completed during the field season of 1890, but this was prevented by inclement weather, and it was found necessary to leave a small area, as well as the revision of certain portions whose structure was not fully understood, until the present summer. Dr. Peale is now in the field, and has been joined by Prof. Van Hise, of the Lake Superior Division, who makes a joint excursion with him for the purpose of examining a group of strata supposed to be of Algonkian age.

The survey of the Yellowstone National Park, under Mr. Arnold Hague, being practically complete, the field work of his corps has been carried to the adjacent district represented on the Livingston atlas sheet. This district lies immediately north of the Park and adjoins the Three Forks sheet on the east. The greater part of it was surveyed in the season of 1890, and the work is to be finished this year. A short time has also been given to supplementary work within the Park, especially on the Pleistocene formations. Mr. Hague himself did not take the field, but has remained in Washington for the purpose of completing his report on an earlier work, the investigation of the geology of the Eureka district of Nevada. The results of the survey of the Yellowstone National Park have been partially presented at various times in reports upon special subjects, and a general report is in preparation.

The work of the Colorado Division, under Mr. S. F. Emmons, relates chiefly to mining geology. There has been little field work during the year, as a large amount of matter is in preparation for publication, and it was deemed best to devote the energies of the division to this, rather than initiate new researches in the field. A small amount of field revision was found necessary, and in the Leadville mining district a supplementary investigation was inaugurated. This district was geologically surveyed ten years ago and a full report has been published; but since field work was completed, many miles of tunnel have been dug, exposing the rock to examination. It has seemed best to base a supplementary report on the new material thus made available, and to this end its collection has been undertaken. Mr. Emmons spent several weeks in an examination of the various galleries and the compilation of mine maps has been commenced.

The work of the Cascade Division, under Mr. J. S. Diller, is areal geology, and its field of operation is in northern California and adjacent portions of Oregon. This field, like the field of the California Division south of it, includes large tracts of metamorphic rocks, the members of which have never been fully discriminated and referred to their proper places in the chronologic scale. It includes also lake beds of several series, the age of which has been somewhat in doubt by reason of the failure to discover organic remains of diagnostic value. During the year several efforts have been made to obtain the paleontologic data necessary for the discrimination of these various formations, and in these efforts, which have in the main been successful, the division has been greatly aided by members of the paleontologic branch of the survey.

The Petrographic Laboratory, also in charge of Mr. Diller, has continued the examination of rocks and minerals submitted to it by various divisions of the Survey, the preparation of thin sections of rock for microscopic study by the petrographers of the Survey, and the preparation of the educational series of rock specimens. The last mentioned task, which has proved greater than was originally estimated, is now nearly done, and the suites of rocks with accompanying text will soon be ready for distribution.

The California Division, under Dr. G. F. Becker, has continued the investigation of the gold belt of California, giving chief attention to the mapping of the formations. Field work has been carried on within the areas of seven different atlas sheets, and five of these are approximately finished. Dr. Becker's personal attention was given largely to the dynamic history of the Sierra Nevada and to problems of correlation on whose solution depends the nomenclature to be employed in publishing the atlas sheets.

Such is the variety of nature that no two districts afford precisely the same problems, and where the problems of two districts are closely allied the data for their solution differ. Generalizations that are easy and manifest in one region may be reached only with great difficulty, or not at all, in another. It is therefore important that the facts of many districts be assembled under one view, so that the generalizations flowing from the whole may be applied to the elucidation of the obscurer problems of each. Many of the researches conducted by the Survey are so broad that it is practically impossible for one individual to become personally familiar with the whole range of phenomena, and the cooperation of the different investigators thus becomes of the highest importance. In the early years of the Survey such cooperation was mainly effected in the office, but occasional resort was had to joint field excursions. Of late years the advantage of field cooperation has been more distinctly appreciated, and, so far as practicable, arrangements are made under which each investigator, before finally submitting his results for publication, visits the district or districts where cognate work is in progress, and under the guidance of his colleagues personally examines the features having the most important bearing on his work.

At the beginning of the fiscal year Messrs. Van Hise, Pumpelly, and G. H. Williams, with Mr. C. D. Walcott, of the paleontologic branch, were engaged in a joint excursion through districts, in New Jersey, New York, Massachusetts, and Vermont, exhibiting metamorphic rocks of Paleozoic, Algonkian, and Archean age. In New Jersey they were accompanied also by Dr. F. L. Nason, of the State Geological Survey. More recently Messrs. Pumpelly, Van Hise, and Willis, together with Prof. J. A. Holmes, State geologist of North Carolina, examined in company a district of crystalline and Paleozoic formations in western North Carolina and adjacent portions of Tennessee. In northern California Mr. Diller, of the Cascade Division, and Prof. Hyatt, of the paleontologic branch, studied together the stratigraphy and paleontology of Mesozoic rocks; and subsequently Mr. Diller accompanied Mr. Dall, of the paleontologic branch, in a search for fossils in Tertiary lake beds. In Montana Dr. Peale, of the Montana Division, engaged in mapping the Three Forks district, and Mr. Weed, of the Yellowstone Park Division, engaged in mapping the contiguous Livingston district, studied together a representative section of Paleozoic formations for the purpose of unifying their work. Mr. McGee, of the Potomac Division, and Mr. Eldridge, of the Florida Division, examined together in South Carolina, Georgia, and Florida a series of localities exhibiting formations common to their fields of research. Last autumn Mr. Johnson, then a member of the Potomac Division, made an excursion in conjuncture with Prof. Smith and Mr. Langdon, of the Alabama State Survey, and Prof. Spencer, of the Georgia State Survey, for the purpose of examining the formations exhibited along the Chattahoochee and Apalachicola Rivers.

SPECIAL AND TEMPORARY INVESTIGATIONS.

From time to time the Survey has undertaken researches so limited in scope and extent that it has not seemed advisable to organize separate divisions for their conduct. Such of them as are closely related to the work of existing divisions are assigned to those divisions for supervision, while others less easy of classification have been assigned, for administrative convenience, to the Division of Geologic Correlation. That division, which is in other respects somewhat anomalous, still remains in my personal charge, and as its work is not elsewhere treated in this volume its doings will be described here more fully than have been those of the other divisions.

Work in Alaska.—The geologic survey of Alaska has not been undertaken, but the Survey has availed itself from time to time of opportunities for exploration and local study when through cooperation with other institutions it could be carried on at small expense. As described in my last report, Mr. I. C. Russell visited the Yukon Valley in 1889 as an attaché of a party sent out by the U. S. Coast and Geodetic Survey. In 1890 he headed an expedition to the vicinity of Mount St. Elias under the joint auspices of the National Geographic Society and the Geological Survey; this year he continues work in the same district under the same auspices. This year also Dr. C. W. Hayes accompanies an exploring party privately fitted out under the direction of Mr. Frederick Schwatka.

In the expedition of 1890 Mr. Russell was assisted by Mr. Mark B. Kerr, topographer, detailed for that purpose from the Geological Survey, and by seven camp men, with Mr. J. H. Christie as foreman. Mr. E. S. Hosmer accompanied the party to its first camp as volunteer assistant and then returned on account of sickness. Men were hired and supplies purchased at Seattle, Washington, and the party was landed at Yakutat Bay by the U. S. S. *Pinta*, detailed for that purpose through the courtesy of the Secretary of the Navy. Through the courtesy of the Secretary of the Treasury it was enabled to leave Yakutat Bay on board the U. S. revenue cutter *Corwin*, Capt. C. L. Hooper, on the 25th of September. The intervening period of eighty-nine days was spent in the exploration of a district extending from Disenchantment Bay at the east to Mount St. Elias at the west and lying from 10 to 20 miles inland. The general character of the work is set forth in the following passage extracted from a report presented by Mr. Russell soon after his return:

En route to Sitka we called at Victoria and Port Townsend, visited Taku Inlet and Glacier Bay, and reached Sitka on the 24th. On the afternoon of the same day we went on board the *Pinta* under command of Captain Farenholt, who had previously received instructions from the Secretary of the Navy to take us to Yakutat Bay. We sailed from Sitka the following morning and reached Yakutat on the afternoon of the 26th.

On the 27th I purchased a canoe and hired others to take us up the bay. The day following we started, with two of the *Pinta's* boats to assist us, and made our first camp on the east side of the bay about 12 miles from its mouth and near the north end of Knight Island. The *Pinta's* boats then returned and the following day we advanced a portion of our camp outfit about 12 miles farther. On the third day after leaving the *Pinta* we reached the actual base of operations on the west shore of Yakutat Bay not far from its head.

At our first camp Mr. Hosmer decided to turn back, as his uncertain health did not warrant the risks involved in camp life. He returned to Yakutat Mission in a canoe with an Indian, and a few days later sailed for Sitka in a small trading schooner. He reached his home safely.

From our camp, on the west shore of Yakutat Bay, I made excursions to the neighboring glaciers and the lower mountains near at hand, and also up the bay to Grand View Island. From this island we had a magnificent view of the mountains and glaciers about the head of the bay. Two of the glaciers come down to deep water and break off in immense cliffs of ice, thus furnishing the ice débris which obstructs all the upper portion of the inlet. One of the glaciers which enters the bay to the west of Grand View Island we named after Mr. Dalton, the pioneer explorer of the upper portion of the bay, and the second one of larger size, which comes down at the immediate head of the inlet, was named in honor of the president of the Geographic Society. So far as yet known, this is the largest and by far the most magnificent glacier in Alaska which comes down to the ocean and gives origin to bergs.

While at our shore camp, Mr. Kerr measured a base line and began a topographic survey. This survey was carried westward throughout the season. The heights of some of the lower stations occupied were measured by means of a mercurial barometer, a base barometer being read by Rev. Carl J. Hendricksen at Yakutat Mission. In this way a vertical base-line was established to be used in the determination of mountain heights.

After making such observations as seemed desirable from our camp on the shore, we began a line of march inland towards Mount St. Elias. At first we traveled along the base of the mountain, camping on the rocky spurs which project into the great glacier that intervenes between the mountains and the sea. About the 1st of August we were approximately midway between Yakutat and St. Elias, at a place we named Blossom Island. At that point an island of rock, a mile or so in diameter, rises above the encircling glaciers, and is covered with most luxuriant vegetation. We there established a base camp, and Mr. Kerr and myself, with two camp hands, started up the Marvine glacier, which skirts Blossom Island on the west. The camp hands who did not accompany us were busy during our absence in advancing rations from the caches made on the march from Yakutat Bay to Blossom Island, and in forwarding necessary supplies to a rendezvous above snow line, from which we obtained the necessary provisions during our stay in the mountains.

On going up Marvine glacier we took the most westerly of its main branches, and found a pass, named Pinnacle Pass, leading westward across the Hitchcock range to the Lucia glacier, which skirts that range on the west. The Hitchcock range is the most westerly spur of Mount Cook. The Lucia glacier rises to the north of Mount Cook, and flows to the southwest and finally to the south. Crossing this glacier we found another opening in the mountains, which we called Dome Pass, leading in the direction which we wished to travel. This took us to another southward flowing glacier, called the Conrad glacier, the most westerly branch of which derives its snow supply from the northeastern slope of Mount St. Elias. We ascended this branch to the immediate base of the pyramid forming the summit of St. Elias and reached an elevation of 8,700 feet, but were turned back by a heavy snowstorm before reaching the divide north of the peak, which would command a view to the north of the main range. We made another attempt two days later, but did not gain as great an elevation as at the first trial. After returning from the second attempt, I made an effort to ascend the Lucia glacier, which promises to lead to a pass by means of which the northern slope of the St. Elias range may be gained. During this trip I was delayed by stormy weather, and finally turned back by a heavy snowstorm which rendered traveling almost impossible. From an elevation of about 5,000 feet on the north side of Mount Cook, I had an unobstructed view of the great drainage basin of the Lucia glacier, and of the many high peaks bordering it on the north. This route furnishes a way for exploring a large part of the interior, and would, I have little doubt, lead to the country draining northward from the St. Elias range.

On returning from the excursion up the Lucia glacier I descended to Blossom Island, where I rejoined Mr. Kerr, who had reached there a few days previously. My stay above the snow line was from August 2 to September 6.

From Blossom Island I crossed Marvine glacier and reached the extreme southern end of the Hitchcock range. From there I made an excursion due south about 5 miles onto the great Malaspina glacier. In the mean time Mr. Kerr returned to Yakutat Bay, with the intention of occupying a station on its eastern shore that would command Disenchantment Bay, which extends easterly from the head of the main inlet. This plan was not carried out, however, owing partly to stormy weather, and Mr. Kerr proceeded to Yakutat Mission, where he occupied a station formerly used by the U. S. Coast Survey. This enabled him to repeat the measurements made some years ago by Dall and Baker and to identify Mount St. Elias, Mount Cook, and Mount Vancouver.

On returning to Blossom Island from my trip to the Piedmont glacier I started at once for Yakutat Bay, where I arrived about September 20. On the 22d the steamer *Corwin*, in command of Capt. C. L. Hooper, arrived and took us on board. The *Corwin* then steamed up the bay, passing Grand View Island, to the mouth of Disenchantment Bay. This enabled us to see considerable country not previously examined, but did not furnish an opportunity for work on shore. Soundings were made at various intervals up to within a mile of the foot of Hubbard glacier, and gave a depth of from 40 to 60 fathoms. The *Corwin* returned to Yakutat Mission the same day, sailed from there on the 25th, and reached Port Townshend, Wash., on October 2. From there I returned to Washington, D. C.

Mr. Russell's report to the National Geographic Society has been printed, constituting pages 53 to 204 of the third volume of the National Geographic Magazine.

In the study of the glacial drift of the northeastern States a leading difficulty has depended on the fact that no glacier of the same type is known to exist at the present time, so that some of the processes theoretically characteristic of the Pleistocene ice sheet have not been directly observed in the study of living glaciers. One of the glaciers described by Mr. Russell, the Malaspina, differs from other known glaciers in such ways as to suggest that it is homologous with some portions of the Pleistocene ice sheet and great interest, therefore, attaches to all of its features. It was, therefore, desirable that Mr. Russell return and undertake its systematic survey. The Survey availed itself of the facilities afforded through the continued interest of the National Geographic Society and the courtesy of the Treasury Department, and made arrangements for another expedition. Mr. Russell once more outfitted at Seattle, engaging six camp hands, with Mr. Christie again as foreman, and set sail on May 30, on board the United States revenue cutter *Bear*, Capt. M. A. Healey. No topographer was attached to this party, it being understood that the Superintendent of the U. S. Coast and Geodetic Survey in connection with work on the Alaskan boundary will probably send a topographic party to the vicinity of Mount St. Elias this summer, and that such party, if sent, will cooperate with Mr. Russell. Advices from Capt. Healey recently received, say that the party was landed through the surf at Icy Bay, near the foot of Mount St. Elias, on June 6, and was thus enabled to begin its field work twenty-two days earlier than last year. Otherwise its auspices were less favorable, for the landing of the party was accompanied by a lamentable accident. Through the upsetting of a boat in the surf, Lieut. L. L. Robinson, of the *Bear*, Mr. W. C. Moore, of the surveying party, and four seamen were drowned.

Mr. Frederick Schwatka undertakes this year to enter the Yukon Valley from the south, via the Taku River, a route heretofore followed by miners but not surveyed; to descend the Yukon River by boats to the vicinity of the mouth of the White, and thence to strike southwestward to a branch of the Copper River, traversing on foot for a distance of about three hundred miles, a region now blank upon the map. He applied to the Geological Survey for a scientific assistant to make observations on the topography, geology, natural history, and ethnography of the route, and, his application being viewed with favor, Dr. C. W. Hayes, of the Appalachian Division of Geology, was at his own desire detailed as such assistant. Dr. Hayes's latest received report was written at Juneau, Alaska, May 23, and stated that the party would start inland the following day.

Work in western Tennessee.—Last year Prof. J. M. Safford, of Nashville, Tennessee, undertook the detailed examination of a district in Stewart County, known to geologists as the Wells Creek basin, and distinguished by the fact that low-lying strata elsewhere in that region covered by later formations are there uplifted so as to outcrop at the surface. During the fiscal year Prof. Safford has been able to give several months' time to the continuation of field work, and has been assisted by Prof. J. M. Hopkins, and Messrs. W. P. Lander and P. M. Jones. Important collections of fossils have been made, and the mapping of the formations is nearly accomplished. It is proposed to complete the field work in the course of a few weeks, and prepare a report as soon afterward as Prof. Safford's other duties will permit.

Work in Connecticut.—The rocks of the State of Connecticut are largely crystalline and metamorphic, but a belt traversing the central part from north to south is occupied by unaltered strata belonging to the Newark system, and with these are associated extensive sheets and dikes of volcanic rock. The general study, and especially the detailed mapping of the rocks of this central belt, were undertaken by Prof. W. M. Davis last year, and the work has been continued as his other duties have permitted during the present fiscal year. He has been assisted for limited periods by Dr. E. O. Hovey, Messrs. J. A. Merrill, H. L. Rich, and S. W. Loper and Prof. W. N. Rice, and the work is making satisfactory progress.

Stratigraphic work in Missouri.—In cooperation with the State survey of Missouri the determination and measurement of the Upper Paleozoic formations of the southwestern portion of the State was undertaken last year, the field work being by Mr. Gilbert van Ingen. During the first ten weeks of the fiscal year he continued his work in Green, Henry, St. Clair, Bates, Newton, and Jasper Counties, measuring and describing the various beds and making large collections of fossils. At the end of that period his work was interrupted by a serious illness from which he has but recently recovered. The study of the fossils and the classification of the formations have been intrusted to Prof. H. S. Williams.

Underground temperatures.—The city of Wheeling, West Virginia, stands on horizontal strata of Carboniferous age. The drill has thus far failed to discover beneath it valuable accumulations of natural gas, petroleum, or brine. In order to test thoroughly the question of their occurrence a number of citizens organized as the Wheeling Development Company, with Mr. N. B. Scott as president, and bored a well to the depth of 4,100 feet. It passed beyond the Carboniferous series of strata and penetrated far into shales of Devonian age. The substances sought were not found, but the well proves of value in other ways. It gives information as to the thickness of certain formations in a region where they had not been previously measured; and it affords one of the best opportunities ever known—probably the very best opportunity—for the measurement of a temperature gradient of the earth's crust. These considerations having been presented to them by Prof. I. C. White, of Morgantown, the company determined to increase the depth of the well in the interest of science. Boring was resumed and continued to a depth of 4,471 feet, and the well was then placed at the service of the U. S. Geological Survey, which undertook the determination of temperature gradients.

The peculiarities which render the well specially available for temperature observations are these: (1) The well is dry. Veins of water were encountered in the upper third of the well, but these have been cut off by iron casings; from the bottom of the casing at 1,570 feet to the bottom of the well, an interval of 2,900 feet, no water enters. As there is no circulation of water through the rock in this interval, we may assume with confidence that the flow of heat through the rock is by conduction only instead of being partly by conduction and partly by convection, as is usually the case. As there is no water in the well, but air only, the well itself does not produce a redistribution of heat along its walls. The efficient convection which would be set up if the well were filled with water does not exist in the slender column of air. The normal temperature of the walls of the well is maintained and can be measured. (2) The strata in the immediate vicinity lie horizontal, having essentially the attitude of deposition and being unaffected by the folds of the Appalachian mountain system. We may therefore assume with confidence that the temperatures and temperature gradients observed are unaffected by the heat resulting from rock crushing or other dynamic agencies.

The actual observation of temperatures was intrusted by the Director to Dr. William Hallock, of the Division of Chemistry and Physics, and in the elaboration of the plans for the work he was aided by Mr. F. H. Newell, of the topographic branch. A preliminary series of observations were made in May, and Dr. Hallock returned to the work with new and improved apparatus early in June.

Division of Geologic Correlation.—The work of this division consists in the assembling of existing knowledge with reference to American formations belonging to the different geologic periods, the discussion of their correlation with one another and with the formations of other countries, and the development of the principles of geologic correlation. The division is constituted chiefly of geologists and paleontologists belonging to other divisions of the Survey, who are selected by reason of their previous familiarity with the formations and faunas of the particular periods. The greater part of its work is now accomplished. Of the twelve essays originally planned as the outcome of its labors, five have been completed and two are in advanced preparation.

Prof. Henry S. Williams, of Ithaca, New York, who undertook the study of the formations of the Carboniferous and Devonian, had finished his work, with the exception of a portion of the writing, in previous years. His report is now in press. His general treatment of the subject is historical, but he classifies it also by problems, taking up one after another the questions of classification and correlation which have occupied the attention of American geologists, giving the history of each discussion or controversy, and showing how in its progress various principles of correlation were appealed to, recognized, or developed.

Mr. C. D. Walcott has completed his historical study of the formations of the Cambrian, and his report also is now in press. As a result of his work, he classifies the Cambrian formations under three chronologic divisions characterized by distinct faunas, and he deduces a tentative history of the continental changes of Cambrian time. That history is further set forth in an essay which accompanies the present volume.

Dr. Charles A. White, to whom was assigned the discussion of the formations of the Cretaceous, likewise completed his report, and it is in the hands of the printer ready to be taken up. Comparing the Cretaceous formations of one district with those of another in serial order, he develops in an impressive way the difficulty of the problem of correlation as dependent upon the natural complexity of the phenomena.

Dr. W. B. Clark, of Johns Hopkins University, who has been similarly engaged on the formations of the Eocene, has completed his work and the manuscript awaits publication. His summary is based chiefly upon the literature, and he does not venture personal opinions as to correlation from province to province.

The report on the formations of the Neocene, prepared by Dr. W. H. Dall, is likewise ready for press. Besides assembling and digesting the literature of the subject, it makes important original contributions based on the author's personal observations. The body of new material with reference to Florida was of such magnitude that it seemed best to exceed the original scope of the work by giving a complete summary of the known geology of that State. For similar reasons the chapter on Alaska was made to include all known data as to its Cenozoic geology. Much of the labor of compilation was performed by Mr. Gilbert D. Harris, and the importance of his contribution has been recognized by giving place to his name on the title page as junior author.

The discussion of the pre-Cambrian formations was assigned to Prof.

C. R. Van Hise, who has prepared himself therefor not only by thorough study of the literature but by personal examinations of the more important classic localities. A portion of the field work was performed during the current year, but his time has been occupied principally with office study and the preparation of manuscript. His memoir is now nearly complete and will probably be submitted in a few weeks.

Mr. I. C. Russell, to whom was intrusted the discussion of the Newark system, completed the manuscript in first draft before resuming field duty in Alaska, but it will not be practicable to give it final form until his return in the autumn. His discussion will differ from that of all the others in that no question as to superior and inferior limits of the group of strata is involved. This system is a peculiarly definite physical unit, and in all discussions of correlation is necessarily considered in its entirety.

Dr. T. C. Chamberlin, who accepted the duty of discussing the classification and correlation of the Pleistocene formations, being fully occupied by other matters, has not yet found time to prepare an essay.

In my last report it was announced that Prof. Ward's essay on correlation by means of fossil plants would be abbreviated by restricting the discussion to the flora of the Jura-Trias and the principles of correlation. This change was arranged with the expectation that the essay could thus be brought out in immediate connection with the others of the series, but as that has proved impracticable, it now seems best to revert to the original plan. Accordingly, Prof. Ward will discuss systematically all American fossil floras, basing his work not only on the literature but on the fossils themselves, and his memoir will not appear for several years. As preparation for this work was organized in his division before the institution of the Correlation Division, and as the work will be brought to completion some time after the publication of the other correlation essays, it does not seem advantageous to modify his original plan in any way for the purpose of bringing it into harmony with the general plans of the division.

For a number of years Mr. W. J. McGee has had in preparation a thesaurus of American formations, designed to afford a complete catalogue of American formation names, together with bibliographic references to their original definitions and all subsequent redefinitions. The preparation of the correlation essays promised to bring together so large a body of material directly available for incorporation in this thesaurus that work upon the latter was suspended. It will now be resumed and the thesaurus will be published as one of the closing papers of the series.

Herewith are submitted also the administrative reports of the several chiefs of the Geologic Divisions.

Very respectfully, your obedient servant,

G. K. GILBERT,
Chief Geologist.

Hon. J. W. POWELL,
Director.

REPORT OF PROF. N. S. SHALER.

U. S. GEOLOGICAL SURVEY,
ATLANTIC COAST DIVISION,
Cambridge, Mass., June 30, 1891.

SIR: I have the honor to submit the following report concerning the administration of my division during the fiscal year 1890–'91.

The work allotted to this division by the Director includes the following matters: An examination into the history of the Atlantic Coast line; an inquiry into the inundated lands of the United States, a group of areas which in the main lie near this shore; the detailed survey of the Narragansett coal field; and the surface geology of the New England States. In accordance with your instructions the last named task has occupied the time of the members of the division during the last year. The work done on the other subjects of inquiry was entirely in the preparation of certain office material, the field work upon them for the present having been put aside.

During the field season beginning June 1, 1890, the aim was to map the surface deposits of the areas delineated by the maps of the New England surveys made during the previous year. In accordance with this plan the several parties were provided with photographic copies of those plane table sheets. While collecting the data necessary for their geological reports the members of the field parties were required continuously to record all errors in the details of this topography which their criticism revealed. The results of this revision were at once sent to the office of the geographer in order that they might be so far as seemed to him desirable embodied in the maps before they went to the engraver.

The field sheets upon which the surface geology was indicated, and the topography inspected, were situated in Rhode Island, Connecticut, Maine, New Hampshire, and Vermont, and in all they numbered eighteen. The following assignments for this field work were made at various times during the season:

To Mr. R. E. Dodge, assistant geologist, and Mr. M. A. Read, field assistant, were in succession assigned the sheets on the westernmost portion of Connecticut and near Portland, Maine; to Mr. J. B. Woodworth, sheets in Rhode Island and Connecticut; to Mr. R. S. Tarr, sheets in southern Vermont; to Mr. J. H. Ropes, sheets in southern Maine. Mr. L. H. Davis assisted Mr. Dodge for awhile in southern Maine and was then given independent work on a portion of the area of that district. Besides the work above indicated Mr. Tarr was for some time engaged in advancing the work of delineating the surface geology on the Massachusetts sheets, all of which had already been engraved. Mr. G. H. Barton was engaged for the field season in observing and delineating the drumlins of Massachusetts, it having been found necessary to have that task done over the whole field by one observer.

During the winter season the assistants so far as retained in the service have been engaged in collating the results of the work done in the field. Twenty-two sheets, with the accompanying descriptions, of the Massachusetts Atlas have been sent to the Washington office and the remainder of the sheets of that map are in an advanced state of preparation. The eighteen sheets prepared during the previous field season have been properly copied and the records concerning them put in order. The necessary delays in formulating the precise plan for the publication of these field sheets has caused delay in transmitting the results to the office.

The geologist in charge of the division has prepared a report concerning the geology of the soils of the United States, which is designed to set forth in a somewhat popular manner the physical history of this element of the surface geology. This report has been published in the annual report of the Director for 1890–'91.

In June, 1891, the field work was resumed, gentlemen being engaged as follows: Messrs. Woodworth and Cobb on the under geology of the Narragansett field; Mr. Tarr on the revision of the Worcester, Mass., sheet; Mr. Barton on the drumlins of Massachusetts; Mr. Davis on the unfinished sheets of New Hampshire, and Mr. Brewster on the unfinished sheets in the State of Connecticut.

At the end of the month of June Mr. Tarr was, at his request, transferred from the Atlantic Coast Division for service with Dr. Wolff in the New Jersey Division.

All of which is respectfully submitted.

Your obedient servant,

N. S. SHALER,
Geologist in charge.

Mr. G. K. GILBERT,
Chief Geologist.

REPORT OF MR. RAPHAEL PUMPELLY.

U. S. GEOLOGICAL SURVEY,
DIVISION OF ARCHEAN GEOLOGY,
Dublin, N. H., July 1, 1891.

SIR: I have the honor to submit my administrative report for the year ending June 30, 1891.

During the season I made visits with assistant geologists through their respective areas, and made reconnaissant excursions with reference to future work.

The Archean and New Jersey divisions have to deal chiefly with crystalline rocks, generally of very obscure and doubtful origin. Their classification and correlation is rendered possible only by applying most recent results of petrographic research of European-American geologists. To these methods the published and unpublished work of the petrographers of the U. S. Geological Survey, and of the Archean Division has contributed greatly.

We are now studying besides those of Central Massachusetts four areas of crystalline sedimentary clastics and of crystalline schists produced by orographic movements acting upon the Archean rocks and upon the later eruptives. These areas are in Central Vermont, Hoosac Mountain, and Southern Berkshire County, Massachusetts, and in the New Jersey Highlands. While having marked individualities, they have certain persistent features in common.

I found as we attacked the problems of classification and correlation of the crystalline rocks that there would be need of a comprehensive comparative study of their mode of occurrence in different fields. For this purpose, accompanied by Prof. Van Hise, I made last summer excursions to the crystalline area in Missouri, in the Marquette and Menominee regions on Lake Superior, in the neighborhood of Philadelphia and Trenton, in the New Jersey and New York Highlands, and in the Adirondacks; and also, without cost to the survey, an extended and instructive trip among the pre-Cambrian rocks of Canada, west of Lake Superior. During the winter, accompanied by Mr. C. L. Whittle, I made a joint excursion with Prof. Van Hise, Mr. Bailey Willis, and Prof. Holmes, State geologist of North Carolina, across the crystalline rocks of North Carolina.

This comparative study has already contributed much toward the classification of our Green Mountain and New Jersey crystalline schists and also in the direction of correlating the pre-Cambrian rocks of Michigan and Canada with those of New England.

It is also throwing much light upon the origin of the crystalline schists.

During the last year the field work of the members of the corps was distributed as follows: Dr. Wolff was employed during the season in determining the structure of the Vermont Valley, near Rutland, and the age of its rocks. In the very successful search for fossils, by means of which the age of the lower limestone was determined as Lower Cambrian, Dr. Wolff was assisted by Mr. Aug. F. Foerste, to whose skill the first and larger part of the fossil discovery was due. Dr. Wolff published in the bulletin of the Geological Society a paper on the "Cambrian Age of the Rutland Valley Limestone." During the winter he was employed a large part of the time on the petrography of the Green Mountain rocks and in preparing for work in the New Jersey Division.

Prof. Emerson was employed during the field season, with five assistants, one of whom was a volunteer, and at such times during the rest of the year as he could spare from his college duties in office work, and occasionally in the field.

His assistants were: Messrs. J. H. Perry, C. S. Merrick, Wm. Orr, jr., F. A. Hathaway, and Robert Crowell (volunteer). Besides supervising the work of his assistants, Prof. Emerson devoted his time in the field mainly to the geology of the Becket atlas sheet, which includes a very important area of crystalline rocks. He has finished the Northhampton sheet ready for printing, and has completed the coloring of the surface geology of nine atlas sheets. Mr. Perry worked on the geology of the Webster and Blackstone sheets, and Mr. Merrick on that of the Groton sheets. These, together with the Worcester sheet, are nearly finished and ready for final coloring. Mr. Orr was occupied in tracing out the many beds of Silurian limestone on the area covered by the Hawley sheet, and Mr. Hathaway in completing the geology of the Winchendon sheet, north of the Massachusetts line.

Prof. Emerson has also worked toward the completion of the text of his monograph on the geology of Hampden, Franklin, and Hampshire Counties, and written a paper accompanied by a map on the Trias of the Connecticut Valley, in Massachusetts.

Mr. William H. Hobbs was employed in the field during July, August, and September in mapping the geology of the larger part of the Sheffield sheet in Massachusetts. During the winter he devoted such time to the petrographic study of his materials as could be spared from his college duties.

Mr. T. Nelson Dale was employed during the field season in mapping the geology of the Berlin sheet in eastern New York and of the New York portion of the Pittsfield sheet.

During part of the time he was assisted by Mr. Foerste, whose discovery of Cambrian fossils in connection with Mr. Dale's structural work, settled definitely the ages of the formations covered by these sheets.

During the winter Mr. Dale was occupied with office work on his last season's material, and as custodian of property. During the latter half of May he completed the work on the sheets in eastern New York, and accompanied Mr. C. D. Walcott over the same area. During the latter half of June he began field work on the rocks of the Vermont Valley, taking up the study where Dr. Wolff left off, near Rutland.

Mr. C. L. Whittle was employed during the field season on the geology of the area topographically surveyed in central Vermont. This area is one presenting many difficulties, and at the same time very important, from the fact that it includes both the Lower Cambrian limestones of the valley, with the equivalent metamorphic conglomerates and schists, and an unconformably underlying series of pre-Cambrian schists and limestones, separating the Cambrian from the core of the Archean complex. During the winter Mr. Whittle was occupied in studying petrographically the rocks of his field. He also accompanied me on a visit to the crystalline schists of North Carolina. In the latter part of May he resumed field work in central Vermont.

By a special arrangement with the New Jersey Geological Survey, the mapping of the geology of the area of crystalline rocks of that State was undertaken by the U. S. Geological Survey. A special New Jersey division was created and placed under my charge in January of the present year.

The area to be studied contains roughly about 800 square miles, and the topographical maps offer an excellent basis for the graphic representation of the geology. Dr. J. E. Wolff, formerly of the Archean Division, was detailed as assistant geologist, who, pending the opening of the season, made repeated excursions to the field, and other preparations for the survey. The work was definitely begun at the end of March, and has continued since through April, May, and June. Of Dr. Wolff's three assistants, Mr. J. G. Westgate began May 24 in the southern part of Warren County. Mr. H. J. Richmond began June 11 in the northern part of Warren County. Mr. R. S. Tarr began June 19 in the northern highlands of New Jersey.

I have the honor to be, your obedient servant,

RAPHAEL PUMPELLY,
Geologist in Charge.

Mr. G. K. GILBERT,
Chief Geologist.

REPORT OF MR. W J McGEE.

U. S. GEOLOGICAL SURVEY,
POTOMAC DIVISION,
Washington, D. C., June 30, 1891.

SIR: I have the honor to transmit the following report of operations in the Potomac Division of Geology during the fiscal year ending today.

PERSONAL WORK IN THE MISSISSIPPI EMBAYMENT.

At the beginning of the fiscal year I was engaged in a reconnaissance of the later Cenozoic formations in the Mississippi embayment, extending from New Orleans northward to somewhat beyond the mouth of the Ohio River. This reconnaissance was so ordered as practically to cover a zone 40 or 50 miles wide between these termini. The lines of reconnaissance were occasionally extended considerably farther eastward, and also westward beyond the Mississippi as far as central Arkansas. In the southern part of this zone special attention was given to the Columbia formation—a littoral and sometimes estuarine deposit recognized in the middle Atlantic slope some years ago, subsequently traced through the southern Atlantic and eastern Gulf slopes, and during the reconnaissance of the present season clearly discriminated in the Mississippi embayment, where it is developed in vast volume. Throughout the entire area traversed especial attention was given to that distinctive and widespread formation originally discriminated and called the Lafayette formation by Hilgard, afterward recognized in Tennessee by Safford and designated the Orange Sand, and more recently discriminated in this division in the middle Atlantic slope and, before the identification of the widely separated deposits was effected, denominated the Appomattox formation. Careful attention was given also to the mineral contents of this formation (for which it seems well to restore Hilgard's original designation), to topographic configuration, to the extensive invasion of the region by modern erosion resulting in part from deforesting, to the characteristics of the soils, etc. Attention was also given to the earlier Cenozoic and to the Mesozoic formations. The modifications in physiography, the fissuring of hills, the extravasation of gravels in the valleys, and the other permanent or long enduring effects of the New Madrid earthquake of 1811-'13, were also studied in some detail. The Lafayette formation was traced northeastward to beyond the Tennessee River and westward to the Washita, and the Columbia formation was traced over a wide area. The reconnaissance resulted in the discrimination of the Neocene and Pleistocene deposits over a considerable part of the Mississippi embayment, in correlating several of these formations with formations already recognized in other parts of the coastal plain, in ascertaining the significance of the topographic and physiographic features of the region, and in elucidating the Neocene and Pleistocene history of a considerable part of the Gulf slope.

The greater part of the journeys were made on horseback. Side and cross trips were made from time to time by rail, and vehicles were sometimes used in reaching certain side points not accessible in other ways.

PERSONAL WORK ON THE SOUTHERN ATLANTIC SLOPE.

On the 1st of January an arrangement was effected under your direction for transferring the work on structure and on the phosphates of Florida to another division, in charge of Mr. George H. Eldridge; and in order to place the results of work in that region by this division more fully and definitely in Mr. Eldridge's possession than seemed possible in any other way, a journey was made in company with that gentleman through portions of the Carolinas, Georgia, and northern Florida. During this journey old observations were verified and extended and new observations were made along several lines in each of the States. Special attention was given to the Columbia and Lafayette formations, and both were traced some distance beyond the previously known limits. The relations of the formations between themselves and to the Neocene and Eocene deposits of southeastern United States were studied and in some measure ascertained. The structure and composition of both were investigated, and the changes in structure and composition supervening on passing from the inland extension of the formation toward the coast were studied, with the aim of establishing means of correlation between the littoral and deep-sea deposits, respectively, of the Columbia and Lafayette formations. Materials were also collected, and part of these have been examined chemically. The journey resulted in material addition to the knowledge of the distribution of the Columbia, Lafayette, and some other formations in Georgia and Florida, and of the characteristics of these formations in a part of the Coastal Plain in which they had not been adequately studied.

PERSONAL WORK ON THE MIDDLE ATLANTIC SLOPE.

In coordinating the studies and investigations of Dr. Williams, Prof. Holmes, and Mr. Darton, it became necessary to make special field trips during the year in Virginia and Maryland. One of these was made in connection with a joint scientific expedition organized by the Geological Survey, Johns Hopkins University, and the Agricultural College of Maryland. This expedition was made in the latter part of May of the present year. It was suggested by Dr. William B. Clark, of Johns Hopkins University, and Prof. Milton Whitney, of the Maryland Agricultural College; and a "board of control" was organized, consisting of these gentlemen as representatives of the institutions with which they are connected, and myself on the part of the Geological Survey. President D. C. Gilman, of Johns Hopkins University, and Maj. H. E. Alvord, president of the Maryland Agricultural College, accompanied the expedition during a part of the work. Other participants were Messrs. George H. Williams, Nelson H. Darton, Gilbert D. Harris, and David White, on the part of the Geological Survey; Dr. E. Lewis Sturtevant, recently of the State Agricultural Experiment Station of New York; Prof. Henry D. Adams, of McGill College, Montreal; Mr. W. H. Holmes, of the Bureau of Ethnology; Dr. H. M. Hurd, of Johns Hopkins University, and several advanced pupils of the Agricultural College and the University. The purpose was a detailed study of the geology and particularly of the soils and greensand deposits of the "western shore" of Maryland on Chesapeake Bay and Potomac River. For the means of transportation the participants in the expedition are indebted to the State board of public works of Maryland, and particularly to Gen. Joseph E. Seth, commander of the Maryland naval police fleet, by whom the steamer *Governor Roberts* was placed at the disposal of the party for the entire journey, with the accompaniment of a sailing vessel for a part of the time. The expedition was successful in extending knowledge of the geology and resources of central Maryland, in coordinating the work of students of stratigraphy, paleontology, and zoology, and in establishing harmony and a measurable division of labor among the three institutions represented, in such manner as to inure to the benefit of each.

PERSONAL WORK ON THE PACIFIC COAST.

Toward the close of the fiscal year a hasty journey was made to the Pacific coast, partly for the purpose of making a comparative study of the prevailing earth forms of that region in connection with those of eastern United States, with a view to the correlation of later earth-forming episodes on opposite sides of the continent. Within recent years students have come to read geologic history and interpret geologic chronology from earth forms as well as from deposits; and it was believed that a comparative study of earth forms on the Atlantic and Pacific coasts would give indications of the relative antiquity of the land surface, and thus afford a means of correlating Pleistocene and possibly Neocene episodes. Although the results of the study are not final, they are highly significant, and will prove valuable in future work on the coastal regions of the United States.

While in California I had the pleasure of conferring with Dr. E. W. Hilgard, formerly State geologist of Mississippi, and also of Louisiana, concerning many of the puzzling problems of southern geology; and I am indebted to him for valuable data, including many unpublished details concerning this subject. Moreover, the journey gave opportunity for a personal conference with Dr. Loughridge (who is now in the University of California, at Berkeley) concerning his report on the Santee River section, and also on the deposits of western Kentucky, which were independenly studied by him under the auspices of the Geological Survey of Kentucky and by myself during last season.

DR. WILLIAMS'S WORK ON THE PIEDMONT CRYSTALLINES.

The Piedmont area of eastern United States, in which the rocks are ancient crystallines, is not an essential part of the geologic province with which this division is primarily concerned; yet, since the Coastal Plain deposits are structurally related to these crystallines, and since, moreover, the newer deposits are largely made up of débris derived from the Piedmont crystallines, there are reasons for combining study of the two provinces. Accordingly during the fiscal year just closing, as during preceding years, the researches in the Piedmont region have been carried forward in the Potomac Division. Dr. George H. Williams, who has charge of these researches, reports as follows on the work of the year:

REPORT OF WORK DONE ON THE CRYSTALLINE AND SEMI-CRYSTALLINE ROCKS OF MARYLAND DURING 1890-'91 BY GEORGE H. WILLIAMS.

During the fiscal year 1890-'91 work has been continued within the Piedmont areas of Maryland and northern Virginia along the lines indicated in previous reports.

In the fall of 1890 the field investigations were mainly directed to discovering the true relationship between the crystalline and semi-crystalline rocks of the Piedmont plateau. To this end the slates on the east of the crystallines in Fairfax and Prince William Counties, Va., were mapped and studied; a section was made along Occoquan Creek—the boundary between these counties—from Manassas to Woodbridge; and three parallel sections were also made from east to west across the entire crystalline and semi-crystalline belt of Maryland. The details regarding these sections, together with the general conclusions drawn from them and much intermediate work were communicated to the Geological Society of America at its Washington meeting, December, 1890, in an illustrated paper entitled, "The Petrography and Structure of the Piedmont Plateau in Maryland," which was published by the society. (Bull. G. S. A., vol. ii, pp. 301-322, March, 1891.

During the year a large amount of microscopical and other laboratory investigation was also carried on upon the petrographic material collected in the course of the above-named field work, and also upon the collections of crystalline rocks gathered during the preceding fiscal year in the neighborhood of Washington. The record of such laboratory work has been systematically kept through a number of years, and seems already to be pointing to results of general value.

Through the spring of 1891, aside from two long trips for the geological exploration of southern and western Maryland, many field excursions have been undertaken for the detailed mapping of the recently completed topographic atlas sheets near Baltimore and Washington.

Fully realizing the necessity of wider observation than could be made within the limits of one small State, for success in dealing with the complex problems of Archean geology, the Director of the Survey authorized the writer to undertake two extended trips, one toward the north and the other toward the south, within the extension of the crystalline belt, of which the Piedmont area in Maryland forms a part. The first of these longer excursions was made in company with Profs. Pumpelly and Van Hise during the summer of 1890, and embraced the more crystalline portions of northern New Jersey, southern New York, western Massachusetts, Vermont, and the Adirondack Mountains. An informal account of its object and results was published in the Johns Hopkins University Circular, No. 84, December, 1890. The second long trip was taken at the instance and with the cooperation of the State Geological Survey of North Carolina during June, 1891. It embraced the examination of several critical points in central Virginia, and a complete east-west section, some 300 miles in length, of the crystalline belt where it is broadest, viz, from Paint Rock on the French Broad River at the Tennessee line to Raleigh, North Carolina. This section was run along the railroad on a hand car, in company with the North Carolina State Geologist, Prof. J. A. Holmes, and has afforded many important structural points, together with a large amount of petrographic material for future study.

Respectfully submitted.

GEO. H. WILLIAMS.

JULY 28, 1891.

DR. SMITH'S WORK IN ALABAMA.

During part of the year Dr. Eugene A. Smith, State geologist of Alabama, has been employed in special investigations for this division. The principal line of work was the construction of a section through the Coastal Plain from the Piedmont region to the Gulf, along the line of the Chattahoochee and Appalachicola Rivers. In this work Dr. Smith had the cooperation of Mr. Lawrence C. Johnson, then of this division, Dr. J. W. Spencer, State Geologist of Georgia, and Daniel W. Langdon, formerly of the Geological Survey of Alabama. The examination was made in September, at low stage of the river, in order that the opportunities for observation of low-lying exposures might be favorable as possible. The study resulted in the development and measurement of a section giving the succession of deposits and the physical and faunal characteristics, and in general the thickness of each from Columbus, Georgia, to the Gulf.

Both before and after this special examination Dr. Smith was employed for some time in studies of the Lafayette and associated formations in the interior of the State, and in conjunction with Mr. Johnson in working up the results of field studies in southern Alabama for the use of this division. In consequence of Dr. Smith's valuable assistance the data concerning the Coastal Plain formations in southern Alabama are now so full as to permit classification of the deposits in many localities, and thus to prepare the way for detailed mapping as soon as topographic bases are completed.

MR. JOHNSON'S WORK ON THE GULF SLOPE.

Mr. Lawrence C. Johnson's connection with this division continued during the first half of the fiscal year. His field work lay in Louisiana, Mississippi, and Tennessee in connection with my own reconnaissance, and in Alabama and in Florida.

During past years Mr. Johnson's observations extended over considerable parts of Louisiana and Mississippi, and he was thus able to give material assistance and guidance in personal work in this region; and for this reason he accompanied me on certain journeys. Accordingly the results of this work are to be credited in part to Mr. Johnson.

In the intervals between his periods of occupation in this manner, Mr. Johnson was employed in assembling and reducing field observations in connection with Dr. Smith, at Tuscaloosa, Alabama. He also participated in the work on the Chattahoochee and Appalachacola Rivers, already referred to. Subsequently he repaired to Florida, where he resumed the investigation of the phosphate deposits. His work here resulted in important additions to knowledge concerning the distribution, value, geologic relations, and genesis of the different classes of phosphate found in Florida; and when this study was transferred to another division on the first of January these results were utilized in a manner otherwise reported to you.

PROF. HOLMES'S WORK IN THE CAROLINAS.

During a part of the year Prof. Joseph A. Holmes, of the University of North Carolina, has been employed in field and laboratory investigation of the formations of the Coastal Plain in North Carolina, and to some extent in South Carolina. In pursuing his investigations Prof. Holmes has availed himself of the courteous permission of the officials of the railways traversing the Carolinas to travel over the various railway lines on a "crank car," and has thus been enabled to visit the principal exposures of the coastal lowland in these States in the most expeditious and economical manner. He has, however, made a number of boat journeys along North Carolina rivers for the purpose of examining exposures in banks and bluffs not otherwise accessible. The fossils and rock specimens collected during his various journeys have been examined in the laboratory, classified, analyzed when necessary, and are now preserved for reference in the preparation of final reports on the work in that region. Prof. Holmes's reconnaissance has extended over practically the whole of the Coastal Plain in North Carolina and over much of the same province in South Carolina; most of the formations have been defined and classified; he has already acquired such information concerning his territory as to permit correlation of part of the Carolinian formations with those of other portions of the Coastal Plain province; and he is now in possession of sufficient data to begin the areal representation of terranes as soon as the necessary topographic bases can be furnished.

DR. LOUGHRIDGE'S WORK IN SOUTH CAROLINA.

During the last fiscal year Dr. R. H. Loughridge, then of the State Agricultural College of South Carolina, was employed to construct a section through the Coastal Plain in the Santee River basin. The field work and a part of the laboratory work required were executed during the last months of the previous year; but during the present year the report has been rewritten and transmitted for the use of the division. It contains valuable data which have been utilized in general correlation of the formations, and in the coordination of work in other portions of the province.

MR. DARTON'S WORK ON THE MIDDLE ATLANTIC SLOPE.

Throughout the year Mr. Nelson H. Darton has been employed in the work of the division in different parts of the Middle Atlantic Slope. In the earlier portion of the year he made a reconnaissance of the inland margin of the Coastal Plain from Richmond to Philadelphia. Later in the season he spent some months in mapping the areal distribution of the Coastal Plain formations on the Fredericksburg Mount Vernon, Washington and Baltimore atlas sheets; and during the year he completed the coloration of the East Washington sheet and those portions of the West Washington and Baltimore sheets occupied by the Neozoic formations. During the winter he prepared for publication as a bulletin the annual record of North American geologic literature for 1890. He also made material additions to the general card catalogue of American geologic literature. Laboratory investigations of field collections were also made and general studies of the phenomena observed in the field were carried forward and revised in proofs of the record of North American geologic literature for 1887–'89, which has just appeared as a bulletin (No. 75). During spring and early summer of the present year he resumed field work, completing the cartography of the areas covered by the sheets already mentioned, and making such a reconnaissance on both sides of Chesapeake Bay as to place himself in position to immediately begin the areal representation of the geologic formations of this portion of the province when the topographic sheets are available. During the latter part of April and the earlier part of May he participated in the joint expedition already described.

In the Ninth Annual Report of the Geological Survey there was described a boring apparatus for taking samples of unconsolidated deposits at various depths which was successfully used in Iowa in determining the stratigraphy of the Pleistocene deposits. Mr. Darton has employed this device in developing the sequence of deposits and in defining the limits of formations in the Coastal Plain during the last year with highly satisfactory results. He has modified the apparatus already described in such manner as to obtain greater strength with diminished weight. With his modifications the apparatus weighs but a few pounds, can be readily carried on foot, on horseback, or in light vehicles, and is capable of bringing samples from all depths up to 20 or 30 feet with slight labor.

OFFICE WORK.

During the year the proofs of a memoir on the geology of northeastern Iowa, forming a considerable part of the Eleventh Annual Report of the Director of the Geological Survey, were received from the printer and the proofs of letter-press and illustrations were revised. The proofs of the other memoir in the same report (The Natural Gas Field of Indiana), which was prepared under my direction and of which I wrote the introductory chapter, were also revised. During the closing portion of the year a memoir on the Lafayette formation, designed for publication in the Twelfth Annual Report, has been written and the accompanying illustrations prepared. The monthly reports of the collaborators of the division have been carefully studied from time to time in order that the various lines of work of the division in the various parts of the province with which it is concerned might be constantly coordinated and carried forward in accordance with the general plans already formulated and stated in other reports. Work upon the geologic map of New York, the construction of which was commenced in this division some years ago, has been continued during the year; but the work of Mr. J. B. Torbert, who has been engaged in its construction, was interrupted in order that he might prepare the analytic and other maps illustrating the memoir on the Lafayette formation already referred to. Accordingly the New York map is not yet completed.

Toward the close of the fiscal year the collection of material for a revised edition of the map of the United States exhibiting the status of knowledge relating to the areal distribution of geologic groups published in connection with the Fifth Annual Report of the Geological Survey in 1884 was commenced and a considerable part of the necessary data accumulated.

I have the honor to be, with great respect, your obedient servant,

W J McGee,
Geologist in charge.

Mr. G. K. Gilbert,
Chief Geologist.

REPORT OF MR. BAILEY WILLIS.

UNITED STATES GEOLOGICAL SURVEY,
APPALACHIAN DIVISION,
Washington, D. C., June 30, 1891.

SIR: I have the honor to submit the annual report of progress covering the operations of the Appalachian Division of Geology for the fiscal year now closed.

ORGANIZATION AND FIELD WORK.

The force of the division consisted during this year of three assistant geologists and myself, aided by such field assistants as the work required.

The beginning of the fiscal year found Messrs. C. W. Hayes and M. R. Campbell in Georgia, with camp outfit, cook, and driver. They continued field work until September 29, and Mr. Hayes then disbanded the party, having during the field season, which began May 5, surveyed in revision and in original work nearly 5,000 square miles. These gentlemen then joined me at Knoxville, and at my request spent the month of October in detailed work on the Cambrian sandstones and shales of the southwestern part of the Cleveland sheet. They reached Washington on November 2.

Mr. Arthur Keith, who took the field with camp outfit, cook, and driver on June 6, was near Maryville, Tennessee, July 1; there I joined him, and we together studied the problems of Chilhowee Mountain and of the Big Butt Range south of Greeneville. On August 18 I went to Knoxville, while Mr. Keith continued his work in the Greeneville and Morristown sheets. On August 30 he returned to Washington, and September 4 proceeded with team and buckboard, and assisted by Mr. Richard H. Gaines, to the survey of the Harper's Ferry sheet, a study which was completed in its first stage by November 3. Mr. Keith then came to Washington for the winter's office work.

I proceeded from Knoxville, with the camp outfit, through the Knoxville, Cleveland, Kingston, and Loudon atlas sheets to review the geology mapped by Messrs. Keith and Hayes, and disbanded camp at Knoxville on October 8. During this work I gave much attention to the marbles of East Tennessee, and studied their character and occurrence and the methods of quarrying. Returned to Washington, I considered questions relating to winter work, and again took the field for two weeks in West Virginia to verify the geologic draft of the Winchester atlas sheet.

OFFICE WORK.

During the entire winter season Messrs. Keith, Hayes, and Campbell were engaged in platting geologic notes on the topographic base maps, in drawing sections, and in writing up the results of field work. I myself developed and applied a plan of office record for geologic results, gave prolonged consideration to the nature of the topographic map which is adequate for the geologist's use, worked on the details of the scheme of publication for geologic maps, and studied the mechanics of structural geology.

RESULTS.

To prepare geologic maps for publication is the principal work of this division, and to this end all efforts have been primarily directed. In Virginia, West Virginia, Tennessee, Georgia, and Alabama surveys have been made, either to discover the distribution of strata in areas not previously examined by members of the Survey, or to revise former results in order that all the maps may come up to the standard of accuracy demanded by the scheme of publication. The present condition of the geologic surveys, specified by atlas sheets, is as follows:

Ready for publication:

Staunton, Virginia, sheet, by N. H. Darton.
Ringgold, Georgia, sheet, by C. W. Hayes.
Chattanooga, Tennessee, sheet, by C. W. Hayes.
Cleveland, Tennessee, sheet, by C. W. Hayes (except SE. corner).
Kingston, Tennessee, sheet, by C. W. Hayes.
Loudon, Tennessee, sheet, by Arthur Keith.
Knoxville, Tennessee, sheet, by Arthur Keith.
Morristown, Tennessee, sheet, by Arthur Keith.
Greeneville, Tennessee, sheet, by Arthur Keith.

Surveyed; to be examined by the geologist in charge:

Winchester, Virginia, sheet, by H. R. Geiger.
Woodstock, Virginia, sheet, by H. R. Geiger.
Harper's Ferry, Virginia and West Virginia, sheet, by Arthur Keith.
Maynardville, Tennessee, sheet, by Arthur Keith.
Stevenson, Alabama, sheet, by C. W. Hayes.
Dalton, Georgia, sheet, by C. W. Hayes.
Rome, Georgia, sheet, by C. W. Hayes.
Fort Payne, Alabama, sheet, by C. W. Hayes.
Gadsden, Alabama, sheet, by C. W. Hayes.

Each of these atlas sheets covers nearly 1,000 square miles of area; the division is therefore prepared to publish maps of nearly 9,000 square miles, and has provisional maps, which will require but little alteration, covering 9,000 square miles more.

In my last annual report it was stated that the geological field work passed through several stages in its progress from the first to the final draft of the map. On beginning work in any district the assistant geologist is furnished a topographic map of the atlas sheet assigned him, and upon this he draws the geology while in the field with approximate correctness and in such detail as the facilities at hand easily permit; this first representation of the geologic areas is supplemented by notebook records, and with their aid it is later corrected in the office by the same assistant. The geologist in charge, equipped with this carefully prepared draft, examines the region and ascertains the character of the work done, and, should it be necessary, gives instructions for additional work by the author of the map. The final copy, sections, and descriptive text are then prepared and submitted for your approval. Experience with this method shows that it may advantageously be modified, where circumstances permit, by drawing the first representation in the field with greater care and with the detail demanded for the final publication. To do this takes more time for any given area and increases the first cost of the assistants' work per square mile; but it insures an accurate result, it reduces the proportion of routine labor in the office, and it facilitates the progress of any one sheet towards publication, since it is possible for the geologist in charge to examine the final details in the field as they develop. Thus is avoided the necessity of allowing a year to elapse between the original survey by the assistant and the verification by the geologist in charge.

While the regular work of mapping lithologic formations has been thus extended in Georgia, Alabama, and Virginia, and the methods of field work have been improved, the scientific problems have been constantly considered. The Appalachian province has been studied by many geologists, and the student of to-day must take account of the views of his predecessors who have worked out the chapter headings of its history. It is still a commonly held opinion that they have done more than this, and that little can be added to our present knowledge, based as it is on the researches of the most eminent American geologists. But the fact that many points are yet in controversy is itself evidence that we do not know or do not understand all the records of the region, and it may warn those now working there that only the most patient and impartial observation will lead to improvement in our knowledge. The history of rock formation and disturbance was not simultaneously similar over this great area, and a fruitful source of misunderstanding has been the inclination to generalize for the whole province from the well-known facts of some limited district. Such, for instance, is the cause of dispute concerning the age of the so-called "Potsdam" sandstone in Virginia and even farther south. Recognizing that our information is in most respects all too incomplete for broad generalizations, the members of the division are endeavoring to collect facts for thorough descriptions of the several districts under survey, and guided by the method of mapping lithologic units rather than theoretic time divisions, they progress steadily, and, I believe, surely, in their task.

Mr. Hayes, following southward from Tennessee a well known phase of Appalachian folding and faulting, traced the "Rome" and "Cartersville" overthrusts along their curved outcrops, which in passing through Georgia form two strikingly parallel quadrants so that their courses change from nearly due south to west. In this section these faults are characterized by nearly horizontal displacements of four miles or more, and they give evidence of antecedent and subsequent periods of folding;

thus it is indicated that Appalachian deformation progressed to its present development by several steps. Mr. Hayes presented an article embodying the principal conclusions of his Georgia work to the Geological Society of America at the last December meeting.

Mr. Keith, pursuing his mapping in East Tennessee, developed the system of faults which isolate the Cambrian of Chilhowee Mountain, and showed on structural and stratigraphic evidence the Silurian age of series of strata hitherto considered older on lithologic grounds. In his work in the Harper's Ferry sheet Mr. Keith developed reasons for placing the sandstones of the Blue Ridge in that region above the valley limestones, and he delivered a paper before the Geological Society setting forth the views of himself and his predecessor in that field, Mr. H. R. Geiger.

In structural geology progress has been made in developing the suggestions of the structural experiments, and the preparation of a final paper on those tests and the application of the hypotheses to Appalachian structure is well advanced. While this work is essentially my own, I am greatly assisted by the detailed facts furnished by the other members of the division.

FURTHER WORK.

The plans for the spring and the fiscal year now beginning were influenced by the condition of the previous work and by the force of the division. This was lessened by the departure of Mr. Hayes on April 10, to accompany Lieut. Schwatka on an expedition to Alaska. On April 15 Mr. Campbell took the field with camp outfit, cook, and driver, to survey the Estillville and other sheets in southern Virginia. Mr. J. V. Lewis, of Chapel Hill, North Carolina, has been appointed as his assistant. Mr. Keith continued office work until June 17, when he proceeded to the revision of details in the draft of the Harper's Ferry sheet. His further work this summer will consist in rounding out our knowledge of that part of east Tennessee where he has already accomplished so much, with the expectation of publishing next year. He is assisted by Mr. J. H. Shields, jr., of St. Louis, and will work without camp. I shall continue to work toward the publication of maps and other results.

Submitted with great respect by

BAILEY WILLIS,
Geologist in charge.

MR. G. K. GILBERT,
Chief Geologist.

REPORT OF MR. GEORGE H. ELDRIDGE.

U. S. GEOLOGICAL SURVEY,
FLORIDA DIVISION,
Washington, D. C., June 30, 1891.

SIR: I have the honor to submit herewith a report of the work of this division for the fiscal year ending June 30, 1891.

The division was established by you on the 1st of January of this year with the following objects in view: The mapping of geologic formations; the construction of sections to exhibit the stratigraphy of the peninsula; and the investigation of phosphate deposits and of other resources of economic value.

By your direction I assumed charge of the division on January 2; Dr. Edmund Jüssen was assigned me as assistant, and a little later Mr. Lawrence C. Johnson, the latter by transfer from the Potomac Division. On February 16 Mr. W. S. Norwood, of Titusville, Florida, joined the division in the capacity of field assistant. In the study of the general geology cooperation has been maintained with Mr. W. J. McGee, in charge of the Potomac Division; with Mr. W. H. Dall, paleontologist, and with Dr. T. M. Chatard in the study of the chemical problems of the phosphate deposits.

Prior to entering upon work in Florida a preliminary examination of the phosphate deposits in South Carolina was made, and in company with Mr. McGee several localities on the Coastal Plain were visited for the purpose of bringing future work in Florida initially into proper relation with that of the Potomac Division. Work in Florida was instituted on January 12.

After the consumption of a few days at the outset in devising a general plan of procedure, during which some preliminary studies of the formations and phosphate deposits of northern Florida were made, reconnaissance work upon the rock phosphate belt of the peninsula was immediately begun and occupied the time to February 11. Upon this work I was accompanied by Drs. Chatard and Jüssen, and the general problems of the geology and chemistry of the rock phosphates were determined. At its completion Dr. Chatard returned to Washington for the purpose of entering directly upon the laboratory studies of the chemistry of the phosphates, and Dr. Jüssen was assigned to the general and detailed study of the Eocene formation within the areal limits of which the phosphates of this class in peninsular Florida occur. Dr. Jüssen has well advanced the work of the Eocene area, but it will require at least a portion of another season to complete it.

Mr. Johnson, upon entering on his duties with the Florida Division (having already a considerable acquaintance with the formations of the Gulf States), was assigned to the field west of the Suwanee River, a field intimately connected in its stratigraphy with that of the States farther to the west, and one, moreover, which is of great importance from the phosphate deposits now rapidly being developed within its eastern half. The general survey of the area lying between the Suwanee and Apalachicola Rivers is now fast nearing completion.

Besides the general direction of the work of the division the explorations conducted by myself during the remainder of the season were the following: The interval between the middle of February and the 15th of March was occupied in the examination of the phosphate deposits and related geology of South Florida. From the nature and rapidity of the commercial development of the two classes of deposits, here occurring, land and river pebble, the work of the last season, although well in hand, can not be regarded as other than preliminary.

The latter half of March was occupied in the examination of the rock phosphate deposits of western Florida. At the time of visiting them the chief developments were in the vicinity of the Econfena, Aucilla, and Wacissa Rivers in Taylor, Madison, and Jefferson Counties, but the deposits are known to extend for considerable distances east and west of the area there developed. The work of Mr. Johnson in this field will materially supplement mine, and, with the important data upon the general geology gathered during his more detailed examination, should make possible the correlation of the formations of western and peninsular Florida.

The month of April, with the exception of the first ten days, during which both official duty and personal illness required that I should remain at Ocala, was passed in a geological reconnaissance of the lake and river system of central southern Florida. The journey was made in a steam launch, the initial point being the town of Kissimmee, at the head of Lake Tohopekaliga, the objective the Gulf of Mexico, the route being through the Kissimmee River and the numerous lakes and streams tributary to it, around Lake Okeechobee, and down the Caloosahatchie River to its mouth. The results of this trip were both general and economic in character, the former in reference to the stratigraphy of the peninsula as far south as the Everglades, the latter in the study of the pebble phosphates of the Caloosahatchie River from Lake Flirt to Fort Myers.

The first half of May was passed in miscellaneous work, including a hasty examination of the east coast, an investigation of the kaolin deposits in the vicinity of Leesburg, a study of peculiar deposits of phosphate at Anthony and Sparr, a few miles north of Ocala, the inauguration of a systematic investigation of the artesian water supply of the State, and the preparations for closing the season's work.

On May 1 Dr. Jüssen was unavoidably called to his home by private matters, and field work on the Eocene area was stopped.

During the period of Mr. Norwood's employment his duties have been confined to preliminary explorations along the eastern side of the peninsula as far south as Lakes Worth and Okeechobee, and to the collection of rock specimens and fossils illustrative of the country over which he traveled.

In the prosecution of the season's work special attention has been paid to the collection of a complete suite of the phosphates and other rocks of the areas studied, and fossils have been gathered wherever found. Attention has also been paid to the methods of treatment in the preparation of the phosphates for market, and the importance of this branch of the industry is fully recognized. In cooperating with Mr. Dall great assistance has been derived from the work already done by him, and it is expected that by combining results a creditable preliminary map of the geology of the State can be prepared before the opening of another season.

On the 16th of May I left the field for the North, revisiting the South Carolina phosphate deposits en route, and reaching Washington on the 20th.

Office work was immediately resumed by Dr. Jüssen and myself, and the time to the close of the year has been chiefly devoted to the arrangement of the season's collections.

Very respectfully, your obedient servant,

GEO. H. ELDRIDGE,
Geologist in charge.

Mr. G. K. GILBERT,
Chief Geologist.

REPORT OF PROF. C. R VAN HISE.

U. S. GEOLOGICAL SURVEY,
LAKE SUPERIOR DIVISION,
Madison, Wisconsin, July 1, 1891.

SIR: I submit the following report of the operations of the division of the Survey under my charge for the fiscal year ending yesterday:

Until last year the plan of operations has included two classes of work: Detailed studies of regions of exceptional scientific interest or economic importance leading to special reports, and studies designed to furnish atlas sheets for the geological map of the United States. Beginning last year, by your direction, a third line of work was taken up, a general study of the pre-Cambrian rocks of North America, preparatory to an account of the present state of knowledge of the Algonkian or Archean. During the year just closed all of these three lines of work have been continued.

FIELD WORK.

Field work has been done by W. S. Bayley, E. T. Eriksen, C. W. Hall, F. P. King, George E. Luther, W. N. Merriam, and myself.

Aside from supervision of other parties, my own time has been given almost wholly to the general work on the pre-Cambrian. In company with Raphael Pumpelly, Bailey Willis, C. D. Walcott, or G. H. Williams, or alone, I have made more or less extended trips in Georgia, east Tennessee, North Carolina, eastern Pennsylvania, northern New Jersey, southern New York, the Berkshire Hills, Green Mountains, Adirondacks, Hastings district of Ontario, and the Marquette and Thunder Bay districts of Lake Superior. For the most part this work has not been of such a detailed nature as to add greatly to previous knowledge of these regions, but the aim has been rather to get such a familiarity with them as would enable me in the preparation of the pre-Cambrian memoir to judge accurately of the results already reached. This statement does not apply to a part of the Adirondacks, where a somewhat closer study was made, nor to the Marquette and Thunder Bay districts, where information was acquired which has an important bearing upon the writer's conception of the general stratigraphy of the Lake Superior region. Also in the other regions visited much interesting material was obtained bearing upon the metamorphism of rocks, upon the development of cleavage and schistosity, and upon the methods which are applicable to the study of the crystalline formations. This work occupied the most of the time from the 1st of July to the middle of October, as well as a fortnight in April.

Mr. Bayley, with Mr. Luther as field assistant, and one woodsman, continued the detailed systematic study of the Marquette district which Mr. Merriam has been carrying on for two years. This year for the first time topographic maps were available to assist in the work. Using these as a basis, locations were made in large measure with stadia telescope and plane table instead of by the method of pacing from section lines. The Goose Lake section, in which the work was done, is the roughest in the whole district, and it would have been nearly impossible to make locations with any considerable degree of accuracy by pacing. The party began work July 2 and remained in the field until September 18. Work in the Marquette district was again resumed May 28 by a party in charge of Mr. Merriam, and is continuing at the present time. His party consists, besides himself, of Mr. Eriksen, field assistant, two compassmen, and one cook.

The Marquette area is one of the key districts of the south shore of Lake Superior, and it is designed to push the work vigorously until its structure is worked out. This done, the areal work of the Upper Peninsula of Michigan will be in such condition that it will be practicable to turn in a number of atlas sheets for the geological map of the United States. Besides being of great structural importance, the Marquette district is the largest iron producer of Lake Superior, and it is hoped that, incident to the structural study, economic results of value will also be obtained. This hope is justified by such an outcome from a similar structural study of the Penokee district. It is designed to present the results of the work in the Marquette area in the form of a monograph, in scope like that already submitted upon the Penokee area.

The beginning of the fiscal year found Mr. King in the field in charge of a party consisting, besides himself, of one woodsman, one packer, and one cook. The work of this party was atlas-sheet mapping in the area between the Penokee and Marquette districts, lying mostly in the sheets bounded by meridians 88° 30′ and 89° 30′, and parallels 46° and 46° 30′. The district was found to be heavily drift-covered; exposures were consequently rare, and it will therefore not be practicable to locate formation lines with accuracy. All information that could be obtained as to the location of ledges was used, so that as much has been found out about this area as can be done without a more detailed study than can be undertaken. The season's work ended September 17, the party covering about 1,000 square miles.

June 1 Mr. King left Madison for the field to continue areal work on the southern part of the atlas sheet lying between the meridians 87° 30′ and 88°, and parallels 46° and 46° 30′. His party consists, besides himself, of one compass man, one packer, and one cook. This work is being continued at the present time.

Mr. Hall did a small amount of field work in central Minnesota. He also collected a set of specimens of amygdaloids occurring at Grand Marais, Minnesota, for the Educational Series of rocks in charge of Mr. Diller.

OFFICE WORK.

Aside from the routine work of the office, my time, both at Madison and in Washington, has been given to the preparation of a report upon the pre-Cambrian of North America. This report comprises a review of the published facts and conclusions as to pre-Cambrian stratigraphy, classified according to districts; a summary of the results which have been reached in each district; and a general discussion of what has been accomplished in pre-Cambrian stratigraphy, with a consideration of the methods of study and the principles of classification and correlation applicable to this part of the geological column. The task of going through and summarizing the literature of the subject has been one of great labor. Mr. Luther has given the most of his time in the office to assistance in the preparation of this report; and Mr. Merriam has spent a considerable amount of time in drawing maps in connection with it. I am able to state that the report, towards which most of my field work and nearly all of my time in the office has been looking for two years, is now ready for transmission.

Mr. Bayley has continued the study of the gabbros of Minnesota, Michigan, and Wisconsin began during the preceding fiscal year. The thin sections of all the gabbros belonging to the division, as well as others loaned by Prof. N. H. Winchell, State geologist of Minnesota, Prof. F. D. Chester of Delaware College, and Dr. Geo. H. Williams of

Johns Hopkins University, have been studied. The contemplated report upon the gabbros of Lake Superior is not yet completed, nor can it be until more field work has been done in the Minnesota region. Aside from this work, Mr. Bayley's time has been given to the description of a number of thin sections for the Educational Series of rocks in the charge of Mr. Diller, and in the transcription and elaboration of his field notes.

The small amount of time which Mr. Hall has given to the survey work has been upon proposed bulletins upon the Minnesota Valley gneisses and upon the granites of central Minnesota. The former is now ready for transmission.

A large number of specimens, photographs, and thin sections have been added to the collection in the office. In press, or in the Washington office ready for press, from the division, are the following reports: A monograph on the Penokee Iron-Bearing Series of Michigan and Wisconsin, by R. D. Irving and C. R. Van Hise; a bulletin on the Eruptive and Sedimentary Rocks on Pigeon Point, Minnesota, and Their Contact Phenomena, by W. S. Bayley; a bulletin on the Gneisses and Crystalline Schists of the Minnesota River Valley, by C. W. Hall; a bulletin on the Present State of Knowledge of the pre-Cambrian of North America, by C. R. Van Hise, is nearly complete and will be forwarded in a few weeks.

Following, are the titles of the papers which have appeared from the division during the year:

(1) The Greenstone Schist Areas of the Menominee and Marquette Regions of Michigan, by G. H. Williams, with an Introduction by R. D. Irving: Bulletin No. 62, U. S. G. S.

(2) Abstract of a Monograph upon the Penokee Iron-Bearing Series of Michigan and Wisconsin, by R. D. Irving and C. R. Van Hise: Tenth Annual Report U. S. G. S., pp. 341–509.

(3) An Attempt to harmonize some apparently conflicting Views of Lake Superior Stratigraphy, by C. R. Van Hise: Am. Jour. Sci., 3d series, vol. 41, 1891, pp. 117–137.

Very respectfully,

C. R. VAN HISE,
Geologist in Charge.

Mr. G. K. GILBERT,
Chief Geologist.

REPORT OF DR. T. C. CHAMBERLIN.

U. S. GEOLOGICAL SURVEY,
DIVISION OF GLACIAL GEOLOGY,
Madison, Wisconsin, July 1, 1891.

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, 1891.

Mr. Warren Upham has been occupied during the entire year in the preparation of manuscript and maps relating to his field work of previous years. The larger part of his time has been given to a monograph on the glacial Lake Agassiz, which is well advanced toward completion. In the earlier part of the year, he finished his report upon the extension of Lake Agassiz north of the international boundary, based upon field work performed under the joint auspices of the geological surveys of the United States and Canada. The duplicate copy of this report furnished the Canadian survey was published as part of the annual report of the Survey for 1888–'89, being entitled "Report of exploration of the Glacial Lake Agassiz in Manitoba" and comprising 156 pages, with a plate of sections and two maps.

Near the end of the year the altitudes determined by railroad surveys and other means in the area of Lake Agassiz and an extensive region adjoining, which Mr. Upham had compiled in connection with his own determinations of the heights of the ancient lake beaches and deltas, have been published as Bulletin No. 72, entitled "Altitudes between Lake Superior and the Rocky Mountains." A considerable part of Mr. Upham's time, during several months, was occupied in repeated verifications of the altitudes given and in arranging the material and in proof-reading the text.

Prof. R. D. Salisbury was engaged in field work during the most of July, all of August, and the earlier part of September, in a special study of the relations of the glacial drift, the loess deposits, and the orange sands in the vicinity of the Mississippi and Ohio Rivers, in southern Illinois, Missouri, Kentucky, and Indiana. The special purpose of the study was to determine the connection of the loess deposits with the drift and their contemporaneity, and to settle the question whether the orange sands are continuous with any portion of the drift or are entirely distinct from it in time of deposition and in mode of origin. In the latter part of December and the first of January, about two weeks were spent in a critical restudy of several localities for the purpose of obtaining more complete and accurate data and for verification. The latter portion of April and the whole of May and June were given to field work in the same general region. The Illinois River was examined from the vicinity of its great bend to its mouth with special reference to the connections and relations of the loess sheets and the gravel terraces of the river valley. The Mississippi Valley, between the mouth of the Missouri and Rock Island, was studied, and the relations of the orange-sand deposits, the loess sheets, and the terraces of the later glacial epoch were determined. Some time was also spent in establishing the character of a newly discovered driftless area in the counties of Calhoun and Pike, Illinois. The relations of the three formations mentioned above were studied in the Ohio Valley between Louisville and Covington.

At the beginning of the fiscal year Mr. Frank Leverett was engaged in mapping the several moraines of the western limb of the Scioto ice-lobe and in tracing each moraine, so far as possible, into connection with its correlative in the Great Miami lobe. This was, in effect, the working out of the evolution of ice-lobation for the region. In the latter part of April the more complete tracing out of the details of the ice-lobation of the Grand River region was undertaken, and the most of August and September and a part of November were occupied in this work. The area included in the study embraces northeastern Ohio, northwestern Pennsylvania, and the southwestern corner of New York. The differentiation of the earlier from the later drifts and the working out of the later phases of lobation and the outline of the ice after the lobe had entirely disappeared were embraced in this study, and certain important relationships of the moraines to ancient lake beaches determined. The latter part of October was employed in a study of the interlobate tract lying between the Grand River lobe and the area of the Scioto glacier. In November the outer moraine of a sublobe of the Scioto glacier lying east of the main lobe, in the region between Canton and Mansfield, Ohio, was traced out and several later moraines of the Scioto lobe proper were traced across the Scioto basin westward to the meridian of Lima.

Field work was suspended November 25. The winter season was given to the preparation of a bulletin on the Grand River Glacier, which was essentially completed, and a bulletin upon The Scioto Glacial Lobe, which reached an advanced stage, but which can be made complete only after some additional field work. An article for the American Journal of Science was prepared upon the "Pleistocene glacial plains of western Pennsylvania."

Prof. James E. Todd has essentially completed the preparation of his manuscript report upon the glacial deposits of southern and central Dakota and northeastern Nebraska. His field work was limited to a few days of review work in the latter part of August and in the latter part of May.

Mr. I. M. Buell did a limited amount of field work in extension of his tracings of the bowlder drift from the crystalline outcrops of central Wisconsin, as previously reported.

My own service on the Survey has been confined chiefly to administrative duty and to field consultation with Prof. Salisbury respecting the

Pleistocene and pre-Pleistocene deposits along the Ohio and Mississippi Rivers in Indiana, Kentucky, and Illinois.

Very respectfully submitted.

T. C. CHAMBERLIN,
Geologist in charge.

Mr. G. K. GILBERT,
Chief Geologist.

REPORT OF MR. W. P. JENNEY.

U. S. GEOLOGICAL SURVEY,
DIVISION OF ZINC,
St. Louis, Missouri, June 30, 1891.

SIR: I have the honor to make the following report of the work under my charge for the fiscal year ending June 30, 1891.

During the first half of the year I was employed at Washington, District of Columbia, examining the material collected the preceding season, and in the preparation of a preliminary report on the deposits of lead and zinc ores in southwest Missouri.

Accompanied by my assistant, Mr. C. E. Kloeber, I left Washington February 1, 1891, and resumed field work, proceeding first to Little Rock, Arkansas, for the purpose of making a comparative examination of the mines of argentiferous lead and zinc occurring in the belt of elevated country stretching from the vicinity of that city westward to Indian Territory. Having completed this investigation of the Arkansas ore deposits, I commenced a detailed investigation of the deposits of zinc and lead ores in the southwestern part of Missouri, this field work being in progress at the close of the fiscal year.

Mr. C. E. Kloeber accompanied me in the work in the field from February 1 until May 31, 1891, when he was compelled by ill health to return to Washington, District of Columbia, his place being filled for the balance of the year by Mr. Richard McCullock.

I desire to express my great indebtedness to Prof. H. S. Williams, of Cornell University, paleontologist of the Geological Survey, for assistance given in the determination of the stratigraphy of the region under investigation. From Prof. J. C. Branner and assistants, of the Arkansas State survey, I received many courtesies and much information of value in the investigation of the mines of that section. To Mr. David White, of the U. S. National Museum, I am indebted for a report on fossil plants collected from certain deposits of the age of the later Coal Measures in Jasper County, Missouri.

Respectfully submitted.

W. P. JENNEY,
Geologist in charge.

Mr. G. K. GILBERT,
Chief Geologist.

REPORT OF MR. A. C. PEALE.

U. S. GEOLOGICAL SURVEY,
MONTANA DIVISION,
Washington, D. C., July 1, 1891.

SIR: I have the honor to submit the following report of operations of the Montana Division for the year ending June 30, 1891:

FIELD WORK.

The first field work of the year was done at Great Falls, on the Missouri River, where three days (July 18 to 21) were spent with Mr. F. H. Knowlton, of Mr. Ward's division, in the examination of the Kootanie beds exposed near there in the banks of the river. An attempt was also made to determine the relations of these beds to the sand coulée coal-beds, but the time at our disposal was too limited to make any satisfactory correlation or identifications. A collection of fossil plants was obtained from three horizons of the Kootanie beds near Great Falls.

From Great Falls we proceeded to Bozeman, where the camp was established July 23. During the previous field season it was found necessary to leave unfinished an area of about 50 square miles in the extreme southwest corner of the Three Forks sheet. The last week of July and the first two days of August were devoted to the working of this area, which is about 75 miles from Bozeman, but to reach which necessitated our traversing about 30 miles on the adjacent Dillon sheet.

The work was satisfactorily accomplished, and after returning to Bozeman the main work of the season was begun August 7, in the southeastern quarter of the Three Forks sheet. This included an area of about 864 square miles of mountainous country, entirely unsettled and without roads, through the central part of which the Gallatin River flows on its way from the Yellowstone Park to the Missouri River. Its eastern and western tributaries rendered access to the adjacent country comparatively easy, and it was all examined and mapped geologically by the end of September, thus completing the atlas sheet. Mr. Knowlton accompanied us throughout the entire trip.

After the return to Bozeman the first week of October was devoted to a flying trip to the Canyon of the Jefferson River above "Three Forks," where an attempt was made to trace two interesting fault lines that occur there. Stormy weather prevented much work being done, and it was reluctantly abandoned until another season.

After shipping the collections of the season, and storing the field property, I proceeded, via Portland, Oregon, to California, where I spent eleven days in work connected with the collection of statistics of Mineral Waters in connection with the Eleventh Census.

Office work was begun in Washington in November and continued until the end of the first week in June, when the field was taken again for the purpose of tracing several fault lines and reviewing certain doubtful areas in different parts of the sheet before finally coloring the atlas sheet geologically.

OFFICE WORK.

My time in the office during the year has been devoted mainly to the collection of Mineral Water statistics for the Eleventh Census. This work has been completed and the results are embodied in an Extra Bulletin (No. 4), entitled "Mineral Waters," published by the Census Office, and will also form a part of the final report on the Mineral Resources of the United States, by Mr. David T. Day.

The manuscript on the "Paleozoic Section in the vicinity of Three Forks, Montana," has also been revised, and a biographical sketch of Dr. F. V. Hayden, with bibliography of his published writings, has been prepared and will probably be published as a Bulletin of the National Museum. These, together with routine office work, occupied all my time from November until June that was not devoted to the work for the Census.

Very respectfully,

A. C. PEALE,
Geologist in charge.

Mr. G. K. GILBERT,
Chief Geologist.

REPORT OF MR. ARNOLD HAGUE.

U. S. GEOLOGICAL SURVEY,
YELLOWSTONE NATIONAL PARK DIVISION,
Washington, D. C., June 30, 1891.

SIR: I have the honor to transmit herewith the following report of operations conducted under my charge during the year ending June 30, 1891.

FIELD WORK.

In this division field work has been confined for the most part to the country lying north of the Yellowstone National Park, situated between the forty-fifth and forty-sixth parallels of north latitude and the one hundred and tenth and one hundred and eleventh meridians west from Greenwich. The area thus defined is embraced within a single map of the geological atlas, and designated the Livingston sheet. The forty-fifth parallel marks the boundary line between the States of Montana and Wyoming.

In accordance with instructions, Mr. Joseph P. Iddings left Washington the latter part of last June, for Bozeman, Montana, to outfit two parties for a season of field work. Mr. Walter H. Weed joined Mr.

Iddings on June 30. All necessary preparations having been completed, both parties, one under Mr. Iddings, the other under Mr. Weed, left Bozeman July 7, for the field of survey.

Early in July Mr. Louis V. Pirsson, of the Sheffield Scientific School of Yale University, left New Haven to become a member of Mr. Iddings's party as an assistant in geology, having already in the previous year rendered valuable aid as a volunteer in field work. At the same time Mr. W. Preston Redmond, of New Jersey, joined the party of Mr. Weed as volunteer assistant. Both gentlemen remained with the parties till the close of the season in the autumn, and were of great assistance in the prosecution of the work.

Mr. Iddings was engaged throughout the entire season in the higher and more rugged portions of the Snowy Range, a grand group of mountains forming the principal physical feature of the country north of the Park. The Snowy Range may be considered as an extension northward of the Absaroka Range, and is sharply defined on the south, west, and north, by the Yellowstone River. Mr. Iddings's time was mainly devoted to investigating and mapping the crystalline schists and gneisses which form the nucleus of an old range, and the later Tertiary volcanic rocks breaking through them. The volcanic rocks, which by their vast accumulations bury nearly everything beneath them for nearly one hundred miles in the Absaroka Range, gradually die out in the Snowy Range.

Considerable time was given to an examination of the mineral developments found in the more elevated portions of the range, near the headwaters of the Boulder River, a broad mountain torrent, which running northward empties into the Yellowstone east of Livingston. Owing to the high altitude of the mines, but little work has been accomplished, although the occurrence of precious metals has been known for many years. The season is short, the obstacles to steady development many; consequently the miners have, in a great measure, temporarily abandoned the field.

All the necessary field work, including the mapping of the different volcanic areas in the Snowy Range, was completed by the middle of October.

To Mr. Weed was assigned the duty of studying the upturned sedimentary beds which form outer ridges encircling the crystalline area on the north and west. These sedimentary beds of Paleozoic and Mesozoic age, extend northward as far as the broad valley of the Yellowstone.

Mr. Weed also explored the belt of mountains lying between the Yellowstone Valley and the Gallatin River to the westward, and stretching from the line of the Northern Pacific Railroad southward to Electric Peak. As this country adjoins the region which Dr. A. C. Peale has so carefully studied, it was thought best for Mr. Weed and Dr. Peale to go over together the contiguous territory in order to compare and correlate the results of their observations. This was accomplished in a manner satisfactory to both of them.

In addition to his other duties, Mr. Weed devoted as much time as possible to questions relating to the glaciation of the higher country on both sides of the Yellowstone River, and to the Pleistocene history of the valley. In the prosecution of this latter work he spent between two and three weeks studying the formations in the valley all the way from Gardiner, where the river leaves the mountainous country of the Park, to Big Timber, east of Livingston.

I instructed Mr. Weed to give special attention to the examination of the Cinnabar and Bozeman coal fields, both of which were situated within the area of the Survey. The Cinnabar field lies on the west side of the Yellowstone Valley, just north of the Yellowstone Park. Although the coal area is limited in extent, the quality is excellent, and the output increasing every year. The Bozeman field lies about forty miles to the north of the Cinnabar field, and has been worked longer than any other coal area in Montana. It was first visited by the geologists of the Hayden Survey, but the seams were never thorougly explored until the organization of the Northern Transcontinental Survey, for whom Mr. George H. Eldridge made an examination which resulted in the opening of the mines at Timberline and Cokedale. Since that time large amounts of coal have been taken out.

Two weeks' time was given to an examination of the geyser basins in the Yellowstone Park, for the purpose of making the usual annual study of the changes taking place in the hot springs from year to year, a subject of much geological importance and one perfectly familiar to Mr. Weed from his experience in previous years. After spending a few days in each of the principal hot spring areas, including the Upper Geyser Basin, Lower Geyser Basin, Norris Geyser Basin, and Mammoth Hot Springs, he returned to his other field of work.

I purposed taking the field myself by midsummer, but owing to a pressure of other duties which delayed me for a longer time than was at first anticipated, I decided to remain in the East, directing the work in the field from here.

Both branches of the Survey closed their labors about the middle of October, the severity of the weather, and incessant storms accompanied by heavy snow-falls, preventing their remaining out till November 1, as had been planned.

Mr. Iddings and Mr. Weed returned to Washington, after a successful season, early in November.

OFFICE WORK.

Since the close of the field season a considerable portion of the time in the office has been occupied in recording the results obtained in the field and in preparing a preliminary geological map of the country on both sides of the Yellowstone River north of the Yellowstone Park. This enables us to map the geological formations through which the Yellowstone River runs, from its source in the great lake on the Park

Plateau to the broad Cretaceous plains east of Livingston. This work necessarily required much time, as it embraced nearly every branch of geological inquiry and included rocks of all ages, from the Archean up to recent Pleistocene deposits. The areal geology has been laid down over the greater part of the Livingston sheet, and during the next season the unsurveyed areas can easily be completed. The work on the monograph and map of the Yellowstone Park has progressed very materially. All preliminary petrographical studies upon the igneous rocks have been completed, and but little remains to be done in the way of chemical investigation, at least on the lines as originally laid down.

During the year I have completed the monograph on the geology of the Eureka district, and will submit it for publication early in the summer. The sedimentary beds exposed at Eureka offer the most complete record of Paleozoic rocks, from the Lower Cambrian to the Upper Coal measures, of any area in the Great Basin. Breaking through these sedimentary beds occur a great variety of Tertiary igneous rocks, the region having been one of great volcanic energy. The monograph is mainly a study of these two classes of rocks and their relations to each other. A geological atlas accompanies the monograph, the area surveyed embracing twenty miles square.

After Mr. Weed's return from Montana, I was anxious that the principal results of his examination of the Cinnabar and Bozeman coal fields should be prepared for publication and made accessible to all interested in the geology of the Western coal areas. These results were recorded in an important paper entitled: "The Cinnabar and Bozeman Coal Fields of Montana," which Mr. Weed read before the Geological Society of America, December 31, 1890. In this article he points out the fact that the coals of the two fields were identical in age and probably occur near the base of the Laramie sandstones. The Bozeman coal rocks were traced over a large area, extending northward for nearly twenty-five miles from the present coal developments. Their great value lies in the close proximity of the mines to the main line of the Northern Pacific Railroad.

For the greater part of the winter Mr. Iddings was engaged in the completion of his report upon the eruptive rocks of Electric Peak and Sepulcher Mountain in the Yellowstone National Park. This work constitutes a chapter in the geological literature of the Park region. The article has been submitted for publication in the Twelfth Annual Report of the Director of the U. S. Geological Survey.

In conjunction with Mr. C. D. Walcott, Mr. Iddings has been studying the pre-Cambrian lavas of the Grand Canyon of the Colorado from material collected by the former on the occasion of his visit to that region. They propose to publish a joint paper on the subject, which is one of much geological interest, as very little is known as to the earlier lavas in the Cordillera. Mr. Iddings also presented a paper to the Philosophical Society of Washington in April on "Spherulitic Crystallization," embodying the results of a study of additional material obtained from Obsidian Cliff, which was collected for the Educational Series of Rocks now in course of preparation by the Survey.

During the last year Mr. Iddings's article "On a Group of Volcanic Rocks from the Tewan Mountains, New Mexico; and on the occurrence of Primary Quartz in certain Basalts" has been published as Bulletin No. 66 of the Survey.

In addition to other publications in connection with the work in the Yellowstone Park Division, I should mention an interesting communication on the mineral, mordenite, published in the American Journal of Science for September, 1890, by Mr. Louis V. Pirsson, a volunteer assistant in the field. Owing to the very high ratio of the silica to the bases, the existence of mordenite as a distinct species has always been questioned, especially as it had never been found in distinct crystals. It was supposed to be a mixture of some undetermined zeolite with more or less silica. The finding of this mineral, crystallized, encrusting the cavities in vesicular basalt, is a matter of much interest to both geologists and mineralogists.

Very respectfully, yours,

ARNOLD HAGUE,
Geologist in charge.

Mr. G. K. GILBERT,
Chief Geologist.

REPORT OF MR S. F. EMMONS.

U. S. GEOLOGICAL SURVEY,
COLORADO DIVISION,
Washington, D. C., June 30, 1891.

SIR: I beg to submit herewith a report of work done in the division under my charge during the fiscal year 1890–'91.

FIELD WORK.

In pursuance of the policy adopted by the Director some time ago of pushing to publication work already in hand as rapidly as consonant with accuracy and thoroughness, no new field work has been undertaken during the year, but portions of the summer months were devoted by the various members of the division to such work, in fields already occupied, as seemed important for the completion of data already gathered, especial regard being had to the economic bearing of the results of our geological investigations.

Leadville.—As ten years have now elapsed since the completion of the field work of my monograph on the geology and mining industry of the

Leadville mining region, during which time underground explorations have been carried on with a rapidity unknown in any other part of the world, resulting in the production of over $150,000,000 worth of silver and lead, and as thereby a great underground area has been made accessible to observation and study, it seemed important that these mine workings should be examined before they became inaccessible through abandonment, in order that the geological facts disclosed by them might be put on record for future scientific use and that it might be seen whether the theories of ore deposition deduced from the original observations were borne out by these facts, or required modification. The mining community of Leadville was extremely anxious that such an examination should be undertaken, considering the present time a critical one in the development of the region, and they offered every facility in their power in furtherance of the work.

The investigation of the underground geology of mining districts is, in its nature, very much more expensive than other geological investigations carried on by the Survey, and the allotment of work for the year was such that but a limited amount of money could be devoted to this investigation. I was authorized, however, to accomplish what I could with this amount. The months of August and September were spent by me in Leadville, during which time I personally examined the underground workings of the larger mines that were accessible and made full notes upon the geological phenomena disclosed by them, with especial reference to the extent and form of the many intrusive bodies of eruptive rock and of the faults that can not be seen at all upon the surface, since upon their determination the probable location, extent, and distribution of the ore in the regions as yet unexplored is largely dependent.

For this determination an accurate location of the various drifts, not only with reference to the mining property on which they have been driven, but with regard to the topographical features of the regions, was quite indispensable. It was a work the magnitude of which could not be foreseen and which was necessarily very expensive, since it practically involved making a large map of the underground workings of the whole region. In gathering material for this map I was most cordially assisted by the various mine owners of Leadville, who were flattering in their appreciation of the value of the work formerly done by the Survey in this region upon which their explorations since its completion had been based. Especial acknowledgments are due to Messrs. A. A. Blow and Charles J. Moore, mining engineers, who have studied closely the geological structure, as disclosed by successive mine openings made in the last ten years. To the latter was intrusted the delicate and laborious task of compiling, connecting, reducing to common scale, and platting upon the general maps, the principal underground workings of the various mines.

In gathering my data I was faithfully assisted, to the extent of their ability, by my stenographer, Mr. H. B. Hitz, and by Mr. McCulloch, mining student at the Washington University of St. Louis. During the last weeks of September I had also the valuable assistance of Mr. W. Cross, who, at my request, made a brief petrographical examination of the eruptive bodies of Breece Hill, the only part of the region where our previous geological determinations will require any essential modifications.

As the gathering of the data for the map could not be completed during the summer, it has been continued during the winter by Mr. Moore, at such times as could be spared from his professional duties; and the additional information thus obtained has been from time to time incorporated upon the general map. From this map I am constructing underground sections which are subject to modification with each contribution of new material. Hence I have been unable in the press of other duties to complete, as I had hoped to do, sufficient graphical data upon which to base the principal additions and modifications of the original report which are required, and the generalizations to be deduced therefrom with regard to the theory of ore deposition in the district, and the best methods for explorations of new ground. As this report can hardly be made ready for publication during the next summer it may be found advisable for me to make another brief visit to the district to gather some additional data before the final writing up of my report.

Elsewhere.—Mr. Whitman Cross spent the months of July, August, September, and a part of October in gathering additional data in fields already examined. These were: In the Denver Basin region during the first half of July; at Canyon City with Mr. Stanton determining points of the structural geology, July 15–17; at Silver Cliff, July 17 to 25, and one week in September, studying points in structural geology suggested by office work, and the openings afforded by the deep shaft of the Security mine; July 26 to September 5 in the Gunnison region, studying geological problems suggested by office work, and determining the geological horizon of supposed rich ore deposits newly discovered in the Tin Cup district; and the last half of September at Leadville, and in October in the Middle Park, examining deposits supposed to correspond to those in the Denver Basin. This last examination was cut short by early snow-falls.

Mr. G. H. Eldridge spent the greater part of the months of September and October in Colorado; 1st, in studying the recent economic developments in the Denver Basin, especially with regard to coal, clays, and building stones; 2d, in bringing the data on artesian wells up to date; 3d, in making an examination of the Florence oil field near Canyon City.

Mr. T. W. Stanton was allowed by Dr. C. A. White to make for me, in the month of July, a further study of the Paleozoic strata exposed at Canyon City with especial reference to the occurrence there of fish remains in strata of Lower Silurian age, a lower geological horizon than any in which they had hitherto been recognized.

OFFICE WORK.

The office work of the various members of the division has consisted in the preparation of the following memoirs, now in different stages of readiness for the press:

First. Report upon the Geology of the Ten-Mile and Silver Cliff mining districts.

Second. Report upon the Geology of the Denver Coal Basin.

Third. Report upon the geology of the Southern Elk Mountains.

Fourth. Supplementary report upon the geology of the Leadville district.

Mr. Cross has completed his portion of the two first named reports and is now occupied upon the study of eruptive phenomena of the region covered by the third.

Mr. Eldridge has been mainly occupied upon the preparation of his portion of the Denver Basin report, but has also laid down the geological outlines of sedimentary formations upon the map to accompany the third report. In the month of January, 1891, he was temporarily detailed from this division, and put in charge of an investigation of the phosphate deposits of Florida, upon which he was engaged until the middle of May.

I myself have been mainly occupied upon general chapters of the first report and upon graphical studies for the supplementary report on Leadville.

OCCASIONAL PUBLICATIONS.

The following papers embodying results of immediate interest have been published during the year by members of this division:

Proc. Col. Sci. Soc., 1890. "Geological sketch of the Rosita Hills, Custer County, Colorado," by W. Cross.

Amer. Jour. Sci., June, 1891. "On Alunite and Diaspore from the Rosita Hills, Colorado," by W. Cross.

Bull. Phil. Soc. Wash. Vol. XI, June, 1891. "Constitution and origin of spherulites in acid eruptive rocks," by W. Cross.

Very respectfully,

S. F. EMMONS,
Geologist in charge.

Mr. G. K. GILBERT,
Chief Geologist.

REPORT OF MR. J. S. DILLER.

U. S. GEOLOGICAL SURVEY,
CASCADE DIVISION,
Washington, D. C., June 30, 1891.

SIR: Herewith I have the honor to submit the annual report of work done by the Cascade Division during the fiscal year ending June 30, 1891.

FIELD WORK.

Accompanied by Mr. J. Stanley-Brown, I left Washington, District of Columbia, July 1, 1890, and proceeded to Astoria, Oregon, where a day was spent studying the sandstone dikes discovered and described by Prof. James D. Dana while engaged upon the Wilkes exploring expedition in 1843. This study was made for the purpose of comparing the sandstone dikes about the mouth of the Columbia with the extensive series we had discovered in the Sacramento Valley of California.

At Riddles, Oregon, 4 days were spent with Mr. W. Q. Brown examining the fossiliferous Cretaceous strata of the region to determine their relation to one another, to the metamorphic rocks, and to the eruptive masses with which they are associated.

The field material having been removed from Ashland, Oregon, to Red Bluff, California, a party was organized at the latter place, and, with the necessary camp outfit and supplies to subsist the party for a month, proceeded to Susanville by way of Lassen Peak and the Cinder Cone to obtain photographs for illustrating a forthcoming report.

While surveying the Lassen Peak district in 1885–'86, a reconnaissance was made of a portion of the Honey Lake region, but the field was not entered for regular cartographic work until July, 1890. At Susanville the party divided, and Mr. Stanley-Brown, with a wagon, camping outfit, and two men, made a preliminary survey of the country northeast of Susan River as far as Surprise Valley and the Warner range, returning to Susanville in the latter part of August. While on the trip he ascended the following prominent peaks—Hot Springs, Observation, Hat, Eagle, Cottonwood, Cedar, Fandango, Warner, and Bidwell—and made a large collection of the eruptive rocks of the region.

Later in the season Mr. Stanley-Brown began detailed cartographic work between Susanville and Eagle Lake, and with Dr. W. H. Dall joined in a search for fossils in the supposed Miocene strata about the northern end of the Sierras.

July 28, without a camping outfit and relying upon the hospitality of the people, I began cartographic work upon the eastern escarpment of the northern end of the Sierras, and soon crossed over to study the fossiliferous rocks in the neighborhood of Indian and Genesee Valleys. I was greatly assisted by Mr. Cooper Curtice, who had already spent some time in that region and collected a large number of fossils. He worked much of the time within the Paleozoic portion of the section, to which his investigations have made very important additions, greatly aiding in the analysis of the complicated stratigraphy.

From August 23 to September 14 I had the valuable association and cooperation of Prof. Alpheus Hyatt, who made large collections of fossils from the numerous horizons within the Jura-Trias while I studied the stratigraphy. It was soon found that the scale of the topographic map—4 miles to 1 inch—was entirely inadequate to admit of the desirable detail in mapping the various geologic formations. On this account more attention was devoted to the general features of the country, to prepare the way for definite cartographic work when a new topographic map on a sufficiently large scale should be prepared. The importance of this field as a source of knowledge concerning the paleontology and stratigraphy of the rocks composing the Sierras can scarcely be overestimated.

Immediately after the departure of Prof. Hyatt, I was joined by Dr. W. H. Dall and Mr. Stanley-Brown's party. In certain deposits having a wide distribution upon the Sierras between Honey Lake and Indian Valley Miocene plants occur quite abundantly. The object of our search in these strata was to discover animal remains affording supplementary evidence concerning their age. We examined the rocks at four widely separated localities, but failed to find the desired fossils.

The party disbanded and returned to Washington, District of Columbia, October 20.

Accompanied by Mr. E. G. Paul I, again left Washington June 2, 1891, for field work in northern California. En route I visited Shoshone Falls of Snake River in Idaho, and I stopped also at Riddles, Oregon, for the purpose of initiating regular geologic field work in that region by Mr. W. Q. Brown. Mr. Brown having previously done considerable work in the valley of Cow Creek, which lies just outside of the district covered by the topographic maps of the Geological Survey, we proceeded southeastward from the unaltered rocks of the Shasta group, across the belt of the metamorphics forming the Rogue River Mountains, to the Chico sandstones and shales of Grave Creek. Beginning at the California line, Mr. Brown then took up the Ashland district of Rogue River Valley, and continued work in that region until the close of the fiscal year.

From Ashland, Oregon, I went to Taylorsville, California, where the remainder of the fiscal year was spent at regular cartographic work upon the area covered by the special topographic maps at that time in course of preparation by Mr. A. F. Dunnington.

OFFICE WORK.

Aside from the administrative and other duties connected with the petrographic laboratory, to which reference will be made, much of my time during the winter was devoted to the elaboration of field notes and studying the collections made during the last field season in northern California.

At the request of Dr. C. A. White I prepared and published in the American Journal of Science, December, 1890, volume 40, pages 476–478, a brief note on the measured sections of Cretaceous rocks upon the northwestern border of the Sacramento Valley.

With the assistance of Mr. De Lancey Gill I completely revised the illustrations of Bulletin 79. The proof has since been read, and the bulletin will be issued in a few weeks.

During the winter Mr. Stanley-Brown was engaged chiefly in plotting his observations and studying his collections. He carefully investigated a fine specimen of bernardinite, and prepared a paper which was read before the Philosophical Society of Washington and afterward published in the American Journal of Science for 1891, volume 42, pages 46–50 He examined and described a specimen of gold-bearing sand collected by Mr. Russell in Alaska, and the results of his study are published as Appendix C to Mr. Russell's report in the National Geographic Magazine, volume 3, 1891, pages 196–198.

Early in May Mr. Stanley-Brown was appointed special agent of the Treasury Department to visit the seal islands of Alaska, and temporarily left the Geological Survey.

PETROGRAPHIC LABORATORY.

While in the office most of my attention has been devoted to the affairs connected with the petrographic laboratory. Three lines of work have been carried on: (1) The preparation of the Educational Series of rocks, (2) the examination of specimens sent to the laboratory for determination, and (3) the preparation of thin sections and polished specimens of rocks for study.

The preparation of the Educational Series of rocks has steadily progressed. Two hundred and fifty specimens of each of the following kinds of rocks have been added to the series within the fiscal year: Breccia from seven miles northeast of Leesburg, Virginia; small diabase dike from Williamsons Point, Lancaster County, Pennsylvania; sericite schist from Ladiesburg, Frederick County, Maryland; quartz schist from Setter's Ridge, Baltimore County, Maryland; vein quartz from Castleton, Harford County, Maryland; silicified wood from the Yellowstone National Park; chalk and flint from near Austin, Texas, and argillite with roofing slate from Monson, Maine.

I desire to acknowledge the valuable aid rendered by Dr. George H. Williams in procuring the specimens in Maryland, by Mr. F. H. Knowlton in collecting the silicified wood, by Prof. R. T. Hill in obtaining the chalk and flint, by Prof. W. S. Bayley, and especially by Mr. J. B. Matthews in presenting a series of well trimmed specimens of argillite and roofing slate.

All of the material from Maryland, Virginia, and Pennsylvania was collected by Mr. W. S. Hunnell alone, excepting the breccia, in which he was assisted by Mr. Paul.

Arrangements are being made for the collection of syenite, hematite, brick clay, hornfels, and stalactites, which, with a few others already provided for, will complete the series. About 5,000 of the specimens previously collected were trimmed, chiefly by Mr. Hunnell, and a much larger number were marked and prepared for final numbering.

The preparation of the bulletin to accompany the Educational Series of rocks is well advanced. In this I am greatly assisted by Messrs. W. S. Bayley, J. P. Iddings, Whitman Cross, George H. Williams, J. E. Wolff, Waldemar Lindgren, J. Francis Williams, and F. H. Knowlton, who are describing the rocks which were collected in their respective fields of study. My acknowledgments are especially due to Mr. W. Merriam, of Madison, Wisconsin, who has taken a series of photographs for illustrating the bulletin, and to Prof. F. W. Clarke, chief chemist of the Geological Survey, for a large number of analyses of rock.

Among the various rock specimens submitted to the petrographic laboratory for study and report or suggestion, may be mentioned a fragment from a sandstone dike in Texas, sent by Prof. R. T. Hill; a remarkably interesting micaceous peridotitic rock from the Flannary dike, Crittenden County, Kentucky, sent by Mr. E. O. Uhlrich, of the Kentucky Geological Survey; several eruptive rocks of New York, by Prof. J. F. Kemp; basalt from the guano deposits of the West Indies, by Prof. C. H. Hitchcock; supposed auriferous and argentiferous perlite from the Black Rock, Nevada, by Mr. E. V. Spencer; banded barite, by Prof. C. Luedeking; numerous specimens of travertine from New Mexico, by Hon. A. Joseph, and a collection of lava and other rocks made by Prof. Cleveland Abbe, of the Weather Bureau, and Mr. E. D. Preston, of the Coast and Geodetic Survey, while engaged upon the scientific expedition to the west coast of Africa.

Mr. W. S. Hunnell has had immediate charge of much of the work of the petrographic laboratory, especially the preparation of thin sections by Messrs. Herman Ohm, Fred. Ohm, and Paul. During the year 4,853 thin sections, some of which were extra large, were made in the laboratory. In doing this work 680 specimens were sawed and 40 specimens were sawed and polished.

Very respectfully, your obedient servant,

J. S. DILLER,
Geologist in charge.

Mr. G. K. GILBERT,
Chief Geologist.

RFPORT OF MR. G. F BECKER.

U. S. GEOLOGICAL SURVEY,
CALIFORNIA DIVISION,
San Francisco, Cal., July 1, 1891.

SIR: During the fiscal year 1890–91 the operations of the California Division have lain mainly in the Gold Belt of California, or on the western slope of the Sierra Nevada, between the parallels of 37° 30′ and 40°. The entire region under investigation comprises twenty atlas sheets on a scale of 1:125,000.

Messrs. Turner and Lindgren have continued to devote themselves chiefly to the areal geology of this region, as in former years. They have accumulated a vast mass of data as to the distribution of the rocks throughout the entire region, maps of the Wheeler Survey having been used to record explorations in advance of the preparation of contour maps. The work is farthest advanced, however, in that part of the area which possesses the greatest industrial importance, and seven of the sheets are now so nearly completed that I hope to submit them for publication at the close of the present field season. The Marysville sheet is substantially finished; the Nevada City and the Colfax sheets are in a very advanced condition; and the Truckee sheet, which is relatively simple, is partly done. These four sheets are on the same west to east tier. The Sacramento and the Placerville sheets, which lie directly south of the foregoing, are almost finished, and work on the Jackson sheet (next south of the Placerville) is progressing rapidly. Portions of several other sheets are fully mapped, but none excepting those enumerated above can be completed for publication this autumn. We hope to be able hereafter to present three or four sheets for publication each winter until that portion of the work is done.

To a certain extent any sheets of the Gold Belt map which may be published at present will be subject to correction. The geological areas will be as accurately outlined as the scale of the map will permit, but the nomenclature adopted cannot be regarded as final. This is due to the imperfection of the paleontological evidence throughout the region. Fossils are extremely rare, and when they are found they are very apt to turn out too imperfect for identification or to belong to undescribed species or sometimes to represent animals with so great a time range as to deprive them of much value for the classification of the strata in which they occur. This uncertainty extends even to the auriferous gravels, which, though deposited for the most part before the glaciation of the Sierra began, may yet prove to be in part coeval with the Quaternary of the Eastern States. On the maps now in preparation the commencement of glaciation is assumed as coincident with the beginning of the Quaternary. Should this assumption prove fallacious, any exact delineation of the Pleistocene on our maps would appear hopeless.

In order to reduce the uncertainties of classification to a minimum, I have availed myself of the services of an expert collector in addition to the regular members of my division. Dr. Cooper Curtice, who was for some time a member of Mr. Walcott's division, has spent three months during the year in portions of the Gold Belt where discoveries of fossils might be hoped for, devoting himself exclusively to the search for organic remains. A fair measure of success has attended his efforts, particularly in Plumas County. Within the last month he has also made important discoveries near Auburn.

During the last season my own attention was devoted to several of the problems arising in the study of the Gold Belt. One of these is the division of the Shasta group of the Cretaceous, and allusion was made to it in my last annual report. My conclusions were communicated last winter to the Geological Society in a paper discussing the relative age of the *Aucella*-bearing beds of Mariposa, of similar beds of the Coast Ranges, of the beds of Cottonwood Creek in Shasta County, and of beds of the Queen Charlotte Islands studied by Messrs. Dawson and Whiteaves, and comparing them with the European Gault.[1] I also examined into the subject of the occurrence of human remains beneath Tuolumne, Table Mountain, and became acquainted with two important pieces of evidence theretofore unpublished. This evidence I have announced in a paper reviewing the entire subject, especially the question of authenticity and the age of the gravels.[2]

I spent the greater part of the last season in an investigation of the structure of the Sierra. The pehnomena which received most attention were the numbreless faults by which the higher portion of the range is traversed. They were found to admit of classification into definite systems and to indicate the direction of the forces which produced them. This study has been published, and, in connection with it, the modeling of the range was also discussed.[3]

During the winter my attention was mainly given to experiments designed further to elucidate the action of rock masses under intense stress, such as that to which the mass of the Sierra has been subjected. The discussion of these experiments is not yet completed.

The month of June I have spent in studying the late formations of the Sacramento Valley. A portion of the gravels of the lowest foot hills are later than the beginning of glaciation on the Sierra, and careful study has been needful to ascertain how to draw the line between them and the adjoining older deposits. At the same time I have taken up the study of the so-called ferruginous "hardpan," an impervious and most deleterious subsoil widely distributed in the eastern Sacramento Valley.

[1] Notes on the early Cretaceous of California and Oregon, by George F. Becker. Bull. Geol. Soc. Amer., vol. 2, pp. 201-208.

[2] Antiquities from under Tuolumne Table Mountain in California, by George F. Becker. Bull. Geol. Soc. Amer., vol. 2, pp. 189-200.

[3] The structure of a portion of the Sierra Nevada of California, by George F. Becker. Bull. Geol. Soc. Amer., vol. 2, pp. 49-74.

I have hopes that its geological and chemical investigation may lead to at least a partial remedy.

Mr. Turner has published an interesting study of the lake beds at Mohawk on the middle fork of the Feather River, discussing their relations to the great andesite eruptions and describing the system of faults by which they are intersected.[1] He also published a paper on the geology of Monte Diablo, describing its sedimentary and eruptive rocks and exhibiting their structure and distribution.[2]

Mr. Lindgren published the results of an investigation on the lithology of the Highwood Mountains in Montana, which was begun some years ago under the Northern Transcontinental Survey. The most important part of this paper is the description of a remarkable eruptive rock of Cretaceous age.[3]

Yours respectfully,

G. F. BECKER,
Geologist in charge.

G. K. GILBERT,
Chief Geologist.

REPORT OF MR. C. D. WALCOTT.

U. S. GEOLOGICAL SURVEY,
DIVISION OF PALEOZOIC INVERTEBRATE PALEONTOLOGY,
Washington, D. C., July 1, 1891.

SIR: I have the honor to present the following report of operations conducted under my charge during the fiscal year ended June 30, 1891:

The personnel of the division consisted of Prof. Joseph F. James, Mr. Ira Sayles, and Mr. John W. Gentry, assistant paleontologists. Besides these, Mr. William P. Rust and Mr. S. Ward Loper were employed as field collectors and temporary laboratory assistants and Prof. Henry S. Williams, of Cornell University, was, as heretofore, attached to the division in connection with a special investigation on the Devonian and Carboniferous groups.

FIELD WORK.

The field operations for the year were (1) the study by Prof. Williams of the Upper Devonian and the Lower Carboniferous horizons of northern Arkansas; (2) a study of the stratigraphy and the collection of the faunas of the Lower Paleozoic rocks of the northern portion of the valley of Lake Champlain; (3) a study of the Lower Paleozoic rocks in the vicinity of Canyon City, Colorado; (4) a study of a section of the Devonian and Carboniferous rocks near Keyser, Mineral County, West Virginia; (5) an examination of certain formations in eastern

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[1] Mohawk lake beds. Bull. Phil. Soc. Wash., vol. 11, p. 385.

[2] The geology of Mount Diablo, California. Bull. Geol. Soc. Amer., vol. 11, p. 383, with maps.

[3] Eruptive rocks from Montana, by Waldemar Lindgren. Proc. Cal. Acad. Sci., ser. 2, vol. 3, pp. 41–57.

Rensselaer County and the northern part of Washington County, New York; (6) the collection of fossils from the Lower Paleozoic in central Kentucky.

Prof. Williams's field work was limited to the special study, during August and September, of the Upper Silurian and Lower Carboniferous formations of Arkansas, with the view of determining their limit and the presence or absence of the Devonian group in this area. Mr. Ira Sayles was engaged in collecting from the Devonian rocks of southern New York, and, in May and June, he measured a section of the Devonian rocks in the vicinity of Keyser, Mineral County, West Virginia, and made a large collection of fossils therefrom under the direction of Prof. Henry S. Williams. Mr. Stuart Weller was engaged in collecting Silurian and Devonian fossils in northern Arkansas and Mr. Gilbert Van Ingen, in southwestern Missouri, for Prof. Williams.

I accompanied Profs. Pumpelly and Van Hise when making an examination, in July, of the contacts of the Cambrian and Algonkian rocks near Fort Ann, Washington County, New York, and of the Algonkian rocks that extend west of Lake George and north as far as Westport, in the Lake Champlain Valley, New York. Prof. Van Hise and myself then proceeded to St. Albans, Vt., to study the Lower Cambrian sections of the township of Georgia. The examination of the Lower Paleozoic rocks in the vicinity of the Canadian and United States boundary, in September, where Messrs. Loper and Rust were making extensive collections of fossils, was followed by a study of a measured section of the Lower Cambrian rocks near North Granville, New York.

A detailed study was made, during the month of December, of the Lower Silurian (Ordovician) section northwest of Canyon City, Colorado, for the purpose of obtaining accurate data upon the geologic position of the oldest vertebrate fossil remains known, and in May, 1891, an examination was made, in connection with Mr. T. Nelson Dale, of Prof. Pumpelly's division, of the Berlin Grit area of eastern Rensselaer County, New York, and, by myself, of a section in the roofing-slate area in the northern portion of Washington County, New York.

Prof. Joseph F. James made a collection of fossils from the Trenton Limestone series in northern central Kentucky, and also examined the rocks of the Cincinnati terrane on the Ohio River.

Mr. William P. Rust was employed as a collector in central New York, also in the upper and lower Champlain Valleys and, in the spring of 1891, at the celebrated Paradoxides locality at Braintree, Mass. Mr. S. Ward Loper also made extensive collections from the Lower Paleozoic, near the Canadian and United States boundary, in northern Vermont.

OFFICE WORK.

The principal work of Prof. Williams was the completion of the correlation essay upon the Devonian and Carboniferous groups. This was transmitted and sent in for publication in February and in June he was engaged in reading the proof. Prof. Williams also made a report to the State geologist of Arkansas upon the Carboniferous material received from him, and a report to Prof. Safford, of Tennessee, upon the question of the geological and paleontological transition from the Silurian to the Carboniferous rocks in Tennessee. This includes the study of the collections obtained by him in northern Arkansas, and the material received from the State surveys of Missouri and Tennessee.

The reading of the proof of the paper upon "The Olenellus Zone in North America," in the Tenth Annual Report, occupied much of my time during July and August. This, in connection with the correlation essay upon the Cambrian group, was the chief office work up to the 1st of March, when the latter was finally transmitted for publication.

In compliance with instructions received from you I left Washington March 5 and proceeded to Ithaca, New York, to examine the collections belonging to the Geological Survey in charge of Prof. Williams, of Cornell University. I then went on to Albany, New York, to study some of the collections of the State Museum, and thence to Cambridge, Massachusetts, where I examined the material of the Geological Survey in the charge of Prof. Alpheus Hyatt and Prof. S. H. Scudder. I next visited New Haven, Connecticut, and made a similar examination of the material in charge of Prof. O. C. Marsh. In New York I visited the School of Mines, Columbia College, for the purpose of examining the material in the charge of Prof. J. S. Newberry, but owing to his absence in the South I was unable to learn very much of it from his assistants. Each of the gentlemen mentioned gave me every facility for examining the collections in their charge, and explained to me their method of recording the material so as to distinguish it from that belonging to their respective museums or to private individuals.

The collections in charge of Prof. H. S. Williams are in the museum building of Cornell University. They are arranged in two rooms in trays and cases, and so separated from the collections of the university that they can be readily distinguished from the latter. Even if the specimens are mixed in trays with specimens belonging to the university or private individuals, for purposes of study or comparison, a distinct green label with its record number readily distinguishes those belonging to the Survey from those of the university, etc. The record numbers, placed upon each green label, were assigned to Prof. Williams from the Geological Survey and National Museum catalogues. Prof. Williams has prepared a card catalogue of all the numbers that he has used, that gives the record of locality, geological formation, collector, date of collecting, and any information that he has relating to the geographic and geologic position of the specimen. A copy of this card catalogue is being prepared to be filed with the records of the Geological Survey.

There are now in Prof. Williams's charge 500 drawers of fossils, the drawers averaging in size 2 feet by 1 foot 6 inches and 3 to 4 inches deep. There are also 13 boxes of duplicates packed and ready for shipment to the Survey whenever they may be required.

The collections in charge of Prof. Alpheus Hyatt, at Cambridge, Massachusetts, are arranged in drawers in a room entirely devoted to their keeping in his private house. The collections belonging to institutions or individuals which are used in the course of his study are kept in another room on the floor above. The collections are in good order, and when it is desired they can readily be taken charge of by the officers of the Survey. The method of recording the specimens is the same as that used by several of the paleontologists of the Survey at Washington, and consists of a round green or yellow label, which is numbered and fastened to the specimen to indicate geographic location and geologic formation, when the latter is known.

The material in Prof. Hyatt's charge is contained in about fifty drawers and includes the collections made since 1888. A copy of Prof. Hyatt's record book will be filed with the Survey.

The collections in charge of Prof. H. S. Scudder are kept in special cases in the laboratory building back of his dwelling house. The specimens are recorded by painting numbers with white paint upon each specimen, which refer to a catalogue kept in a Geological Survey record book. The number of specimens recorded to date is 1,458, and there is a small collection from Florissant, Colorado, not recorded, which will probably bring up the total to 2,000 specimens. There is also some material from the Hayden Survey that will be transferred to the record of the Geological Survey.

The large collections of vertebrate remains in charge of Prof. O. C. Marsh, at New Haven, Connecticut, are kept in the fire-proof Peabody Museum building and in a large storage shed adjoining. The method of recording is somewhat different from the other collections, but it is very thorough and complete.

In the field where the specimens are collected a label is placed inside of each box as it is packed. On this "U. S. Geological Survey" is printed in bold letters. On the outside of the box "U. S. Geological Survey" is plainly marked before it is shipped. When received at Prof. Marsh's laboratory, in New Haven, a record is made of each box received, and to each an entry number is assigned. This number is at once recorded on the box and, when the box is opened, on the label and on each and every specimen contained in the box with an oil paint. When it is necessary to remove a number, in working out specimens, from the matrix, the number is copied on some other portion of the rock or directly on the fossil before it is removed from the other portion. This number is the record of locality, stratigraphic position, and history of discovery; additional information is added from time to time under the number in the record book. This includes the identification of the genus and species and any data that may be of importance. The removal of the number from any specimen at once deprives it largely of scientific value, and it is to the interest of every one working on the collections to have it kept intact. When the final work is done and the specimen is identified, labeled with its name, and ready for exhibition, it receives a catalogue number. The old number, however, still follows it in the record of the latter.

The record of the entry numbers is kept in duplicate, and Prof. Marsh is now preparing another duplicate set, to be filed with the Geological Survey. This will show the number of boxes of specimens received from 1882 to 1891. The laboratories and storage rooms provided by the Yale University Museum represent a floor space of over 9,000 square feet, for which the Geological Survey does not pay rent. In addition to the collections at New Haven there are seventy boxes of vertebrate fossils stored in the Armory building in Washington and a collection is now being prepared for exhibition in the U. S. National Museum.

I visited the School of Mines, New York City, where the collections in charge of Prof. J. S. Newberry are kept; but, owing to his severe illness and absence in the South, I was unable to obtain any data upon which to base a report. He has in his charge the Hayden collection of fossil plants from Florence, Colorado, which contains about 1,000 specimens, also a large lot of Puget Sound plants, and the collection made by Dr. C. A. White and Maj. J. W. Powell, in the Green River group.

The collection of fossil plants in charge of Prof. Wm. M. Fontaine, of the University of Virginia, is now being packed by him, and will be shipped to the Survey within a short time.

The result of my observations, as a whole, indicates that the collections in the charge of paleontologists not in the city of Washington are in good condition, and in the event of the death or disability of the persons in whose charge they are could be readily identified, packed, and shipped to the Geological Survey at Washington.

Considerable time was given during the last three months of the year to the preparation of a paper for the Twelfth Annual Report entitled "The North American continent during Cambrian time" and the latter part of June to reading the proof of the correlation essay upon the Cambrian group. Attention was given to questions relating to the administrative work of the paleontological branch during the months of July, August, March, and June.

The routine work of the office and laboratory was attended to during the year, and a number of small collections were examined and reported upon to the geologists of the Survey. In addition to this, a large collection of Lower Paleozoic fossils from Canyon City, Colorado, was examined and notes taken for a report, and a large collection of fossils, that had been made by Mr. William P. Rust in the States of New York and Vermont, was examined and a study series selected therefrom, the remainder being packed and placed in storage, owing to the crowded condition of the laboratory.

A considerable amount of work was done by Mr. S. Ward Loper in the preparation of a series of Lower Paleozoic fossils for study and also for exhibition at the meeting of the International Geological Congress next August. Mr. Loper was employed until May in this and in the preparation of the material that he collected during the field season for study. Mr. William P. Rust worked out the material collected by him in the lower Champlain Valley, and transmitted to the laboratory, in February, 1,557 specimens prepared for study from the Calciferous and Chazy zones and 225 specimens from the Trenton limestone of Central New York.

Prof. Joseph F. James was engaged in assisting me in various ways in the preparation of the correlation essay after his return from the field to the 1st of March, when he was transferred to the Geological Survey library, where he assisted in reading the proof of the correlation essay that was received during June.

During the year two papers, growing out of the general studies of the division, were published, viz: "Description of new forms of Upper Cambrian fossils" (Proc. U. S. Nat. Mus., vol. 13, 1890, pp. 267–279, Pls. XX, XXI); "The fauna of the Lower Cambrian or Olenellus zone" (U. S. Geol. Survey, Tenth Ann. Rep., 1888–89. Part I. Geology, pp. 509–658; colored map, text illustrations, 69 figures, and Pls. XLIII–XCVIII; published in 1890).

Very respectfully,

CHAS. D. WALCOTT,
Paleontologist in charge.

Hon. J. W. POWELL,
Director.

REPORT OF PROF. ALPHEUS HYATT.

U. S GEOLOGICAL SURVEY,
DIVISION OF LOWER MESOZOIC PALEONTOLOGY,
Cambridge, Massachusetts, June 30, 1891.

SIR: I have the honor to report that in accordance with instructions received from you I proceeded to Taylorsville, Lassen County, California, in August, 1890, to cooperate with Mr. J. S. Diller in the exploration of Mount Jura and the immediate vicinity, and remained there collecting and observing from August 23 until September 15. We obtained over 2,000 pounds of fossils, and found several distinct horizons besides those mentioned in previous reports as occurring in the Trias and Jura at this place. Four large boxes of fossils that were received by me at Cambridge about December 1, 1890, have been unpacked, labels secured, all specimens trimmed, and a considerable number of species identified.

Dr. Cooper Curtice, of Dr. Becker's division, visited the same locality before I arrived at Taylorsville and collected largely from some of the same horizons. These fossils were generously placed at my disposal and have been labeled and incorporated with the other collections. They have added largely to our materials and contain some species not previously obtained, as well as some remarkably fine fossils.

The work of revising, naming, and describing the Triassic fossils from near Soda Springs, Idaho, has also been carried forward and the larger part of these are ready for publication.

The geological sections made in San Miguel County, New Mexico, in 1889, have been drawn out, corrected, and placed in color upon a single sheet ready for engraving, and also the descriptive text for them complete. The work of naming and describing the fossils progressed rapidly in the early part of the year and most of the species were described. This work was laid aside for a time on account of the importance and pressing requirements of the work on the fossils from Mount Jura, but has been resumed and is now making good progress.

The foreign collections in the Museum of Comparative Zoology, the use of which has been kindly permitted by the director, Mr. Alexander Agassiz, have been of important assistance for the comparison of species and the determination of the comparative age of faunas.

Respectfully submitted.

ALPHEUS HYATT,
Paleontologist in charge.

Hon. J. W. POWELL,
Director.

REPORT MR. C. A. WHITE.

U. S. GEOLOGICAL SURVEY,
DIVISION OF UPPER MESOZOIC PALEONTOLOGY,
Washington, D. C., July 1, 1891.

SIR: I have the honor to submit the following report of the operations of this division for the year ended June 30, 1891.

OFFICE WORK.

From July 1, 1890, I was occupied in the preparation of a work, begun a couple of years previously, entitled "A Review of the Cretaceous Formations of North America," the finished manuscript of which was delivered at your office upon February 10, 1891. This is one of a series having special reference to the correlation with one another of all the geological formations of North America, which have been prepared in accordance with the plan outlined by you.

The scope of my work embraces a discussion of all the North American formations which have by any author been referred to the Cretaceous system, and therefore certain formations at the base and top of the system respectively are included, although the opinion of geologists is divided concerning their Cretaceous age, and although some of those formations are discussed by the respective authors of the memoirs in this series which relate to the immediately preceding and succeeding systems.

Upon completion of the manuscript for the forementioned work I began the preparation of another upon the Laramie and related formations. These formations occur in various parts of the great interior portion of the continent and are known from northern Mexico to far within British America. This work is in progress at the close of the present fiscal year, but as it will require a considerable amount of investigation in the field it probably can not be finished within two or three years.

Besides these labors a considerable portion of my time has been occupied in the examination of questions arising in connection with various collections of fossils which have been sent to this division for investigation and report, by different parties connected with the Survey and by correspondents of the Survey and of the Smithsonian Institution, and also in the consideration of questions pertaining to the preparation and preservation of the fossils of the division.

The actual labor of the preparation and installation of these fossils has largely fallen upon Mr. T. W. Stanton, and this has constituted a large part of his office work during the last fiscal year. Besides the preparation and installation of these fossils, which for many years have accumulated in this division, Mr. Stanton has given much attention to their systematic study and specific identification, especially of the collections which he himself has made.

A large part of the fossils which have accumulated within the last few years, as well as those already in possession of the U. S. National Museum, have been by Mr. Stanton installed in its cases and recorded in its record books. The fossil collections pertaining to this division are therefore in a more accessible condition than they have heretofore been. Besides these labors Mr. Stanton has devoted considerable time to the preparation of a review of the invertebrate fauna of the Colorado division of the Cretaceous system as it is developed in the great interior portion of this continent. It is expected that when finished this work will be published as an illustrated bulletin of the Survey, and it is estimated that it will contain two or three hundred pages.

Besides the usual clerical work of the division and the important assistance he has rendered to me in my labors, Dr. C. B. Boyle has continued his work upon the bibliography of North American Mesozoic invertebrate Paleontology, together with a catalogue of all the published species. As the latter will contain an entry for every republication of each species, as well as for the original description, the work will be a comparatively large one. It is expected that it will be published as a bulletin of the Survey, and that it will contain between 600 and 700 pages. This important work is now so far progressed that its publication may be expected during the coming fiscal year.

Leonard A. White has been employed as a temporary assistant in this division from January 29 to June 30, inclusive. He has been engaged in assisting Mr. Stanton in the Museum work already mentioned, and in giving general assistance in the clerical and routine work of the division.

FIELD WORK.

Although this division of the Survey is officially designated as a paleontological one, all its investigations are prosecuted with direct reference to structural geology, especially to that which pertains to the United States domain. In other words, its investigations are properly geological, although they are prosecuted mainly from a biological standpoint. Therefore field work constitutes a large part of the labors performed by the members of the division, and all the plans for prosecuting its work involve various journeys to the field and extended studies there, as well as the collection of the fossil remains which faunally characterize the respective formations under investigation. With these objects in view several journeys have been made to the field within the last fiscal year.

At the beginning of the fiscal year Mr. Stanton was already in the field in Colorado, where he specially investigated the Colorado division of the Cretaceous system. His principal work was done in Huerfano Park, but considerable work was also done at other localities in Colorado. The principal results of this work will appear in his proposed publication already mentioned.

At the request of Mr. S. F. Emmons, in charge of the division of the Rocky Mountains, Mr. Stanton, while in Colorado, reexamined the section near Canyon City, which he had previously examined under the direction of Mr. Emmons. It was among the fossil collections thus obtained from these strata that Mr. Walcott reported the important discovery of fish remains, mention of which is made in his administrative report for this fiscal year.

Mr. Stanton returned from his field work in Colorado on September 1 and resumed office work, but on October 5 he left Washington for field work in Texas. This journey was undertaken for the purpose of continuing the investigation of the upper portion of the marine Cretaceous series there which I had prosecuted upon two former occasions. The special object of his work was to study the stratigraphical relations of the beds which bear the remains of a molluscan fauna which is closely like that of the Ripley formation of Mississippi and Alabama, and to make as full collections as practicable of those fossils. This work being satisfactorily performed he returned to Washington on November 19 and resumed his office work.

During the progress of my work on the North American Cretaceous formations it became necessary to make some field observations in the Atlantic border region. I therefore left Washington for that purpose on October 6, visited various localities in Virginia and North Carolina, and returned on the 20th of the same month.

Having learned upon this journey that certain necessary observations in North Carolina could be more advantageously made in winter, Mr. Stanton left Washington for that purpose on January 20, completed his observations there and returned on February 5.

In pursuance of my plan for further studies of the Cretaceous formations of the Gulf States Mr. Stanton took the field in the region traversed by the Chattahoochee River, leaving Washington on March 2 and returning on April 3.

On June 1 Mr. Stanton left Washington for field work in Colorado, where he is engaged at the close of this fiscal year.

Respectfully submitted,

C. A. WHITE,
Geologist in charge.

Hon. J. W. POWELL,
Director.

REPORT OF MR. W. H. DALL.

U. S. GEOLOGICAL SURVEY,
DIVISION OF CENOZOIC INVERTEBRATE PALEONTOLOGY,
Washington, D. C., July 1, 1891.

SIR: I have the honor to submit the following report on the work of the divison of Cenozoic Paleontology during the fiscal year ended June 30, 1891.

The force of the division, besides occasional labor temporarily engaged during field work, has included R. E. C. Stearns, Paleontologist, Gilbert D. Harris, Assistant Paleontologist, and Mr. Frank Burns. These persons have been continuously employed on field or office work during the year.

OFFICE WORK.

Dr. Stearns has been chiefly engaged on the routine work, of which he has had general supervision under my direction. Many of the letters asking for information, of which a large number have been received, have been referred to him for reply, and his familiarity with the recent and Tertiary fauna of western America has rendered his services in this very useful. Beside the time devoted to routine work Dr. Stearns has been engaged in studying the invertebrate fossils of the Colorado desert region, in which fair progress has been made.

The routine work of the division, as in former years, consists largely of receiving, unpacking, cleaning, assorting, classifying, recording, naming, labeling, cataloguing and arranging in order for easy reference the fossils of Cenozoic age, and their related later forms, that have been collected by members of the Survey or presented by private individuals interested in geology.

Another branch of the work consists in reporting on such specimens as are brought in by members of the Survey desirous of knowing the age of the strata from which they were obtained; or by private students of paleontology desirous of knowing the names of their fossils; or, lastly, by the directors of the State surveys who desire to have the benefit of comparison with typical collections, such as may be found in the National Museum.

The labor of furnishing information on these and cognate subjects to inquirers from all parts of the country is serious and constantly increasing. In the year 1888–'89 forty-five such applications were made and attended to; in 1889–'90, sixty-nine; in the year just ending the number has mounted to one hundred and sixty-six. It is obvious that this indicates a growing interest in the work the Survey has been doing; an appreciation of the fact that information is available on application, and, judging by the fact that most of the applications were free from trifling or gross ignorance, an increase in the number of persons whom the study of recent and fossil invertebrates attracts. I have always felt that, so far as it could be done without neglect of necessary official work, the furnishing of such data to inquirers was an important part of the work of the division.

The material referred to the division for examination and report has in all cases been promptly attended to, no arrears of current work of this sort remaining at the end of the year. No account has been kept of the identifications made for members of the Survey, but for outsiders the number of species examined and identified is not less than 1,800 in round numbers, and the notes thereon amount to between 600 and 700 pages of manuscript. The great amount of current work and of absences on field work have prevented any great impression being made on the large arrearages which existed before I took charge of this division. However, even on this line some progress has been made.

In providing cases and material for handling and arranging the collections in question we are indebted to the National Museum, their ultimate custodian. The final registration of material since my last report to date of writing was 5,700 entries, corresponding to about 17,500 specimens against 6,323 entries and 20,000 specimens during the year 1888–'89, and about 6,000 entries during the preceding year, 1889–'90.

As facilitating the work of the Survey in this direction I have, with your permission, continued to act as honorary curator, Department of Mollusks and Tertiary Fossils of the U. S. National Museum, as for many years past.

FIELD WORK.

Geological work in the field under the supervision of the chief geologist has been actively pushed during the last year with valuable results. On the 18th of August, 1890, I departed for field work in northern California, returning to Washington, Oct. 21. During this interval, the gravels of the Sierra were explored for fossils in cooperation with Dr. J. S. Diller, who has been engaged in studying and mapping them. An examination of the Tertiaries of Oregon, at Astoria, Eugene City, etc., with the kind cooperation of Prof. O. B. Johnson, of Seattle University, and Prof. Thos. Condon, of the State University of Oregon, yielded important results in clearing up several previously doubtful questions as to their aid and distribution. The rocks of the Chico group were studied at Redding and those of the Sacramento Valley at Stockton and vicinity, which afforded a good many new data, while interesting results in the Livermore Valley were attained by the kind and generous cooperation of Dr. Wm. Hammond, U. S. Army (retired).

In pursuance of the policy of exploring for typical fossils the classical localities of the older paleontologists, Mr. Burns was sent to explore the beds at Natural Well, Duplin County, North Carolina, from which valuable geological data and a large mass of material were obtained during the month of January, 1891.

To determine the age of the bone beds of South Florida, hitherto in controversy, the writer visited that region in the month of January, obtaining definite and conclusive observations as to their Pliocene age. At the same time numerous other mooted questions in regard to Floridian geology were investigated.

In March Mr. Burns was directed to descend the Altamaha River, Georgia, from the Eocene area to the end of the rock formation, with a view of determining the age and boundaries of the wide-spread grits of that river. They proved to be Miocene, analogous to the Grand Gulf beds of Hilgard, and their transverse section was for the first time definitely ascertained. Mr. Burns returned early in April, having been entirely successful in the mission intrusted to him.

In April Mr. G. D. Harris was detailed to accompany the State expedition, under the auspices of Johns Hopkins University, directed by Prof. W. B. Clark, which visited many of the important Tertiary outcrops of the Maryland shore.

On the 26th of May Messrs. Harris and Burns were directed to proceed to Easton, Maryland, to examine the Tertiary rocks and obtain specimens from the localities frequented by Conrad and the other older paleontologists. The results of this expedition, though satisfactory, are not yet reported on in detail, and a statement of them is therefore impracticable at the present time.

During the last year, as for some time past, we have had the hearty cooperation in the work of exploration of Messrs. T. H. Aldrich, of Alabama, and Joseph Willcox, of Philadelphia, as well as several other public-spirited private individuals.

SPECIAL RESEARCHES.

The work of preparing the Correlation Essay on the Plio-Miocene of the United States has been carried to completion during the year. A large part of the time of Mr. G. D. Harris and myself has been devoted to this work, the manuscript and illustrations of which have been turned in to the chief geologist. In addition to compiled material which has involved a very great amount of labor, the report comprises a good deal of fresh and unpublished material, especially in regard to Georgia, Florida, California, Oregon, and Alaska Territory.

The printing of Part I of the writer's report on the Tertiary Mollusks of Florida, in progress at the time of his last report, was completed in August, 1890, forming a small folio volume of 200 pages, with twelve plates. The second part of this work is in preparation, and will, like the first, be published by the Wagner Free Institute of Science, Philadelphia.

A number of other short papers on the invertebrates of the United States, bearing more or less directly upon our work, have been printed by the writer, by Dr. R. E. C. Stearns, and by Mr. G. D. Harris in various periodicals during the current year.

In conclusion I wish to bear testimony to the faithfulness, energy, and intelligence with which the staff of the division without exception have cooperated with me in pushing the progress of the work, improving its quality, and increasing its quantity.

Very respectfully,

WM. H. DALL,
Paleontologist in charge.

Hon. J. W. POWELL,
Director.

REPORT OF PROF. O. C. MARSH.

U. S. GEOLOGICAL SURVEY,
DIVISION OF VERTEBRATE PALEONTOLOGY,
New Haven, Connecticut, June 30, 1891.

SIR: I have the honor to submit the following report of the work of this division during the last year:

In compliance with your letter of general instructions, I have continued the work of collecting vertebrate fossils and investigating those of special interest to science. This work has gone on sytematically and with success during the year.

The field work of this division during the year has not been as extensive as in previous years, but has been prosecuted with a view to supplement the results attained during the two preceding seasons. Researches in the Laramie have been continued systematically, especially to gain additional information in regard to the remarkable development of reptilian life that came to a close at the end of this period, and likewise to learn more about the limited mammalian life that was contemporaneous with it. The discoveries thus made in these two directions have been important, and the collections secured are of great value to science. Among the reptiles the gigantic Ceratopsidæ were the dominant forms during this period, and the large number of remains secured, although as yet only partially investigated, have shown these animals to be among the strangest forms of reptilian life yet discovered. They were so huge in size and peculiar in structure and so abundant throughout the period in which they lived that they make the deposits in which they are entombed one of the most distinct horizons yet determined, and this fact alone renders the investigations recently undertaken of importance to geologic science. The other reptiles that lived with them serve to emphasize still more clearly the prominent features of the reptilian age and the profound climatic changes that brought this peculiar fauna to its extinction.

The contemporary mammalian life, although meager and diminutive, possesses high scientific value from the fact that it immediately preceded the great mammalian age of Tertiary time. A special effort has been made, therefore, during the last year to obtain all the material possible, and more than a thousand specimens of Cretaceous mammals have now been obtained from the Laramie beds.

The strata next above the Laramie in southern Dakota and Wyoming are the Brontotherium beds of the Lower Miocene, and here explorations were continued with good success during part of the past season. All the field work in this region has been under the immediate charge of my able assistant, Mr. J. B. Hatcher, but I visited the more important localities during the autumn and endeavored to collate the facts previously ascertained.

While the evidence now seems conclusive that vertebrate life affords by far the most accurate record of the past, especially during later geologic time, the importance of bringing together all other information bearing on the subject is equally evident. This point has been kept constantly in mind during the last year, and a careful record has been made, both geographic and stratigraphic, of the localities of all important specimens collected, and the most characteristic remains of invertebrates and plants found with them have been carefully preserved. This will aid materially in the exact correlation of the work of this division with that of others of the Survey, and it is hoped will fix more accurately several horizons hitherto in doubt.

The collections of vertebrate fossils obtained in the West during the last few years, especially the more recent discoveries, are so important that their prompt investigation seemed imperative, and this work has taken a great deal of my own time during the last year. The preparation of specimens for examination has mainly occupied the time of my assistants in the laboratory, and in this necessary work good progress has been made.

A large series of vertebrate fossils has been selected for the National Museum, and a part of them are already prepared and will soon be placed on exhibition. This work will be continued until the space allotted to this branch of Paleontology is filled by characteristic specimens from each formation.

Very respectfully,

O. C. MARSH,
Paleontologist in charge.

Hon. J. W. POWELL,
Director.

REPORT OF MR. LESTER F. WARD.

U. S. GEOLOGICAL SURVEY,
DIVISION OF PALEOBOTANY,
Washington, D. C., July 1, 1891.

SIR: I have the honor to submit the following report of the operations of the Division of Paleobotany during the fiscal year ended June 30, 1891:

FIELD WORK.

Mr. David White was in the field on the 1st of July and did not return to Washington until September 22. He remained at Gay Head until August 9, continuing his search for fossil plants in the Amboy clays of that place, and making a thorough study of the geology of Martha's Vineyard. His labors were highly successful, and a large collection was shipped to Washington.

From this time until his return he was engaged in attempting to connect these deposits with those of similar age on Long Island and in New Jersey, also in seeking to trace the formation to the adjacent islands, but the greater part of his time was spent on Long Island, where beds similar to those of Gay Head occur. He succeeded in working out the problem as fully as the limited time at his disposal would permit.

From April 23 to April 30 Mr. White accompanied the joint geological expedition of the Johns Hopkins University, the U. S. Geological Survey, and the Maryland State Agricultural College from Baltimore down Chesapeake Bay and up the Potomac River to Washington. Collections of diatomaceous earth and fucoids were made from the Neocene at Herring Bay and Plum Point. At Drum Point a lignitic bed lying apparently in the Neocene was examined, and fragments of dicotyledonous leaves, lignitized wood, insects, and fruits were gathered. Other lignitic material was collected from the Neocene near Burch's, on the Patuxent River, at several points near St. Mary's, on St. Mary's River, from the Eocene along the Potomac River at Pope's Creek and Glymont, and from the Potomac formation at Cockpit Point. Specimens of richly diatomaceous earth were also gathered from the Lower Neocene at Nomini Cliffs and Pope's Creek.

Prof. F. H. Knowlton left Washington for Montana on the 14th of July in company with Dr. Peale, with whom he remained as long as Dr. Peale's investigations continued, returning to Washington on October 3. His object was to study the fossil plants of the Bozeman coal mines and adjacent strata in Dr. Peale's department, these being about the only paleontological remains that occur in this region. They are very scarce, and prolonged research was required to find any available data, but a considerable collection was made, which is of great importance, especially as showing the extension of the so-called Volcanic Tertiary of the

Yellowstone Park. Prof. Knowlton also availed himself of every opportunity to collect silicified wood for microscopic study.

Mr. Prosser left Washington on July 14 for field work in the eastern Catskills of New York, where fossil plants are of considerable importance in determining stratigraphy. Two sections were made, each starting on the Upper Silurian and terminating in the Catskill stage. The first section is from Kingston, along the line of the Ulster and Delaware Railroad, in Ulster County, to the Grand Summit Station, and the second fifteen miles farther northeast, in Greene County, along the Kaaterskill Creek and up Round Top Mountain. He returned to Washington on August 19.

On November 7 he was detailed by the chief geologist for field work in Arkansas, under the directions of Prof. H. S. Williams and Dr. J. C. Branner. The work consisted in an examination of a portion of the area of the novaculite series of rocks in western central Arkansas. He returned to Washington December 27, and his field notes have been elaborated and submitted to Dr. Branner.

I left Washington on the first day of August and proceeded first to Gay Head to superintend the work conducted there by Mr. White, and in company with him went over the Gay Head section carefully, after acquainting myself with the results arrived at by him. While there we visited the island of No Man's Land and most of the Elizabeth Islands for the purpose of studying the deposits of these islands in connection with those of Gay Head. Later on we also visited Nantucket and the islands of Tuckernuck and Muskeget with the same object in view.

On the 8th of August I joined Prof. Wm. M. Fontaine at New Haven, Connecticut, according to a previous arrangement, for the purpose of continuing our studies of the Triassic formation. We spent several days at the museum of Yale College examining the Triassic collections there and taking important notes. We also made some local field excursions from New Haven, in company with Prof. Dana. We then procured a conveyance and proceeded across the Triassic belt to the Connecticut River, and up that river to the most northern limits of the Trias, viz, at Gill, Massachusetts. In making this journey we zigzagged several times across the belt to visit the principal localities. We found Mr. S. W. Loper actively engaged in studying the Triassic geology of the Connecticut Valley under Prof. William M. Davis, and he had already found a number of deposits yielding fossil plants. At Middletown we visited the Wesleyan University museum and examined the collection there from that formation. We also made a careful inspection of the important collection at Amherst, where most of the older types, that have been figured, are on exhibition. We returned to New Haven on the 20th, Prof. Fontaine proceeding to Virginia. After rejoining Mr. White and continuing our investigations for a few days, I returned to Washington on the 30th of August.

Since the latter part of March I have been engaged, as opportunity would permit, in the field study of the Potomac formation in the vicinity of Washington and in the States of Maryland and Virginia. This work was found essential to the continuance of my essay on the correlation of the Lower Cretaceous plant-bearing deposits. My former studies in the Potomac formation have been chiefly confined to the State of Virginia, where, in company with Messrs. McGee and Fontaine, I have made several excursions. But there are many points in dispute in regard to the geologic position of the several members of the Potomac formation, especially those about Baltimore and in the State of Maryland in general. I therefore set myself the task of investigating these disputed points and am still engaged in this research. My operations in this field consist of isolated excursions from Washington. My work is chiefly stratigraphical, although careful search is made for new localities at which vegetable remains occur, these constituting about the only paleontological evidence that has thus far been discovered.

OFFICE WORK.

The force of the division during the year has included Mr. David White, Mr. Charles S. Prosser, Prof. Knowlton, Assistant Paleontologists, and Mr. F. von Dachenhausen, draftsman, the last detailed from the Division of Illustrations. In addition to these Mr. A. C. Gisiger remained in the division till October 31.

The classification of the office work for the year will be the same as for previous years.

(1) *Preparation of illustrations.*—Mr. von Dachenhausen has continued during the year to assist in the preparation of illustrations. His work has consisted in the main in inking in drawings made by Messrs. White and Knowlton, who block out their illustrations in pencil. He has also assisted me in perfecting the former original drawings of the Laramie types where on careful investigation I have found them defective. In this way he has been constantly supplied with an abundance of work.

(2) *Identification of fossil plants.*—Since returning from the field the entire force has been engaged a large part of the time in the study and identification of the collections made and of other collections previously made or sent to the division for determination. Mr. White finished his Gay Head forms early in the winter as far as could be done without access to Dr. Newberry's forthcoming work on the flora of the Amboy clays. It was therefore deemed inadvisable to proceed further until this work should be accessible. Mr. White has done, in addition to this, a large amount of work of this class upon the Carboniferous flora of Missouri, as represented in collections which Prof. Jenney and others have sent from that State.

Mr. Prosser has also studied, as far as time would permit, the collections made by him in New York State. Some of his time has been necessarily devoted to determining the collections and working up his notes made in Arkansas, which do not relate to fossil plants, except in a minor degree.

The large collection made at Golden, Colorado, by the Rev. Arthur Lakes and obtained by Prof. Emmons, was sent to the Division of Paleobotany and Prof. Knowlton commenced work upon it in October. He has determined most of the cryptogamic, coniferous, and monocotyledonous plants in the collection, leaving the new dicotyledonous species for further study.

Prof. Knowlton has done the same for the combined collections which had been previously made from the Bozeman coal mines, viz, those furnished by Dr. Peale and Mr. Weed and also by himself. These collections will be treated by me as belonging to the Laramie group, and the results will be embodied in my monograph of the flora of that group.

Observing the especial aptitude for this class of work which Prof. Knowlton evinces, it occurred to me to ask him to assist me in the study of my Laramie types. My work has been heretofore almost exclusively confined to the difficult study of the dicotyledonous leaves, while Prof. Knowlton's special knowledge and preparation enabled him better to study the lower forms. I have, therefore, assigned to him, as part of his work, the determination of the cryptogams, conifers, and monocotyledons of the Laramie group, and he commenced upon this work in January last. He is making a very thorough revision of the work previously done on these forms in this country, which he finds greatly to need such revision.

The exceedingly great difficulty in identifying fossil plants from leaves by nervation and form alone and the predominance in all collections of later formations of this kind of specimens have induced me to undertake a very extended research and as complete a comparison as possible of the Laramie types of this class with figures made by other authors. For nearly two years I have been engaged in this preliminary but very necessary examination and I have gone over the entire literature of paleobotany, comparing all the types in my possession with the figures that have been previously published. I did not complete this general study until late in April, and since that time I have been engaged in the classification by genera of the dicotyledonous forms. This classification, although still imperfect, is much more reliable than it could otherwise have been.

(3) *Preparation of manuscript.*—Mr. White has made a good beginning upon his report on the plants collected by Prof. Jenney in Missouri. I have examined the manuscript as far as it has been written, and consider his work very thorough and important. He will probably offer it, when finished, as a bulletin of the Survey.

The only other manuscript work done in the division during the year has been that of the correlation essay. I completed the chapter relating to the American Trias on the 23d of December. In April I prepared a summary of the results arrived at in that chapter which is now ready for publication. Since that time I have also prepared a paper on the value of fossil plants as aids to geologic correlation and the methods to be employed in the study of correlation by means of fossil plants.

The work reported last year of editing and completing the manuscript of Prof. Lesquereux's monograph of the Flora of the Dakota Group was continued during the summer and finished in December, during which month it was sent to press.

(4) *Correction of proofs.*—The proof of the volume just mentioned began to arrive early in April and engrossed the greater part of the time of Prof. Knowlton and myself during that month and the month of May, two proofs of the entire work being carefully revised and corrected.

(5) *Bibliographic work.*—Mr. White has so far advanced with the preparation of the bibliography of fossil plants as to consider it desirable to have it announced in the publications of the Geological Survey as in preparation, and this has now been done. If work upon this important subject proceeds slowly it is in consequence of the great number of other duties which devolve upon Mr. White.

(6) *Catalogue work.*—In my last administrative report I set forth at some length the nature of this work. Although it was necessary to withdraw Mr. Gisiger from this duty for a considerable portion of his time, in order to have him engross upon the typewriter the monograph of the flora of the Dakota group by Prof. Lesquereux, nevertheless, such was his ability and industry that before leaving the division a large number of the works to be catalogued were completed. The necessity, from lack of funds, of dispensing with his services at the end of October, was a severe blow to this part of my plan, but it has been continued by Miss Schmidt with eminent success, and great progress has been made since that time. In fact, with the exception of a body of the older and more difficult literature, the work of cataloguing the books has now been brought nearly to completion.

Of course a very large number of slips have been added to the index since last year, when they were estimated at one hundred and sixty thousand. It is probable that before their completion they will number nearly two hundred thousand slips, each slip representing a distinct entry in some work on paleobotany. Mr. Prosser has devoted more than three hours per day, when not in the field, to the revision of this great slip index and the selection of "type slips," as explained in my last report. With this work he has now proceeded to the letter M, and it is probable that at the present rate of progress a year will be required to complete this part of the work, which is necessary as preparatory to the working out of the synonymy of the literature of the fossil plants.

(7) *Care of the collections.*—This part of the work of the division has been under the immediate supervision of Prof. Knowlton, and the routine work has been performed chiefly by Mr. T. E. Williard. Large collections

have been received during the year and great care has been taken that a record of them should be carefully kept, that the Survey should be credited with all the specimens collected by its members, and that as rapidly as possible the determined species should be placed either upon exhibition or in a study series for the use of the scientific public. The new system of registering adopted last year by Prof. Knowlton has been rigidly enforced, and proves of great value to this work, both in the matter of economy of time and of facility of reference.

Prof. W. M. Fontaine submits the following report of the work done by him during the year:

In the summer of 1890 I made, in company with Prof. Ward, a reconnaissance of the Connecticut older Mesozoic. The object was to compare these strata with those farther south, to examine, if possible, fossil plants collected from the formation, some of which had been incidentally reported in various scattered papers and some being now in the hands of different parties and not reported. It was especially desired to determine whether or not there is a probability of finding new plant localities in these beds.

Later in the summer I made collections of fossil plants from the older Mesozoic of the Richmond coal fields. This work was not completed.

In office work I was engaged in studying, describing, and drawing fossil plants collected by me from the basal beds of the Carboniferous of Virginia.

I also determined and described small collections of fossil plants made by the Director of the Survey, and by Mr. Knowlton, from the (Trias) older Mesozoic of the copper mines of New Mexico. Several minor points connected with Mesozoic fossil plants have been referred to me by Prof. Ward.

Of late I have been occupied with selecting, labeling, and packing for shipment the collections of fossil plants from the older Mesozoic and the Potomac formations now in my hands.

Respectfully submitted.

LESTER F. WARD,
Geologist in charge.

Hon. J. W. POWELL,
Director.

REPORT OF PROF. SAMUEL H. SCUDDER.

U. S. GEOLOGICAL SURVEY,
DIVISION OF FOSSIL INSECTS,
Cambridge, Massachusetts, June 30, 1891.

SIR: The preparation of a monograph of the Tertiary rhynchophorous Coleoptera, or snout beetles, of the United States has occupied the principal attention of my division during the last year, and is so far advanced as to show that our Tertiary fauna is extremely rich and varied, about one hundred species having already been described in full, and at least one of the families proving already to be almost or quite as rich in forms as is the existing fauna. This work will be completed during the coming year. The only other descriptive work has been (1) upon a small collection of Pleistocene beetles found by Prof. B. K. Emerson in the old bed of the Connecticut River, in Massachusetts, an account of which was furnished him for a report he has in preparation for the Survey, and (2) the description of a new genus and species of dragon fly found in the explorations of my party summer before last in the Roan Mountain shales in Colorado, and interesting as the first discovery of fossil Gomphinæ in this country.

The material brought home from the western explorations of my division mentioned in my last report has been carefully overhauled, and the refuse material has been further split and examined with the result of adding two or three hundred more specimens to the collection. Each specimen in the collection has been carefully marked with a distinctive white number, catalogued, where necessary specially mounted, and all roughly classed. They have still to receive the distinctive labels of the Survey, a work which will next receive attention, and a copy of the catalogue will then be made and transmitted to Washington.

The manuscript of an index to the described fossil insects of the world has been finished; it was forwarded to Washington last August, and the last proof read in May, forming Bulletin 71 of the Survey, a volume of nearly 750 pages. The proof of a bibliography of fossil insects, a complement to the preceding, was also completed in September, forming Bulletin 69, a pamphlet of about 100 pages. The reading of the proof of my Tertiary Insects of North America, forming Vol. XIII of the Hayden series of reports, issued under your auspices, was also completed in September, forming a quarto volume of over 700 pages and 28 lithographic plates. Besides these publications, four papers on the older (mostly Carboniferous and Triassic) insects of North America have been published in the Memoirs of the Boston Society of Natural History, and have also been embodied in the first of two volumes on the fossil insects of North America independently published by the writer, the first volume comprising a collection of papers on pre-Tertiary insects previously published, making a quarto volume of about 450 pages and 35 lithographic plates, the second, the volume on Tertiary insects above referred to. Finally a short paper on the Fossil Hemiptera of British Columbia has been published in the Contributions to Canadian paleontology of the Geological Survey of Canada.

A card catalogue of the described fossil insects of each distinct locality in North America has been prepared for office use.

The only field work undertaken during the year was a brief visit to the lignite beds of Gay Head, Massachusetts, to see whether they could be profitably worked for remains of insects. While some fragments of the chitinous covering of beetles were found, these were so extremely few and of such a fragmentary nature as to render further work in this direction undesirable.

A great deal of time has been given to the selection of material for the draughtsman and the examination and correction of his drawings at every stage of their progress. These have been confined mostly to

Hemiptera, aculeate Hymenoptera, and rhynchophorous Coleoptera. In all, eighty-one enlarged drawings in ink have been completed, ready for photographic reproduction when needed.

Respectfully submitted.

SAM. H. SCUDDER,
Paleontologist.

Hon. J. W. POWELL,
Director.

REPORT OF MR. F. W. CLARKE.

U. S. GEOLOGICAL SURVEY,
DIVISION OF CHEMISTRY AND PHYSICS,
Washington, D. C., June 30, 1891.

SIR: I have the honor to submit the following report of work done in the Division of Chemistry and Physics during the fiscal year ending June 30, 1891.

In the scientific force of the division, numbering seven chemists and two physicists, no changes have been made; and in its essential features the work has followed the lines established during previous years. In the ordinary routine work of the chemical laboratory 262 finished analyses have been reported, mostly of rocks and minerals collected by field geologists of the Survey, and a much larger number of specimens received from various sources have been reported upon qualitatively. In field work, on the other hand, little has been done; one week spent by myself in a study of certain vein granites in New Hampshire, and about ten days devoted by Dr. E. A. Schneider to the vermiculite localities of southeastern Pennsylvania, covering, apart from the investigations of Dr. T. M. Chatard, to be mentioned later, all that was accomplished outside of the laboratory.

Personally, aside from the usual administrative duties, my own work is mainly represented by a joint research with Dr. Schneider into the chemical constitution of the micas, chlorites, and vermiculites. This research is a continuation of one completed during the previous year, and has led to a general solution of the problem under consideration. The results are already written up, and will appear in a forthcoming bulletin. Since May 1 much of my time has been occupied with preparations for the exhibit of the Survey to be made at the World's Fair in Chicago, and the collections to be displayed are already well started.

During the year 1889-'90, Dr. W. F. Hillebrand published a remarkable paper upon uraninite. In that mineral, which occurs chiefly in Archean granites, he discovered nitrogen, a discovery of great importance in its geological bearings. During the year just closed he has extended that investigation, examining several new occurrences of the mineral, and confirming his earlier results. He has also begun synthetic experiments, with a view to ascertaining in what manner the nitrogen of uraninite is combined; but no final conclusions have as yet been reached.

To Dr. Chatard a special study of our national resources in mineral phosphates has been assigned. This task is chiefly important on the economic side; and so far the work has touched only the recently discovered deposits of Florida. In February and March Dr. Chatard spent over a month in making field collections, and since his return he has analyzed many samples, and has made exhaustive experiments upon the analytical methods to be used in the investigation. Earlier in the year he examined a series of zinciferous clays collected by Mr. W. P. Jenney in Missouri, in which work a careful study of analytical processes also became necessary.

In mineralogy, several interesting researches have been completed. One mineral, collected by Mr. R. L. Packard in the Seven Devils Mining District of Idaho, was examined by Dr. W. H. Melville, and proved to be a new species, to which the name powellite has been given. The mineral is a calcium molybdate, isomorphous with the corresponding tungstate, scheelite, and is interesting as the completion of a mineralogic series. Dr. Melville has also examined a natrolite from the elæolite-syenite of Magnet Cove, Arkansas, a remarkable bismuthinite from Mexico, and a radiated brown tourmaline from California. Mr. Eakins has analyzed and described the very rare mineral tscheffkinite from a new locality in Bedford County, Virginia; and, in connection with Mr. Whitman Cross, new occurrences of ptilolite, diaspore, and alunite from Colorado. He has also analyzed two new meteorites; one a stone from Washington County, Kansas, the other an iron from Pulaski County, Virginia.

In purely chemical investigations I can only report a continuation by Dr. H. N. Stokes of his work upon the silicic ethers and some experiments by Dr. Schneider upon inorganic colloids. Both researches are still in progress; but Dr. Stokes has already published an account of a new silicophosphoric chloride, a compound of quite novel character, obtained incidentally to the regular study of the main problem. The problem itself is to ascertain the chemical nature of the silicic acids, which play so fundamental a part in most of our rock-forming minerals.

In the physical laboratory Dr. Carl Barus has continued his studies upon the thermodynamics of solids and liquids, and has especially considered the chemical behavior of solids under pressure, a subject which bears directly upon elasticity and viscosity. Incidentally to this work, various subsidiary researches were necessary relating to improvements in the screw compresser used in the experiments, and to the comparison of the pressure gauges employed. The Amagat, Bourdon, and Tait gauges were all investigated, and the last-named gauge was found available up to 2,000 atmospheres of pressure. It is also the most convenient of application.

Dr. Barus, with the help of the experience gained in the foregoing researches, has been able, furthermore, to explore the isothermals of liquid matter far enough to show the nature of the continuity of the solid and liquid states. He is now studying the changes of specific heat, and of thermal conductivity encountered in passing along a given isothermal from liquid to solid, and intends to coordinate these measurements with the corresponding volume changes.

In the earlier part of the fiscal year Dr. William Hallock measured the thermal expansion of several samples of marble and one of slate. Early in 1891 this work was temporarily laid aside, in order to take up the measurement of the effect of pressure upon the melting point of ice. In the middle of April this study was in turn interrupted in order that Dr. Hallock might visit Wheeling, and there carry out a series of observations upon the deep artesian well now being driven in that city. Upon that investigation he is still engaged.

Very respectfully,

F. W. CLARKE,
Chief Chemist.

Hon. J. W. POWELL,
Director.

REPORT OF MR. DAVID T. DAY.

U. S. GEOLOGICAL SURVEY,
DIVISION OF MINING STATISTICS AND TECHNOLOGY,
Washington, D. C., July 1, 1891.

SIR: In submitting the administrative report for the fiscal year ended June 30, 1891, of the Division of Mining Statistics and Technology which you have given to my charge, I have the honor to state that in accordance with instructions of the Honorable the Secretary of the Interior, based on the request of the Superintendent of the Census referred to in my last administrative report, I have conducted the investigation into the mineral industries of the United States for the Eleventh Census in addition to the duties in this office, which have consisted of general correspondence with producers of minerals and others seeking information in regard to the amount of minerals produced and other statistical questions, the examination of specimens forwarded to me for determination of their economic importance, and information concerning the statistical and technical matters related to mineral matters furnished to foreign legations. During this time active preparation also has been made for a statistical canvass of the United States to follow that of the Eleventh Census. This canvass was begun shortly after the commencement of the present calendar year. It has already shown that the mineral industries during the calendar year 1890 were in a condition of increased activity as compared with the preceding year. The total production of coal will prove especially great. At the close of the year the production of metallic tin was begun as a new industry in this country in California, and the manufacture of this metal into tin plates was also inaugurated the same year at St. Louis.

The following statement gives a summary of the condition of the mineral industries of the United States in 1890.

METALS.

Iron and steel.—The production of pig iron in the United States in the year 1889 was 7,603,642 long tons, or 8,516,079 short tons, valued at $120,000,000, taking as the standard of valuation the price of No. 1 anthracite pig iron in Philadelphia. This was greater than the product of any previous year; but in 1890 the product increased greatly, reaching 9,202,703 long tons, or 10,307,028 short tons, valued at $151,200,410. The production of Bessemer steel in the United States in 1890 was 4,131,535 short tons, against 3,281,829 short tons in 1889, a gain of nearly 26 per cent. The consumption of limestone for flux in iron-ore smelting was 6,318,000 long tons in 1889 and 7,000,000 long tons in 1890.

Gold and silver.—In 1889 the mines of the United States produced, according to the census returns, 1,590,869 fine ounces of gold, with a coining value of $32,886,744, and 51,354,851 ounces of silver, with a coining value of $66,396,988. In 1890 the product, according to the Director of the Mint, was: Gold 1,588,880 ounces, valued at $32,845,000, and silver, 54,500,000 ounces, with a coining value of $70,464,645.

Copper.—The copper product remained nearly stationary in 1889 and 1890, being 231,246,214 pounds in 1889 and 265,115,133 pounds in 1890, worth respectively $26,907,809 and $30,848,797.

Lead.—The total product increased in 1889 to 182,967 short tons, worth $16,137,689, compared with 180,555 short tons in 1888, worth $15,924,951. In 1890 the product decreased to 161,754 short tons, worth $14,266,703. The producers carried a stock of 10,389 short tons on January 1, 1891, as compared with 7,715 short tons on January 1, 1890. The lead content of the ores imported from Mexico was 26,570 tons in 1889 and 18,124 tons in 1890. The production of lead in the first half of 1891 increased to 95,121 short tons.

Zinc.—In 1888 the total product of spelter was 55,903 short tons, worth $5,500,855. In 1889 it increased to 59,188 short tons, worth $5,824,099 and in 1890 to 63,683 short tons, worth $6,266,407. The stocks in the hands of producers are small, considering the magnitude of the industry. On January 1, 1890, these stocks were 1,268 short tons, and on January 1, 1891, had decreased to 1,134 tons.

Quicksilver.—The industry continues to decline in spite of active prospecting for new supplies. In 1888 the product was 33,250 flasks of 76½ pounds net, valued in San Francisco at $1,413,125. In 1889 this declined to 26,484 flasks, although the price was $45 per flask, which was sufficient to cause strong inquiry for new supplies. In 1890 the product decreased to 22,926 flasks, the average price increasing to $48.33 per flask. The product all came from California.

Nickel.—During the years 1889 and 1890 the condition of the industry changed completely, due to the development of extensive supplies in Canada. The inquiry for still other new deposits was nevertheless stimulated by the successful tests of steel containing a small percentage of nickel for armor plates. Previously the markets were regulated principally by the output of the New Caledonia mines. In 1888 the total product in the United States was 203,328 pounds. In 1889 this increased to 217,663 pounds and in 1890 to 223,488 pounds, worth $134,093. The product from Canadian matte was 35,000 pounds in 1889 and 100,000 pounds in 1890.

Cobalt oxide.—The product has followed the nickel industry except that proportionately more nickel has been produced than cobalt oxide, because the Canadian matte contains scarcely any cobalt. The New Caledonian producers have produced a greater proportion of cobalt by the aid of a manganiferous iron ore containing nickel and cobalt. The product in 1889 was 12,955 pounds and in 1890 10,000 pounds. The price remained at about $2.50 per pound.

Chromic iron ore.—The industry remains unchanged. The supplies come from California, together with increasing importations from Turkey and Asia Minor. The output in California in 1889 was 2,000 long tons and in 1890 11,000 long tons.

Manganese.—Product in 1889, 24,197 long tons, which include a small shipment from Colorado. In 1890 the product was 25,000 long tons, worth $250,000. The importations are increasing. In addition, manganiferous iron ores were produced to the amount of 83,434 tons in 1889 and 75,000 tons in 1890.

Aluminum.—The production of aluminum continued and increased from about 500 pounds in 1888 to 19,200 pounds in 1889, and 60,000 pounds in 1890. The price per pound during this period decreased from $4.50 per pound in 1888 to $1 per pound in 1890 for ingots. The manufacture of aluminum into musical instruments, thin sheets for ornamental purposes, and into various utensils is increasing.

FUELS.

Coal.—In 1889 the total product of coal of all kinds was 141,229,513 short tons, valued at the mines before any expenses for shipment, at $160,226,323. The product included 45,600,487 short tons of Pennsylvania and other anthracite, worth $65,879,514, and 95,629,026 short tons of bituminous coal and lignite, valued at $94,346,809.

In 1890 the total product increased to 153,389,724 short tons, a gain of 8·61 per cent over 1889. The total value at the mines was $170,876,904. Of the above, 46,468,641 short tons were anthracite, worth

$61,445,683, and 106,921,083 short tons were bituminous coal and lignite, worth $109,431,221.

Petroleum.—The product in 1889 was 35,163,513 barrels, valued at $26,963,340. In 1890 the product was 47,000,000 barrels, worth $30,-000,000.

The features of the two years have been the successful refining of Lima, Ohio, oil, which now supplies a large share of the domestic trade, and the great increase in production in 1890 in Pennsylvania.

Natural gas.—The product measured in terms of the coal displaced shows a decline from $22,629,875 in 1888, to $19,897,099 in 1889. The product declined again in 1890.

STRUCTURAL MATERIALS.

Building stone.—The product in 1889 includes granite to the value of $14,464,095, at the place where produced and in the condition in which it was first sold; marble, $3,488,170; sandstone, $10,816,057; bluestone, $1,689,606; limestone, $19,095,179; and slate, $3,482,513. In 1890 the total value of these products aggregates $54,000,000. Even allowing for a considerable growth in the industry since 1888, these figures show that the statement then made was too small.

ABRASIVE MATERIALS.

Buhrstones.—The product continued to decrease. In 1889 the product was valued at $35,155, and in 1890 at about $30,000.

Grindstones.—The supply still comes from Ohio and Michigan. The consumption has increased in grinding wood pulp. The product in 1889 was valued at $439,587, and in 1890 at $450,000.

Oilstones and whetstones.—This industry derives its supplies from well established quarries in Arkansas and New Hampshire. In 1889 the product amounted to 2,354,000 pounds, chiefly novaculite, and valued at $32,980. In 1890, 2,500,000 pounds were produced, worth $35,000 in the rough state.

MISCELLANEOUS.

Precious stones.—The product is small and, with the exception of agatized wood, the tourmalines regularly produced in Maine and a few gems from North Carolina, consists principally of tourists' jewelry. It was valued at $188,807 in 1889, and $200,000 in 1890.

Phosphate rock.—In 1889 the production of phosphate rock was established as a new industry in Florida and its importance is increasing. The total product from all sources amounted to 550,245 long tons in 1889, which was the greatest amount ever reported. In 1890 the product was 575,000 long tons, worth $2,800,000.

Marls.—The product in 1889 was about 139,522 short tons, worth $63,956, and in 1890, 125,000 short tons, worth $50,000. There is little change in the industry.

Salt.—Product in 1889, 10,000,000 barrels, worth $5,000,000, and in 1890, 8,683,943 barrels, worth $4,707,869.

Bromine.—The product in 1889 was 300,000 pounds, valued at $90,000. In 1890 this decreased to 100,000 pounds on account of the accumulation of stock.

Borax.—In 1889 the product was 8,000,000 pounds, worth $500,000, and in 1890 the product remained about stationary.

Sulphur.—In 1889 and 1890 the Utah works were closed by litigation. There was a small product from the Nevada mines amounting to 1,150 short tons. Efforts are being made to open the Louisiana mines.

Pyrites.—The product from Virginia, Massachusetts, and Vermont amounted to 93,705 long tons, worth $202,119 in 1889, and in 1890 to 87,856 long tons, worth $235,611.

Barytes.—The use of this material is increasing. The main sources of supply are mines in Missouri, Virginia, and New York. The total product in 1889 was 19,161 long tons and in 1890, 20,000 long tons.

Gypsum.—In 1889 the product was 267,769 short tons of crude gypsum, worth $764,118 and in 1890, 275,000 short tons, worth $800,000.

Ozokerite.—Development work was continued in the region near Soldiers' Summit, Utah, and 50,000 pounds were produced in 1889 and 100,000 pounds in 1890.

Asphaltum.—During the last two years the product on the Pacific coast has increased markedly and the price has declined. Product in 1889, 51,735 short tons, worth $171,537, and in 1890, 60,000 short tons, worth $200,000. The production of gilsonite in Utah continues and amounted to 492 short tons in 1889 and 1,105 tons in 1890.

Soapstone.—The use of this material in the form of slabs for various purposes increases. The total product of all kinds was 36,461 short tons in 1889 and 49,809 short tons in 1890. Of this, 23,746 short tons and 34,809 short tons respectively consisted of fibrous talc from New York.

Mica.—The production decreased in 1889, but is now increasing again; product in 1889, 49,500 pounds, worth $50,000, and in 1890, 60,000 pounds, worth $75,000.

Mineral paints.—The product includes ocher, metallic paints, and some umber and sienna; it amounted to 32,307 long tons in 1889 and 35,000 long tons in 1890.

Graphite.—The principal product in 1889 was 400,000 pounds of refined graphite from Ticonderoga, New York, worth $33,000. In 1890 this product was about stationary. Besides this, cheaper grades were obtained from several localities for use in making foundry facings, etc.

Fluorspar.—The supply from Rosiclare, Illinois, and Evansville, Indiana, is sufficient for the gradually increasing use as a flux in cupola furnaces and for chemical purposes. The product was 9,500 short tons in 1889, and 8,250 short tons in 1890. Some artificial fluorspar is made as a by-product in the decomposition of Greenland cryolite.

Infusorial earth.—From the usual sources, the product was 3,466 short tons in 1889 and 5,000 short tons in 1890.

Mineral waters.—Total product in 1889, 12,780,471 gallons, worth $1,748,458, and 14,000,000 gallons in 1890, worth $2,000,000.

In addition to myself, the office force consisted of Mr. W. A. Raborg and Mr. E. W. Parker, who entered on duty as statistician in this division on May 16, 1891.

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

DAVID T. DAY,
Geologist in Charge.

Hon. J. W. POWELL,
Director.

REPORT OF MR. F. H. NEWELL.

U S. GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, D. C., July 1, 1891.

SIR: I have the honor to submit the following statement of work done in the Division of Hydrography for the year ended yesterday.

On the 1st of last July there were in the field nine hydrographers and assistants carrying on operations in as many basins of the arid regions. Their work consisted in measuring the discharge of various rivers at stations previously established and computing the daily discharge of these streams. The hydrographer and his assistants moved from place to place in the region assigned, measured streams at different stages, and endeavored to obtain the discharge for various heights of water from lowest stage to highest flood. From these measurements and a study of the habits of each river tables were constructed, by which, the height on any day being known, the corresponding discharge could be read off.

While field work was in progress, the hydrographer studied the topographic and climatic peculiarities of each sub-basin in the region under examination, the causes of anomalies in the behavior of the streams being especially an object of research, and by this means a considerable body of facts, believed to be valuable for the purpose, has been put on record. Each hydrographer obtained information concerning the development of irrigation in his division, both as to its present condition and future probabilities. These statements were transmitted monthly, together with all hydrographic data, to the office at Washington, where the material was critically reviewed, computations completed and verified, and the matter prepared for publication.

In the Upper Missouri and Yellowstone basins Mr. J. B. Williams had charge of six gauging stations, situated respectively on the West Gallatin about 20 miles from Bozeman, on the Madison near Red Bluff, on Red Rock Creek, a tributary of the Jefferson, on the Sun River eighteen miles above Augusta, and on the Yellowstone, at the town of Horr, six miles below Cinnabar.

In the Arkansas basin in Colorado were nine stations under the charge of Mr. Robert Robertson, assisted by Mr. R. P. Irving. These stations were located mainly on the upper tributaries of the Arkansas, the stations being selected largely with reference to facilities for storage of water. These were situated on the East Fork of the Arkansas, on Tennessee Fork, on Lake Fork, on Twin Lake Creek, below the outlet of the lakes, at Hayden on the Arkansas, on Clear Creek, on the Middle and South Forks of Cottonwood Creek, and at Canyon City.

In the Rio Grande basin two permanent gauging stations, that at Del Norte, Colorado, and one at Embudo, New Mexico, were under the charge of Assistant Hydrographer W. B. Lane, while the station at El Paso, Texas, was in charge of Assistant Hydrographer H. P. Croft, who also carried on sediment observations and measurements of evaporation.

In the Gila basin in Arizona, Mr. W. A. Farish made gaugings at the station on the Gila at the Buttes, fifteen miles above Florence, and also established a station on the Salt River in the canyons nearly fifty miles above Phoenix. The work in this basin was exceedingly arduous on account of the lack of transportation facilities, the almost tropical heat of summer, and the violence of the floods.

In the Carson and Truckee basins in Nevada and California Mr. Wm. P. Trowbridge had charge of stations on Prosser Creek, the little Truckee and Truckee River near Boca, California, on the Truckee at Laughtons, above Reno, and at Vista, below Reno, also on the East Fork of the Carson at Rodenbah, Nevada, on the West Fork of the Carson near Woodford, California, and on the main Carson at Empire, Nevada, about five miles east of Carson City.

In the Salt Lake and Sevier basins Mr. T. M. Bannon had gauging stations on the Bear River at Battle Creek, Idaho, and at Collinston, Utah, on the Ogden and Weber Rivers in the canyons near the city of Ogden, on the American Fork, Provo and Spanish Fork Rivers, in the canyons entering Utah Lake Valley, and on the Sevier at Joseph and Leamington.

In the Snake River basin Mr. F. M. Smith made measurements at the permanent stations on the North Fork of the Snake, on Fall River, Teton River, and the South Fork of the Snake, and on the Snake at Eagle Rock, Idaho. He also had charge of a second party, making measurements on the Owyhee and Malheur Rivers in Oregon and the Weiser River in western Idaho.

Reports from the hydrographers in the field, including the original notes and observations, when received at this office were examined, abstracted, and filed, and materials for an annual report of progress were prepared during July and August. At the end of August, there being no further allotment for continuing hydrographic field work, the parties were disbanded and property turned over to the Topographic Branch of the Survey. At that time there still remained a large accumulation of undigested hydrographic information awaiting preparation for publication. Reports of the height of rivers at the stations occupied by the hydrographers continued to come in throughout the year, affording the data for computing the daily mean discharge of some of the more important streams.

This matter was placed in charge of Mr. Cyrus C. Babb for examination and reduction to concise form, results being shown both by tables and diagrams. The work has progressed rapidly, permitting the preparation of a paper, herewith submitted, on the hydrography of the arid lands. This paper summarizes the present condition of our knowledge regarding many of the rivers of that portion of the country, and also gives a somewhat detailed description, compiled largely from the observations of hydrographers, of the Rio Grande basin, the Gila basin, and the catchment area of Bear River.

The information concerning the development of irrigation has been utilized in a different direction. During the past year I was detailed for six months to the Census Office as special agent for the investigation of irrigation, and by permission made use in the Census Bulletins of the material collected by the Geological Survey, by this means amplifying and completing data which otherwise was in parts too fragmentary for publication.

Very respectfully, your obedient servant,

F. H. NEWELL,
Topographer in charge

Hon. J. W. POWELL, *Director*.

REPORT OF MR. DE LANCEY W. GILL.

U. S. GEOLOGICAL SURVEY,
DIVISION OF ILLUSTRATIONS,
Washington, D. C., June 30, 1891.

SIR: I have the honor to submit the following statement of work done in the division under my charge during the fiscal year ending June 30, 1891.

The personnel of the division is as follows: John L. Ridgway, Daniel W. Cronin, H. Hobart Nichols, H. A. C. Hunter, F. W. von Dachenhausen, Chas. R. Keyes, Daniel P. O'Hare, Henry S. Selden, Malcolm B. Cudlipp, and Wells M. Sawyer.

Mr. Ridgway has been engaged for the past year principally in the preparation of paleontologic drawings. As my assistant he has rendered valuable service in the superintendence of general draughting and the routine office work. Mr. Cronin's work has been the preparation of maps and geologic sections. Mr. Nichols has been employed principally in the preparation of geologic landscapes and diagrams. Early in December Mr. Hunter undertook the preparation of a large number of drawings of Echinoderms for Prof. Wm. B. Clark. These he completed early in May and since that time has been steadily employed on miscellaneous office work. Mr. von Dachenhausen has been engaged exclusively in paleontologic drawings for Prof. Lester F. Ward and his assistants. Mr. Keyes has been temporarily employed, from time to time, in the preparation of paleontologic drawings for Professor Clark. Messrs. O'Hare, Selden, and Cudlipp were detailed from the topographic corps to assist me in February and since then have been employed on general map, diagram, and section work. Mr. Sawyer, whose services date from March 11, has been engaged in miscellaneous office work.

Drawings numbering 1,520 have been produced by the draftsmen of this division within the fiscal year. This is nearly double the number produced in any previous year, and the showing is most satisfactory. The drawings are classified as follows:

Paleontologic	601
Geologic sections and diagrams	733
Geologic landscapes	20
Maps	55
Miscellaneous	111

The illustrations for two annual reports (2 vols. each), two monographs, and seven bulletins were transmitted to the Public Printer during the fiscal year. The illustrations for these publications were classified for engraving as follows:

Chromolithography	44
Lithography	3
Wood engraving	19
Half-tone engraving	235
Photo-engraving	681

That part of the routine office work which consists in the criticism and revision of engravers' proof has been very heavy this year. Complete record and specifications of all illustration material sent in for publication has been kept by me, and through the hearty cooperation of the Government Printing Office the transmittal of proof to and from the contracting engravers has been greatly facilitated.

The work of classification and storage of engraved blocks and electrotypes has been pushed as rapidly as such material has been received from the Public Printer.

The printed editions of all chromolithographic and photo-gelatine work used as illustrations in the reports of the Survey during the year have been examined by me at the Government Printing Office.

No field work has been undertaken by me or my assistants during the year.

The photographic laboratory has been conducted, as in previous years, under the able management of Mr. J. K. Hillers, assisted by C. C. Jones, assistant photographer, and John Erbach, Chas. A. Ross, and Edward Block, photographic printers. On account of the great press of office work no field work was undertaken by him during the year. The following is a statement of work done in the photographic laboratory during the year.

Negatives.		Prints.	
Size.	Number.	Size.	Number.
28 by 34	226	28 by 34	1,761
22 by 28	59	22 by 28	320
20 by 24	422	20 by 24	2,481
14 by 17	82	14 by 17	339
11 by 14	163	11 by 14	1,462
8 by 10	231	8 by 10	2,983
5 by 8	....	5 by 8	777
4 by 5	....	4 by 5	1,481

Very respectfully, your obedient servant,

DE LANCEY W. GILL,
In charge.

HON. J. W. POWELL,
Director.

REPORT OF MR. S. J. KÜBEL.

U. S. GEOLOGICAL SURVEY,
DIVISION OF ENGRAVING AND PRINTING,
Washington, D. C., June 30, 1891.

SIR: The following exhibit of the operations of the Division of Engraving and Printing for the year ending June 30, 1891, is respectfully submitted.

This division was created in February, 1890. Before that date all the Survey's map-engraving and map-printing was done by contract. Since that date a part has been done by contract and a part by the division. Contract work has not diminished, but work done by the division has steadily and rapidly increased. Begun on a limited scale last year, expansion has steadily followed, organization been perfected, and an increasing output of results made.

This division now employs 12 persons: 1 chief, 7 engravers, 2 printers, and 2 assistants. At the beginning of the year it employed 1 chief, 4 engravers, and 1 printer. The machinery at the beginning of the year consisted of 2 hand lithographic presses and a copper-plate press. In addition to those it now has, installed and in use, a Hoe lithographic power press No. 3, an Emmerich and Vanderlehr stone-grinding machine, a Cottrell copper-routing machine, a C. & C. four-horse power electric motor, and a Brown & Carver 44-inch paper-cutting machine. These are all in use and wholly satisfactory. Besides these it has 1,557 engraved copper plates, a large supply of lithographic stones, paper, printing material, and a lot of furniture and instruments used for engraving and printing purposes.

At the beginning of the year the division occupied two small rooms, one containing the chief and 4 engravers, the other the printer, the presses, and their belongings. It now occupies four rooms, two containing the engravers and one the chief, and the fourth being the press-room, about three times as large as the former one. The division is well prepared to meet current demands upon it, but further expansion will be necessary if the demands continue to grow as they are now doing and promise to continue doing. Its most important need is additional room.

ENGRAVING.

Personnel.—Messrs. H. T. Knight, O. J. Stuart, W. D. Evans, and E. H. Daniel have been employed throughout the year. Mr. A. Kress joined the division in July, 1890, Mr. C. J. Helm in February, 1891, and Mr. L. E. Davis in March, 1891.

Work done.—The work of the engravers has consisted in:

(1) The production of a series of copper plates bearing patterns designating geologic features. Of these plates 11 have been completed after repeated studies and trials both as to acceptability of pattern and method of execution. By a method of surface printing from engraved copper plates one of the chief obstacles to the production of these plates has been overcome.

(2) The engraving of 24 topographic atlas sheets of the area known as the Arkansas Coal Belt. These sheets on a scale of 1 : 62500 were, as usual, engraved on 3 plates showing respectively public culture, drainage, and topography. The work was done in conjunction and by an arrangement with the Geological Survey of Arkansas. The manuscript maps from which these engravings were made did not conform to the atlas sheets as engraved, and thus joining as well as engraving was necessary, a matter of considerable labor and difficulty.

(3) The engraving of topographic atlas sheets produced by the Survey. The Desplaines, Riverside, Larned, and Cheney atlas sheets were completely engraved and work begun on the Carson, Golden, Baltimore, and Relay sheets.

(4) The engraving of a base map of the United States, size 17 by 28 inches, scale 1 : 7,000,000, containing 1,000-foot contours, has been begun recently; also, an index or progress map to show the location of the various sheets and the progress of survey and publication.

(5) The engraving of other new work as follows: (*a*) Example of surveyed control of a reservoir, 3 plates; (*b*) map of Clear Lake, 3 plates; (*c*) map of Snake River Canal Line, 3 plates; (*d*) map of drainage basin of Bear River, 4 plates; (*e*) sketch map of Alaska, 1 plate; (*f*) diagram segregation of lands; (*g*) diagram used in noting discharge of rivers; (*h*) the addition of Rhode Island and part of Connecticut to the previously engraved wall map of Massachusetts.

(6) Revision of engraved plates. Much time, care, and labor is spent in revising, correcting, and adding new data to the plates. This work is essential in order to have the maps keep pace with the changes, par-

ticularly in regions of rapid development, and be kept up to the latest information.

(7) Some engraving of an experimental character has been done, and a few plates have been engraved bearing diagrams, scales, sketches, etc.

PRINTING.

Before the creation of the division, office editions of the various atlas sheets were printed and obtained from the engravers under contract. The establishment of a map-printing office in the Survey has done away with this practice. All atlas sheets are now printed in the Survey and much more cheaply than was done by contract. It is also found advantageous to have presses at command, so that the delay due to contracts may be avoided. For some atlas sheets there is an active demand, for others a less demand. Thus all copies of certain sheets are quickly used up, and much of the labor of the press room has consisted in printing additional copies of these sheets, editions ranging from 50 to 500. They are usually printed in three colors, public culture in black, drainage in blue, and hill forms in brown, but departures from this usage for special needs are not infrequent. The atlas sheets are all engraved on copper, on three plates, and then, for the most part, transferred to and printed from stone. As each transfer involves a few dollars' expense, a few transfers have been made to zinc for preservation and resulting economy. It is proposed to make more extended use of this zincographic process hereafter.

Work done.—The work of the printing section has consisted, in addition to transferring, proving, printing, stone-grinding, printing of plate proofs, and various bits of unclassified work, of: (1) The printing of 26,000 atlas sheets, each in three colors. (2) The printing of 3,000 copies of a contour map of the United States. This is a contour map, 49 by 81 inches, on a scale of 1 : 2,500,000, or about 40 miles to the inch, and is printed in four colors. It is composed of nine sheets. (3) The printing of an edition of 750 copies of a chart for the U. S. Hydrographic Office entitled "Tracks Followed by Full-powered Steam Vessels." This chart is in two sheets and in three colors.

Personnel.—In December, 1890, Mr. Donald Barr, who had been employed as printer since the organization of the division, left it and was succeeded by Mr. R. H. Payne, of New Jersey, who has discharged his difficult and delicate duties with fidelity, zeal, and ability. Since March, 1891, Mr. Hermann Krauss, of New York, has been employed as pressman and has given satisfaction. Mr. J. B. Altmann has continued his position as printer and general assistant in the press room. Of late, also, Mr. W. C. Souder has rendered useful service in the press room.

The total number of engraved copper plates on hand June 30, 1891, is 1,557, and the total number of atlas sheets engraved is 500.

Respectfully submitted.

S. J. KÜBEL,
Chief Engraver.

Hon. J. W. POWELL,
Director.

REPORT OF MR. W. A. CROFFUT.

U. S. GEOLOGICAL SURVEY,
EDITORIAL DIVISION,
Washington, D. C., June 30, 1891.

SIR: This division was occupied during the fiscal year in examining manuscripts and proofs of annual reports, papers, monographs, and bulletins which the Director approved for publication. It is gratifying to announce that the publication of the annual reports, monographs, and bulletins of the Survey, with the earnest cooperation of authors and of the Public Printer and his assistants, has at last been brought up to date. The editorial work of the year which this progress involved is outlined thus:

Manuscript and proof read.

Manuscript read.	Proof read.
Eleventh Annual, part II. Bulletins 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, and 91.	Tenth Annual Report. Eleventh Annual Report. Monograph XVII. Bulletins 58, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80 (in part), 81 (in part).

This aggregates as follows:

Galleys received from Public Printer	2,390
Galleys corrected and returned	2,250
Pages received from Public Printer	10,976
Pages corrected and returned	10,729

Bulletins 58, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, and 77, Monograph I, Mineral Resources of the United States for 1888, Ninth Annual Report, 1887-'88, and Tenth Annual Report, 1888-'89, have been published during the year.

The following are the publications designated:

Eleventh Annual Report of the U. S. Geological Survey, 1889-'90, by J. W. Powell.

Monograph XVII, The Flora of the Dakota Group, a posthumous work, by Leo Lesquereux.

BULLETINS.

58. The Glacial Boundary in Western Pennsylvania, Ohio, Kentucky, Indiana, and Illinois, by George Frederick Wright, with an introduction by Thomas Chrowder Chamberlin.
62. The Greenstone Schist Areas of the Menominee and Marquette Regions of Michigan, a contribution to the subject of dynamic metamorphism in eruptive rocks, by George Huntington Williams, with an introduction by Roland Duer Irving.
63. A Bibliography of Paleozoic Crustacea from 1698 to 1889, including a list of North American species and a systematic arrangement of genera, by Anthony W. Vogdes.

64. A report of work done in the Division of Chemistry and Physics, mainly during the fiscal year 1888-'89. F. W. Clarke, chief chemist.
65. Stratigraphy of the Bituminous Coal Fields of Pennsylvania, Ohio, and West Virginia, by Israel C. White.
66. On a Group of Volcanic Rocks from the Tewan Mountains, New Mexico, and on the Occurrence of Primary Quartz in Certain Basalts, by Joseph Paxson Iddings.
67. The Relations of the Traps of the Newark System in the New Jersey Region, by Nelson Horatio Darton.
68. Earthquakes in California in 1869, by James Edward Keeler.
69. A Classed and Annotated Bibliography of Fossil Insects, by Samuel Hubbard Scudder.
70. Report on Astronomical Work of 1889 and 1890, by Robert Simpson Woodward.
71. Index to Known Fossil Insects of the World, including Myriapods and Arachnids, by Samuel Hubbard Scudder.
72. Altitudes between Lake Superior and the Rocky Mountains, by Warren Upham.
73. The Viscosity of Solids, by Carl Barus.
74. The Minerals of North Carolina, by Frederick Augustus Genth.
75. Record of North American Geology for 1887 to 1889, inclusive, by Nelson Horatio Darton.
76. A Dictionary of Altitudes in the United States (second edition), compiled by Henry Gannett.
77. The Texan Permian and its Mesozoic Types of Fossils, by Charles A. White.
78. A report of work done in the Division of Chemistry and Physics, mainly during the fiscal year 1889-'90. F. W. Clarke, chief chemist.
79. A Late Volcanic Eruption in Northern California, and its peculiar lava, by J. S. Diller.
80. Correlation papers—Devonian and Carboniferous, by Henry Shaler Williams.
81. Correlation papers—Cambrian, by Charles Doolittle Walcott.
82. Correlation paper—Cretaceous, by Charles A. White.

Respectfully,

W. A. CROFFUT, *Editor.*

Hon. J. W. POWELL,
Director.

REPORT OF MR. CHAS. C. DARWIN.

U. S. GEOLOGICAL SURVEY,
DIVISION OF LIBRARY AND DOCUMENTS,
Washington, D. C., June 30, 1891.

SIR: I have the honor to present the following statement of work done during the past year in this division and its three branches of Library, Documents, and Correspondence:

LIBRARY.

The growth of the library this year is the largest in its history and has required the removal of one class division into a room separate from the main library. The accession of pamphlets has made necessary the transfer of the pamphlet collection to one of the document rooms and the construction of additional cases for its preservation; the largely increased number of maps has broken the simple arrangement heretofore followed and required the erection of new cases in a separate room. Thus the books and maps handled daily are now stored in four rooms instead of in one as formerly.

The total number of accessions for the year in books, pamphlets, and maps is 7,717, making the contents of the library as shown below:

Contents of the library June 30, 1891.

	Books.	Pamphlets.	Maps.	Total.
On hand June 30, 1890	27,515	37,957	20,000	85,472
Received 1890-'91 by exchange	1,471	3,060	2,337	7,717
Received 1890-'91 by purchase	649	200		
On hand June 30, 1891	29,635	41,217	22,337	93,189

The average circulation is now about 1,060 volumes per month.

Seven hundred books were sent to the Government bindery during the year and 1,048 volumes returned bound—including 496 of those sent last year.

The cataloguing is fully up to date.

DOCUMENTS.

The list of publications of the Survey corrected to June 30, 1891, is given in the advertisement to this volume.

Exchange.—Four thousand five hundred and thirty-one books and pamphlets and a number of maps have been received during the year by exchange and 8,116 sent out.

The library has distributed publications by way of exchange as follows:

Exchange distribution.

	Copies.
Monograph I	736
Mineral Resources, 1888	738
Bulletin 58	738
Bulletin 59	738
Bulletin 60	738
Bulletin 61	738
Bulletin 63	738
Bulletin 64	738
Bulletin 66	738
Ninth Annual Report	1,476
Total	8,116
United States atlas sheets	3,486
Total	11,602

Sales.—The sale account shows that 4,187 copies of survey publications have been sold during the last year as against 2,931 sold during the year preceding.

Free distribution.—34,689 volumes and 2,600 proofs of atlas sheets have been distributed gratuitously. This includes twenty sets of the following: Monographs II to XII, Bulletins 1 to 40, and Mineral Resources for 1882, 1883–'84, 1885, and 1886, and eight hundred sets of the following: Monographs I, XIII to XVI, Mineral Resources for 1887 and for 1888, and Bulletins 41 to 64, making 27,520 volumes, all of which were furnished to the Secretary of the Interior for distribution to the libraries entitled to receive them under the "joint resolution to distribute copies of special memoirs and reports of the U. S. Geological Survey."

The work done by the document branch of the library during the year is exhibited in the following table:

Publications distributed in 1890–'91.

Books distributed gratuitously	34,689
Books sent out in exchange	8,116
Books sold	4,187
Proofs of atlas sheets sent gratuitously	2,600
Proofs of atlas sheets sent in exchange	3,486
Total number of books and maps distributed	53,078

The correspondence of the division has amounted to 11,110 letters sent and 17,345 letters received, a daily average of over 36 letters sent and over 56 letters received. The files and indexes of these letters and the records of publications distributed are fully up to date.

Recapitulation.

LIBRARY.

Accessions:	
Books	2,120
Pamphlets	3,260
Maps	2,337
Making total contents	93,189

Documents.

Received from Public Printer	59,000
Distributed by exchange	8,116
Distributed gratuitously	34,689
Sold	4,187
Atlas sheets distributed	6,086

Correspondence.

Letters received	17,345
Letters sent out	11,110

I am, sir, very respectfully,

CHAS. C. DARWIN,
Librarian.

HON. J. W. POWELL,
Director.

REPORT OF MR. W. F. MORSELL.

U. S. GEOLOGICAL SURVEY,
MISCELLANEOUS DIVISION,
Washington, D. C., June 30, 1891.

SIR: I have the honor to submit the following report of work done in the Miscellaneous Division during the year ending June 30, 1891.

The business of the division falls mainly under two general heads, (1) the keeping of records of correspondence, of appointments, and of attendance and leaves of absence, and (2) the framing and writing of letters, reports, etc.

The number of letters received and recorded during the year was 3,050, a daily average of 10, the total being about the same as last year. The number of outgoing letters and reports recorded is about the same as the number received. About half of these were written in the Miscellaneous Division while the other half, though signed by the Director or the Chief Clerk, were written in other divisions and merely recorded and mailed in the Miscellaneous Division. The records of letters sent and letters received are twofold records, consisting each of a bound register and a card brief. This system, after long trial, is found to be simple, accurate, and satisfactory. Appointments, original and other, to the number of 125 or thereabouts, were recorded, as were also the resignations and other separations of the year, and a brief record of persons temporarily employed without formal appointment was also kept. The system of record used for appointments is, like that for the correspondence, a twofold one. The keeping of the record of attendance and leaves of absence consumed about half the time of one clerk, being a task of considerable detail.

In addition to the general correspondence above referred to there were compiled each month for the Secretary of the Interior three reports, viz, (1) the monthly report of the operations of the Survey, (2) the report of employees and changes in personnel, and (3) (until quite recently, when the Department abandoned the requirement) a report of attendance.

In addition to the work above indicated much work of a miscellaneous character was done by the division, including shorthand dictations received from various officers, the copying of manuscripts and permanent indices, the drawing of requisitions on the Department for the Survey printing, etc.

I am, with respect, your obedient servant,

WM. F. MORSELL,
In charge.

Hon. J. W. POWELL,
Director.

REPORT OF MR. JNO. D. McCHESNEY.

UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., July 30, 1891.

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, 1891, amounting to $618,615.33.

Very respectfully,

JNO. D. MCCHESNEY,
Chief Disbursing Clerk.

HON. J. W. POWELL,
Director U. S. Geological Survey.

Abstract of disbursements made by Jno. D. McChesney, chief disbursing clerk U. S. Geological Survey, during the fiscal year 1890–'91.

SALARIES, OFFICE OF DIRECTOR.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
July 31	1	G. P. Marvine	Services, July, 1890	$60.60
31	2	May S. Clark	...do	60.60
31	3	Pay roll of employés	...do	2,831.60
Aug. 15	1	John D. Sheehan	Services, August 1 to 14, 1890	27.39
30	2	Pay roll of employés	Services, August, 1890	2,816.00
Sept. 27	1	May S. Clark	...do	60.60
30	2	Pay roll of employés	Services, September, 1890	2,643.80
Oct. 4	1	J. D. Harrover	Services, September 27 to 30, 1890	5.22
29	2	May S. Clark	Services, September, 1890	58.80
31	3	Pay roll of employés	Services, October, 1890	2,695.20
Nov. 17	1	Henry A. Connor	Services, November 1 to 15, 1890	24.46
21	2	May S. Clark	Services, October, 1890	60.60
30	3	Pay roll of employés	Services, November, 1890	2,660.20
Dec. 30	1	...do	Services, December, 1890	2,945.97
1891.				
Jan. 31	1	...do	Services, January, 1891	3,060.30
Feb. 28	1	...do	Services, February, 1891	2,764.40
Mar. 31	1	...do	Services, March, 1891	3,060.30
Apr. 15	1	J. D. Harrover	Services, April 1 to 10, 1891	13.19
30	2	Pay roll of employés	Services, April, 1891	2,916.12
May 29	1	...do	Services, May, 1891	3,026.30
June 30	1	...do	Services, June, 1891	2,870.05
30	2	G. P. Marvine	...do	59.30
		Total		34,721.00

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

1890.				
July 21	1	Justinian Caire	Odometer	$15.00
22	2	J. Stanley Brown	Traveling expenses	89.75
24	3	J. S. Diller	...do	72.05
24	4	A. Carlisle & Co.	Supplies	6.45
24	5	Cone & Kimball Company	Subsistence supplies	58.23
28	6	Goldberg, Bowen & Co.	Field subsistence	58.81
28	7	Isaiah Rendall	Field supplies	62.32
28	8	Golden Gate Woolen Manufacturing Company.	Blankets	15.00
29	9	Isaiah Rendall	One horse	100.00
29	10	Joseph Sellwood	Field subsistence	25.01
29	11	Northern Pacific R. R	Transportation of assistants	87.80
31	12	J. Stanley Brown	Services, July, 1890	101.10
31	13	C. Whitman Cross	...do	168.50
31	14	Lawrence C. Johnson	...do	117.90
31	15	Bailey Willis	...do	252.70
31	16	N. S. Shaler	...do	270.00
31	17	H. W. Turner	...do	134.80
31	18	W. Lindgren	...do	134.80

Abstract of disbursements made by Jno. D. McChesney, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
July 31	19	J. S. Diller	Services, July, 1890	$202.20
31	20	I. C. Russell	...do	202.20
31	21	G. F. Becker	...do	337.00
31	22	W. J. McGee	...do	252.70
31	23	O. C. Marsh	...do	337.00
31	24	J. B. Hatcher	...do	250.00
31	25	F. Berger	...do	80.00
31	26	H. Gibb	...do	70.00
31	27	O. A. Peterson	...do	65.00
31	28	Peter Olsen	...do	55.00
31	29	W. H. Utterback	...do	55.00
31	30	F. H. Knowlton	...do	117.90
31	31	Samuel H. Scudder	...do	210.60
31	32	J. Henry Blake	...do	151.60
31	33	Nelson H. Darton	...do	126.40
31	34	Mark B. Kerr	...do	151.60
31	35	T. Nelson Dale	...do	150.00
31	36	Julius Pfister	...do	29.67
31	37	Benjamin G. Palmer	...do	25.00
31	38	Benjamin K. Emerson	...do	100.00
31	39	F. C. Boyce	...do	60.00
31	40	C. L. Whittle	...do	100.00
31	41	A. C. Peale	...do	148.80
31	42	Washington Gaslight Co	Laboratory supplies	43.26
31	44	Ira Sayles	Services, July, 1890	117.90
31	45	T. W. Stanton	...do	75.80
31	46	W. S. Bayley	...do	135.00
31	47	C. R. Van Hise	...do	337.00
31	48	George E. Luther	...do	101.10
31	49	James H. Drummond	Services, July 10 to 31, 1890	53.22
31	50	Gilbert Van Ingen	Traveling expenses	46.90
31	51	A. C. Peale	Services, July, 1890	168.50
31	52	Walter H. Weed	...do	151.60
31	53	Pay roll of employés	...do	589.70
31	54	...do	...do	817.10
31	55	...do	...do	1,182.60
31	56	...do	...do	1,369.77
31	57	...do	...do	1,171.50
31	58	...do	...do	1,111.30
31	59	...do	...do	799.70
31	60	...do	...do	370.60
31	62	John Tyner	Services, July 1 to 15, 1890	29.03
31	63	Charles Atcheson	Services, July 1 to 14, 1890	27.09
31	64	William B. Clark	Services, July, 1890	125.00
31	65	Watersmeet Lumber Co	Field subsistence	19.88
31	66	Pay roll of employés	Services, July, 1890	181.10
		Total		14,063.54

APPROPRIATION FOR GEOLOGICAL MAPS OF THE UNITED STATES, 1891.

1890. July 31	1	Pay roll of employés	Services, July, 1890	$803.10

Abstract of disbursements made by Anton Karl, special disbursing agent U. S. Geological Survey, during the month of July, 1890.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

1890.				
July 14	1	Marcus Baker	Traveling expenses	$9.90
19	2	Fauth & Co	Instruments	1,900.00
30	3	William J. Peters	Services, July	134.80
30	4	L. M. Hoskins	...do	108.00
30	5	C. T. Reid	...do	70.80
29	6	G. E. Hyde	...do	75.80
31	7	Edward Kübel	...do	176.90
29	8	W. W. Maxwell	...do	25.00
29	9	Charles M. Yeates	...do	151.60
29	10	Thomas C. Nelson	...do	50.00

Abstract of disbursements made by Anton Karl, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
July 30	11	B. Peyton Legare	Services, July, 1890	$60.00
30	12	Van H. Manning, jr	....do	101.10
29	13	S. S. Gannett	....do	168.50
30	14	Pay roll, Wallace	....do	375.40
29	15	Pay roll, Lovell	....do	310.40
29	16	Pay roll, Cummin	....do	320.44
29	17	Pay roll, Kramer	....do	161.10
29	18	Pay roll, Baldwin	....do	304.82
29	19	Pay roll, Herron	....do	307.70
30	20	Pay roll, Barnard	....do	487.40
30	21	Pay roll, Nell	....do	469.30
30	22	Pay roll, Hackett	....do	305.12
30	23	Pay roll, Cooke	....do	266.90
30	24	Pay roll, Fletcher	....do	491.60
30	25	Pay roll, Urquhart	....do	231.10
30	26	Pay roll, Blair	....do	395.60
29	27	Pay roll, Hawkins	....do	252.90
29	28	Pay roll, Smith	....do	155.80
31	29	Hersey Munroe	....do	84.20
30	30	John H. Klemroth	....do	134.80
31	31	Philip Vasa Mohun	....do	50.00
30	32	Pay roll, Wilson	....do	145.80
31	33	Pay roll, Gordon	....do	323.70
30	34	Pay roll, Sutton	....do	193.70
31	35	R. Lee Longstreet	....do	101.10
31	36	Pay roll, Karl	....do	3,544.85
31	37	Pay roll, Towson	....do	242.90
31	38	W. A. Callahan	....do	4.84
31	39	L. D. Brent	....do	75.80
31	40	D. C. Harrison	....do	117.90
31	41	William J. Peters	Field expenses	46.30
31	42	....do	....do	39.15
31	43	....do	....do	40.50
31	44	....do	....do	121.70
31	45	Van H. Manning, jr	....do	120.75
31	46	Louis Nell	....do	99.00
31	47	....do	....do	80.64
31	48	....do	Traveling expenses	8.35
31	49	A. E. Murlin	Field expenses	66.26
31	50	E. C. Barnard	....do	66.08
31	51	Robert D. Cummin	....do	94.26
31	52	Pay roll, Murlin	Services, July, 1890	308.70
		Total		13,979.26

Abstract of disbursements made by Jno. D. McChesney, chief disbursing clerk U. S. Geological Survey, during August, 1890.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

1890.				
Aug. 9	1	Raphael Pumpelly	Services, July, 1890	$337.00
9	2	Frank Leverett	....do	135.00
9	3	W. S. Bayley	Traveling expenses	43.50
9	4	S. F. Emmons	....do	81.65
9	5	H. B. Hitz	....do	86.65
9	6	T. Nelson Dale	....do	28.20
9	7	Bailey Willis	....do	29.62
9	8	....do	Cash paid for expenses	103.56
9	9	J. S. Diller	....do	147.54
9	10	William T. Finch	Services, July 7 to 8, 1890	3.00
9	11	G. W. Metcalf	Services, July 5 to 31, 1890	17.41
9	12	A. Hermann	Services, July, 1890	84.20
9	13	William P. Rust	....do	81.00
9	14	Warren Upham	....do	101.10
11	15	Alpheus Hyatt	....do	250.00
11	16	L. G. Thompson, agent	Care and forage of animals	25.46
12	17	Pay roll of employés	Services, July, 1890	100.00
12	18	Joseph A. Holmes	....do	135.00
12	19	W. H. Snyder	....do	50.00
12	20	J. E. Wolff	....do	117.90
12	21	Collier Cobb	....do	50.00
12	22	George H. Williams	....do	135.00
12	23	Gilbert Van Ingen	....do	75.00
12	24	William H. Hobbs	Services, July 7 to 31, 1890	80.64

Abstract of disbursements made by Jno. D. McChesney, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Aug. 12	25	R. S. Tarr	Services, July 12 to 31, 1890	$34.00
14	26	James M. Safford	Services, July 2 to 25, 1890	92.91
14	27	J. A. Merrill	Services, July, 1890	50.00
14	28	James G. Bowen	Care and forage of animals	39.75
14	29	F. W. Clarke	Traveling expenses	17.60
15	30	W. H. Hobbs	...do	46.27
16	31	Pennsylvania R. R. Co	Transportation of assistants	29.50
16	32	Aug. F. Foerste	Traveling expenses	16.30
16	33	J. B. Woodworth	Services, July, 1890	50.00
16	34	R. E. Dodge	...do	50.00
16	35	Edmund O. Hovey	...do	75.00
16	36	W. T. Lander	...do	75.00
16	37	William Orr, jr	Services, July 11 to 31, 1890	9.00
16	38	Aug. F. Foerste	Services, July 14 to 31, 1890	58.06
16	39	Paul M. Jones	Services, July, 1890	25.00
16	40	John M. Hopkins	...do	30.00
16	41	Herbert Lowell Rich	...do	48.40
16	42	Mary C. Mahon	Services, July 12 to 31, 1890	30.00
19	43	S. F. Morine	Shoeing, etc	54.50
18	44	John H. Klemroth	Traveling expenses	15.70
21	45	Charles D. Walcott	...do	84.72
22	46	Lewis S. Hayden	Publication	5.00
23	47	New York Central and Hudson River R. R.	Transportation of assistants	63.00
26	48	Northern Pacific R. R	...do	88.40
26	49	George Cartner	Publications	7.50
29	50	E. J. Pullman	Supplies	21.29
27	51	David T. Day	Traveling expenses	35.01
30	53	Samuel H. Scudder	Services, August, 1890	210.60
30	54	J. Henry Blake	...do	151.60
30	55	T. W. Stanton	...do	75.80
30	56	F. H. Knowlton	...do	117.90
30	57	Ira Sayles	...do	117.90
30	58	Joseph F. James	...do	101.10
30	59	Eimer & Amend	Laboratory supplies	20.76
29	60	De Lancey W. Gill	Traveling expenses	20.50
30	61	Pay roll of employés	Services, August, 1890	589.70
30	62	...do	...do	1,182.60
30	63	...do	...do	55.09
30	64	...do	...do	1,370.00
30	65	...do	...do	1,013.10
30	66	...do	...do	1,111.30
30	67	...do	...do	799.70
30	68	...do	...do	370.60
		Total		10,758.59

APPROPRIATION FOR GEOLOGICAL MAPS OF THE UNITED STATES, 1891.

1890. Aug. 30	1	Pay roll of employés	Services, August, 1890	$803.10

Abstract of disbursements made by Anton Karl, special disbursing agent U. S. Geological Survey, during August, 1890.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

1890.				
Aug. 16	1	A. E. Murlin	Field expenses	$90.80
16	2	E. C. Barnard	...do	142.02
16	3	L. C. Fletcher	...do	79.84
16	4	...do	...do	63.35
16	5	...do	...do	104.52
16	6	...do	...do	91.82
16	7	...do	...do	154.57
16	8	M. Hackett	...do	86.37
16	9	...do	...do	132.32
16	10	Louis Nell	...do	113.52
16	11	Charles M. Yeates	...do	62.38
16	12	...do	...do	86.75
16	13	R. Lee Longstreet	...do	60.25
16	14	...do	...do	55.75

Abstract of disbursements made by Anton Karl, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Aug. 16	15	R. Lee Longstreet	Traveling expenses	$5.25
16	16	Philip Vasa Mohun	...do	6.95
16	17	R. C. Anderson & Co	Field supplies	61.17
16	18	J. S. Fowler	...do	20.00
16	19	W. G. Chapman	...do	12.00
16	20	W. F. McDonald	Repairs	62.50
16	21	Mrs. C. E. Smith	Services, July	25.00
16	22	C. L. Murlin	...do	40.00
16	23	Mamie M. Peyton	...do	25.00
16	24	A. F. Dudley	Field expenses	91.43
16	25	Glenn S. Smith	...do	134.30
16	26	...do	...do	131.53
16	27	W. H. Lovell	...do	103.30
16	28	W. M. Beaman	...do	113.19
16	29	Lincoln Martin	...do	86.31
16	30	Frank Sutton	...do	164.66
16	31	Marcus Baker	Traveling expenses	30.67
16	32	G. W. Fox	Field expenses	45.00
16	33	William Kramer	...do	97.46
16	34	...do	Traveling expenses	21.71
16	35	Albert M. Walker	...do	48.81
16	36	S. S. Gannett	...do	36.63
16	37	...do	Field expenses	69.97
16	38	M. B. Lambert	...do	170.29
16	39	...do	Traveling expenses	15.47
16	40	Robert D. Cummin	...do	7.96
16	41	...do	Field expenses	125.28
16	42	Ewing Speed	...do	71.63
16	43	...do	Traveling expenses	1.65
16	44	W. F. Shoemaker	Transportation	90.00
16	45	R. O. Gordon	Field expenses	133.10
16	46	Charles F. Urquhart	...do	148.40
16	47	George T. Hawkins	...do	235.15
16	48	H. S. Wallace	...do	36.60
16	49	...do	...do	50.75
16	50	A. E. Wilson	...do	82.75
16	51	H. B. Blair	...do	180.24
16	52	William H. Herron	...do	49.15
16	53	...do	...do	122.25
16	54	Van H. Manning, jr	...do	200.30
16	55	William J. Peters	...do	16.90
16	56	...do	...do	89.25
16	57	G. E. Hyde	...do	152.18
16	58	D. C. Harrison	...do	221.75
16	59	H. L. Baldwin, jr	...do	162.31
16	60	L. C. Fletcher	...do	47.52
16	61	Z. D. Gilman	Instruments	16.00
16	62	Gottlieb Spitzer	Supplies	4.75
16	63	S. J. Haislett	...do	12.00
16	64	Fred A. Schmidt	Paper	41.00
16	65	William D. Clark & Co	Material for mounting maps	39.45
16	66	W. & L. E. Gurley	Instruments	40.00
30	67	S. S. Gannett	Field expenses	102.60
30	68	Charles M. Yeates	Services, August, 1890	151.60
30	69	Thomas C. Nelson	...do	50.00
30	70	Mrs. C. E. Smith	...do	25.00
30	71	W. W. Maxwell	...do	25.00
30	72	G. E. Hyde	...do	75.80
30	73	James Goode	...do	19.35
30	74	R. Lee Longstreet	...do	101.10
30	75	Hersey Munroe	...do	84.20
30	76	S. S. Gannett	...do	168.50
30	77	R. U. Goode	...do	210.60
30	78	John H. Renshawe	...do	210.60
30	79	Pay roll, Lambert	...do	160.80
30	80	Pay roll, Cook	...do	266.90
30	81	Pay roll, Lovell	...do	310.40
30	82	Pay roll, Wallace	...do	375.40
30	83	Pay roll, Nell	...do	469.30
30	84	Pay roll, Murlin	...do	348.70
30	85	Pay roll, Fletcher	...do	491.60
30	86	Pay roll, Sutton	...do	193.70
30	87	Pay roll, Smith	...do	105.80
30	88	Pay roll, Cummin	...do	219.80
30	89	Pay roll, Baldwin	...do	311.60
30	90	Pay roll, Hackett	...do	445.12
30	91	Pay roll, Blair	...do	395.60
30	92	Pay roll, Barnard	...do	487.40

Abstract of disbursements made by Anton Karl, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Aug. 30	93	Pay roll, Gordon	Services, August, 1890	$352.40
30	94	Pay roll, Wright	Services, July, 1890	22.52
30	95	Pay roll, Towson	Services, August, 1890	242.90
30	96	Pay roll, Herron	...do	307.70
30	97	Pay roll, Kramer	...do	161.10
30	98	Pay roll, Hawkins	...do	252.90
30	99	Pay roll, Manning	...do	161.10
30	100	Pay roll, Harrison	...do	193.70
30	101	Pay roll, Urquhart	...do	231.10
30	102	Pay roll, Wilson	...do	145.80
30	103	Pay roll, Peters	...do	297.60
30	104	Pay roll, Karl	...do	3,222.27
30	105	Glenn S. Smith	Field expenses	231.90
		Total		16,950.64

Abstract of disbursements made by Arnold Hague, special disbursing agent U. S. Geological Survey, during August, 1890.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

1890.				
Aug. 31	1	Pay roll of employés	Services, July, 1890	$412.80
31	2	E. H. Shuster	Services, August, 1890	75.80
31	3	Pay roll of employés	Services, July, 1890	177.89
		Total		666.49

Abstract of disbursements made by C. D. Davis, special disbursing agent U. S. Geological Survey, during August, 1890.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

1890.				
Aug. 19	1	Charles Oley	Services, July, 1890	$90.00
19	2	Francis P. King	...do	45.00
19	3	W. M. Davis	...do	25.00
19	4	...do	Traveling expenses	18.55
19	5	R. E. Dodge	...do	48.61
19	6	Aug. F. Foerste	...do	44.53
19	7	William Orr, jr	...do	36.35
19	8	Joseph H. Perry	...do	49.04
19	9	Raphael Pumpelly	...do	375.89
19	10	John S. Mendenhall	Field supplies	10.28
19	11	...do	Field subsistence	126.90
19	12	G. P. Putnam's Sons	Supplies	8.85
20	13	C. W. Hayes	Field supplies, etc	146.27
20	14	Pay roll of employés	Services, July, 1890	256.10
20	15	A. C. Peale	Field expenses	76.85
20	16	W. & L. E. Gurley	Barometer, etc	20.55
21	17	Edmund O. Hovey	Traveling expenses	49.01
21	18	Raphael Pumpelly	...do	11.05
21	19	J. B. Woodworth	...do	47.45
21	20	T. Nelson Dale	...do	36.57
21	21	J. E. Todd	Services, July, 1890	52.50
21	22	Raphael Pumpelly	Rent of rooms, etc., July, 1890	50.15
21	23	J. M. Safford	Field expenses	44.50
22	24	R. S. Tarr	Traveling expenses	46.72
22	25	Richard Bliss	Services, July, 1890	26.70
22	26	Herbert Lorren Rich	Traveling expenses	24.51
22	27	S. Ward Loper	...do	49.74
22	28	J. A. Merrill	...do	49.79
22	29	H. W. Turner	Field expenses	55.70
22	30	G. F. Becker	...do	125.85
22	31	W. J. McGee	Traveling expenses	158.95
26	32	J. M. Hopkins	...do	6.66
26	33	W. T. Lander	...do	18.56
26	34	P. M. Jones	...do	4.96
26	35	W. H. Snyder	...do	48.16
26	36	Aug. F. Foerste	...do	26.40

Abstract of disbursements made by C. D. Davis, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Aug. 30	37	Pay roll of employés	Services, August, 1890	$817.10
30	38	Walter H. Weed	...do	151.60
30	39	G. F. Becker	...do	337.00
30	40	W. J. McGee	...do	252.70
30	41	J. S. Diller	...do	202.20
30	42	I. C. Russell	...do	202.20
30	43	A. C. Peale	...do	168.50
30	44	H. W. Turner	...do	134.80
30	45	F. C. Boyce	...do	60.00
30	46	Lawrence C. Johnson	...do	117.90
30	47	C. Whitman Cross	...do	168.50
30	48	Mark B. Kerr	...do	151.60
30	49	J. Stanley Brown	...do	101.10
30	50	W. Lindgren	...do	134.80
30	51	William H. Hall	...do	100.00
30	52	T. Nelson Dale	...do	150.00
30	53	George W. Metcalfe	...do	20.00
30	54	S. Ward Loper	Services, July, 1890	70.16
30	55	Lawrence C. Johnson	Traveling expenses	63.83
30	56	N. H. Darton	...do	112.23
30	57	W. P. Jenney	Services, July, 1890	185.30
30	58	C. R. Van Hise	Services, August, 1890	337.00
30	59	J. H. Drummond	...do	75.00
30	60	W. S. Bayley	...do	130.00
30	61	George E. Luther	...do	101.10
30	62	W. Lindgren	Field Expenses	61.45
30	63	...do	Traveling expenses	22.00
30	64	J. M. Safford	...do	40.30
30	65	George W. Metcalfe	...do	28.45
30	66	Pay roll of employés	Services, August, 1890	332.70
30	67	William B. Clark	...do	125.00
30	68	Arthur Keith	...do	101.10
30	69	N. S. Shaler	...do	260.00
30	70	C. W. Coman	Services, July, 1890	50.00
		Total		7,678.32

Abstract of disbursements made by Jno. D. McChesney, chief disbursing clerk U. S. Geological Survey, during September, 1890.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

1890.				
Sept. 6	1	John B. Rodgers	Services, August 30 to September 6, 1890.	$33.06
4	2	Washington Gaslight Co	Laboratory supplies	43.38
4	3	W. R. Sawyer	Hire of horse and wagon	26.50
4	4	William P. Rust	Services, August, 1890	104.00
4	5	C. C. Willard	Rent of office, August, 1890	266.66
4	6	Z. D. Gilman	Supplies	205.37
8	7	M. R. Brown	Publications	1.50
8	8	T. W. Stanton	Traveling expenses	120.29
8	9	J. F. Manning	Laboratory supplies	7.50
8	10	P. H. Christie	Services, August 30, 31, 1890	9.75
8	11	Norton Bros	Hire of horse and wagon	12.50
8	12	United States Express Co	Freight, July, 1890	76.30
10	13	John C. Parker	Supplies	.60
10	14	J. W. Queen & Co	Laboratory supplies	6.75
15	16	James S. Hunter	Services, September 9 to 13, 1890	15.00
18	17	Charles S. Prosser	Traveling expenses	102.55
27	18	C. D. White	Services, August, 1890	117.90
29	19	F. W. Clarke	Traveling expenses	54.48
30	20	Samuel H. Scudder	Services, September, 1890	203.80
30	21	Harriet Biddle	Services, July 1 to September 30, 1890.	30.00
30	22	Ira Sayles	Services, September, 1890	114.20
30	23	J. Henry Blake	...do	146.80
30	24	O. C. Marsh	Services, August, 1890	337.00
30	25	...do	Services, September, 1890	326.00
30	26	W. L. Magoon	Services, August, 1890	55.00
30	27	...do	Services, September, 1890	55.00
30	28	O. A. Peterson	Services, August, 1890	65.00
30	29	...do	Services, September, 1890	65.00
30	30	J. B. Hatcher	Services, August, 1890	250.00

Abstract of disbursements made by Jno. D. McChesney, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Sept. 30	31	J. B. Hatcher	Services, September, 1890	$250.00
30	32	W. H. Utterback	Services, August, 1890	55.00
30	33	....do	Services, September, 1890	55.00
30	34	R. W. Westbrook	Services, July 1 to September 30, 1890.	75.00
30	35	W. A. Washburne	....do	90.00
30	36	H. Gibb	Services, August 1 to September 30, 1890.	160.00
30	37	F. Berger	....do	160.00
30	38	L. P. Bush	....do	100.00
30	39	T. A. Bostwick	Services, July 1 to September 30, 1890.	250.00
30	40	A. Hermann	Services, August 1 to September 30, 1890.	165.80
30	41	Baltimore and Ohio R. R. Co	Transportation of assistant	70.50
30	42	E. E. Jackson & Co	Supplies for illustrations	40.00
30	43	Lester F. Ward	Traveling expenses	200.13
30	44	Washington Gaslight Co	Laboratory supplies	42.63
30	45	C. C. Willard	Rent for September, 1890	266.66
30	46	Alpheus Hyatt	Services, August, 1890	250.00
30	47	George W. Shutt	Services, July, 1890	252.70
30	48	....do	Services, August 1 to September 30, 1890.	497.30
30	49	William P. Rust	Services, September, 1890	104.00
30	50	Joseph F. James	....do	97.80
30	51	Pay roll of employés	....do	570.60
30	52	....do	....do	1,154.80
30	53	....do	....do	1,245.53
30	54	....do	....do	703.77
30	55	William Baumann	Services, September 1 to 23, 1890	40.85
30	56	James S. Smith	....do	49.45
30	57	Pay roll of employés	Services, September, 1890	1,171.40
30	58	....do	....do	1,077.40
30	59	....do	....do	775.60
30	60	....do	....do	358.80
		Total		13,182.61

APPROPRIATION FOR GEOLOGICAL MAPS OF THE UNITED STATES, 1891.

1890.				
Sept. 4	1	Z. D. Gilman	Engravers' supplies	$0.80
10	2	E. Morrison	....do	3.00
16	3	Ernest Kübel	Copper plates for maps	53.20
30	4	Pay roll of employés	Services, September, 1890	771.83
		Total		828.83

Abstract of disbursements made by Anton Karl, special disbursing agent U. S. Geological Survey, during September, 1890.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

1890.				
Sept. 4	1	Howard A. Graham	Traveling expenses	$7.45
4	2	Marcus Baker	....do	35.80
8	3	John H. Renshawe	....do	42.98
12	4	Louis Nell	Field expenses	143.74
15	5	A. E. Murlin	....do	52.32
15	6	....do	....do	92.36
15	7	....do	....do	19.89
15	8	M. Hackett	....do	229.43
15	9	....do	....do	103.37
15	10	....do	....do	89.27
15	11	....do	Traveling expenses	14.70
15	12	Charles E. Cook	Field expenses	102.86
15	13	....do	....do	88.24
15	14	C. G. Van Hook	Traveling expenses	29.45
15	15	T. B. Tribble	....do	6.55
15	16	E. C. Barnard	Field expenses	199.90
15	17	....do	....do	279.10

Abstract of disbursements made by Anton Karl, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Sept. 15	18	E. C. Barnard	Field expenses	$85.40
15	19	Louis Nell	...do	167.14
15	20	...do	...do	148.99
15	21	Charles M. Beates	...do	143.52
15	22	William J. Peters	Traveling expenses	21.35
15	23	...do	Field expenses	81.37
15	24	...do	...do	100.78
15	25	...do	...do	83.90
15	26	Van H. Manning, jr	...do	62.70
15	27	...do	...do	116.82
15	28	L. C. Fletcher	...do	124.63
15	29	...do	...do	86.58
15	30	...do	...do	96.29
15	31	...do	...do	124.75
15	32	William H. Herron	...do	90.82
15	33	...do	...do	30.45
15	34	...do	...do	29.40
15	35	...do	...do	61.35
15	36	...do	...do	95.10
15	37	H. S. Wallace	...do	38.90
15	38	R. M. Towson	...do	274.85
15	39	H. B. Blair	...do	158.30
15	40	S. S. Gannett	...do	63.70
15	41	...do	Traveling expenses	52.09
16	42	John H. Renshawe	...do	27.10
16	43	H. L. Baldwin, jr	Field expenses	136.22
16	44	G. E. Hyde	...do	92.77
16	45	...do	...do	60.00
16	46	...do	Traveling expenses	51.29
16	47	R. Lee Longstreet	Field expenses	74.95
16	48	...do	...do	54.25
16	49	C. T. Reid	Traveling expenses	20.45
16	50	D. C. Harrison	Field expenses	132.20
16	51	Charles F. Urquhart	...do	118.75
16	52	A. E. Wilson	...do	70.55
16	53	Julius Ulke	Services, August, 1890	35.00
16	54	Amos L. Tittle	Transportation	51.75
16	55	Robert D. Cummin	Field expenses	71.37
16	56	...do	...do	126.58
16	57	...do	Traveling expenses	12.72
16	58	Judson D. Lincoln	...do	6.50
16	59	W. H. Lovell	Field expenses	103.00
16	60	Lincoln Martin	...do	97.00
16	61	A. F. Dudley	...do	100.00
16	62	William Kramer	Traveling expenses	22.69
16	63	...do	Field expenses	72.37
16	64	Julien J. Mason	Traveling expenses	7.05
16	65	...do	Field expenses	27.37
16	66	J. J. Mason	...do	54.50
16	67	Albert M. Walker	...do	32.90
16	68	...do	Traveling expenses	10.43
16	69	M. B. Lambert	...do	8.30
16	70	...do	Field expenses	175.72
16	71	Ewing Speed	...do	32.07
16	72	...do	Traveling expenses	7.00
16	73	W. M. Beaman	Field expenses	126.61
16	74	Floumoy Bros	Subsistence and forage	100.80
16	75	...do	Subsistence	155.75
16	76	W. F. Shoemaker	Transportation	36.12
17	77	Herbert M. Wilson	Services, August, 1890	40.76
18	78	Fauth & Co	Instruments	112.50
18	79	Frank Sutton	Field expenses	186.56
18	80	Nannie M. Peyton	Services, August, 1890	25.00
19	81	The Chattanooga Saddlery Co	Field supplies	18.00
24	82	C. G. Van Hook	Field expenses	66.10
29	83	S. A. Aplin	Traveling expenses	33.95
30	84	Judson D. Lincoln	...do	21.70
30	85	H. S. Wallace	Field expenses	89.55
30	86	Anton Karl, pay roll	Services, September, 1890	3,681.40
30	87	A. E. Murlin, pay roll	...do	342.60
30	88	John H. Renshawe	...do	203.80
30	89	George T. Hawkins, pay roll	...do	299.20
30	90	R. O. Gordon, pay roll	...do	392.60
30	91	Glenn S. Smith, pay roll	...do	103.40
30	92	Thomas S. Clark	...do	25.00
30	93	...do	Traveling expenses	45.45
30	94	A. A. Curtis	Services, September, 1890	20.00
30	95	C. G. Van Hook	...do	81.60
30	96	M. Hackett, pay roll	...do	350.40
30	97	R. M. Towson, pay roll	...do	239.20

Abstract of disbursements made by Anton Karl, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Sept. 30	98	Louis Nell, pay roll	Services, September, 1890	$414.80
30	99	R. Lee Longstreet	...do	97.80
30	100	Charles M. Yeates	...do	146.80
30	101	William Kramer, pay roll	...do	157.80
30	102	L. C. Fletcher, pay roll	...do	481.80
30	103	W. H. Lovell, pay roll	...do	304.20
30	104	M. B. Lambert, pay roll	...do	199.90
30	105	W. W. Maxwell	...do	25.00
30	106	G. E. Hyde	...do	73.40
30	107	Thomas C. Nelson	...do	50.00
30	108	L. M. Hoskins	...do	8.00
30	109	Robert D. Cummin, pay roll	...do	165.40
30	110	Charles E. Cooke, pay roll	...do	192.80
30	111	D. C. Harrison, pay roll	...do	187.60
30	112	E. C. Barnard, pay roll	...do	380.20
30	113	Frank Sutton, pay roll	...do	187.60
30	114	H. B. Blair, pay roll	...do	338.80
30	115	Van H. Manning, jr., pay roll	...do	157.80
30	116	Philip Vasa Mohun	...do	50.00
30	117	R. Lee Longstreet	Field expenses	54.80
30	118	R. O. Gordon	...do	304.85
30	119	Louis Nell	...do	169.47
30	120	Van H. Manning, jr	...do	338.00
30	121	William H. Herron	...do	56.00
30	122	M. Hackett	...do	427.74
30	123	William J. Peters	...do	89.40
30	124	...do	...do	6.30
30	125	Charles M. Yeates	...do	236.12
30	126	L. C. Fletcher	...do	133.20
30	127	...do	...do	54.30
30	128	R. U. Goode	Traveling expenses	80.85
30	129	Joseph W. Jones	...do	9.39
		Total		18,138.61

Abstract of disbursements made by C. D. Davis, special disbursing agent, U. S. Geological Survey, during September, 1890.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Sept. 3	1	G. K. Gilbert	Traveling expenses	$80.60
3	2	Arthur Keith	...do	50.45
6	3	J. M. Safford	Services, August, 1890	78.26
6	4	R. S. Tarr	...do	50.00
6	5	J. M. Hopkins	...do	14.52
6	6	W. T. Lander	...do	38.71
6	7	J. E. Wolff	...do	95.11
6	8	Benjamin G. Palmer	...do	25.00
6	9	C. L. Whittle	...do	100.00
6	10	P. M. Jones	...do	15.32
6	11	Gilbert van Ingen	...do	75.00
6	12	W. R. Lee Porter	...do	69.68
6	13	Francis P. King	...do	45.00
6	14	Charles Oley	...do	90.00
6	15	Harry W. Wentworth	...do	60.00
6	16	Richard McCulloch	...do	60.00
6	17	J. B. Woodworth	...do	50.00
6	18	Pay roll of employés	...do	256.10
6	19	...do	...do	100.00
6	20	Henry B. Hitz	Traveling expenses	51.55
6	21	Albert P. Brigham	...do	42.55
6	22	R. S. Tarr	...do	97.85
6	23	J. B. Woodworth	...do	68.92
6	24	S. F. Emmons	...do	76.60
6	25	...do	Field expenses	17.00
6	26	A. P. Baker	Office rent, August, 1890	43.75
8	27	Joseph Sellwood	Subsistence	23.19
8	28	...do	Supplies	28.39
8	29	Raphael Pumpelly	Office supplies	14.55
8	30	Warren Upham	Services, August, 1890	101.10
9	31	Aug. F. Foerste	...do	100.00
9	32	...do	Traveling expenses	59.59
9	33	Bailey Willis	Field expenses	110.17
9	34	J. M. Safford	Traveling expenses	45.72
9	35	C. W. Hayes	Field expenses	113.03

Abstract of disbursements made by C. D. Davis, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Sept. 9	36	W. J. McGee	Traveling expenses	$161.73
10	37	J. E. Wolff	Field supplies	8.01
10	38	...do	Traveling expenses	23.25
10	39	Raphael Pumpelly	Services, August, 1890	337.00
10	40	W. P. Jenney	...do	185.30
11	41	Collier Cobb	...do	50.00
11	42	Benjamin K. Emerson	...do	100.00
11	43	T. Nelson Dale	...do	48.49
13	44	S. Ward Loper	...do	72.57
13	45	...do	Traveling expenses	44.17
13	46	E. O. Hovey	...do	39.05
13	47	...do	Services, August, 1890	75.00
13	48	H. L. Rich	...do	46.78
13	49	...do	Traveling expenses	33.76
13	50	George W. Metcalfe	...do	37.76
13	51	N. H. Darton	Services, August, 1890	126.40
13	52	Joseph H. Perry	Services, July and August, 1890	106.00
16	53	R. D. Salisbury	Services, July 7 to September 9, 1890.	275.00
16	54	J. A. Merrill	Services, August, 1890	35.48
16	55	W. M. Davis	...do	20.00
16	56	...do	Traveling expenses	15.04
16	57	Charles S. Merrick	...do	63.08
17	58	S. H. Davis	...do	32.52
17	59	R. E. Dodge	...do	68.83
17	60	H. W. Turner	Field expenses	78.61
17	61	W. T. Turner	Services, July 23 to August 31, 1890.	32.25
17	62	Julius Dfister	Services, August 1-21, 1890	27.09
17	63	William Orr, jr	Services, August 1 to September 1, 1890.	14.00
17	64	Joseph H. Perry	Traveling expenses	57.73
17	65	William Orr, jr	...do	33.38
17	66	Moritz Fischer	...do	20.55
18	67	Arthur Bibbins	Services, July and August, 1890	88.71
19	68	C. W. Coman	Services, August, 1890	50.00
20	69	G. K. Gilbert	Traveling expenses	24.06
20	70	J. H. Drummond	Services, September 1-14, 1890	35.00
22	71	Joseph Sellwood	Field expenses	17.44
22	72	J. E. Todd	Cash paid for services	24.20
22	73	Gilbert van Ingen	Field expenses	11.97
24	74	Richard McCulloch	Services, September 1-15, 1890	30.00
26	75	W. Lindgren	Field expenses	152.97
26	76	J. S. Diller	Services, September, 1890	195.60
29	77	I. C. Russell	...do	195.60
29	78	W. Lindgren	...do	130.40
29	79	H. W. Turner	...do	130.40
29	80	Seth. C. Hathaway	Services, August 24 to September 30, 1890.	50.32
29	81	F. C. Boyce	Services, September, 1890	60.00
29	82	J. Stanley Brown	...do	97.80
29	83	C. Whitman Cross	...do	163.00
29	84	N. H. Darton	...do	122.20
29	85	George H. Eldridge	...do	163.00
29	86	Lawrence C. Johnson	...do	114.20
29	87	Mark B. Kerr	...do	146.80
29	88	Walter H. Weed	...do	146.80
29	89	G. F. Becker	...do	326.00
29	90	W. J. McGee	...do	244.60
29	91	Pay roll of employés	...do	790.80
29	92	...do	...do	1,066.70
30	93	...do	...do	324.60
30	94	A. C. Peale	...do	163.00
30	95	Charles S. Merrick	Services, August, 1890	52.00
30	96	W. R. Lee Porter	Services, September 1 to 10, 1890	20.00
30	97	William H. Hobbs	Services, September 1 to 5, 1890	16.66
30	98	Morrison Brothers	Subsistence	25.62
30	99	N. H. Darton	Traveling expenses	145.31
30	100	Arthur Bibbins	Services, September, 1890	50.00
30	101	W. H. Snyder	Traveling expenses	32.90
30	102	R. E. Dodge	Services, August, 1890	50.00
30	103	...do	Services, September, 1890	50.00
30	104	J. B. Woodworth	...do	50.00
30	105	William B. Clark	...do	125.00
30	106	N. S. Shaler	...do	260.00
30	107	Lawrence C. Johnson	Traveling expenses	45.76
30	108	Francis P. King	Services, September, 1890	45.00
30	109	George E. Luther	...do	97.80
30	110	C. R. Van Hise	...do	326.00
		Total		11,074.76

Abstract of disbursements made by Arnold Hague, special disbursing agent U. S. Geological Survey, during September, 1890.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Sept. 19	1	Jos. P. Iddings	Services, July, 1890	$168.50
19	2	Highsmith & Winter	Field material and expenses	122.50
19	3	J. R. Biering	Pasturage	16.00
19	4	Pay roll of employés	Services, July, 1890	210.00
		Total		517.00

Abstract of disbursements made by H. C. Rizer, disbursing agent U. S. Geological Survey, during September, 1890.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

1890.				
Sept. 17	1	William B. Lane	Field expenses	$15.50
17	2	Reeves & Co	Supplies	42.85
17	3	S. A. Newman	Forage	25.20
17	4	Stuart P. Johnson	Field expenses	95.48
18	5	Fred. J. Knight	Traveling expenses	72.55
19	6	W. & L. E. Gurley	Material	43.40
19	7	C. H. Stone	Traveling expenses	24.25
19	8	F. M. Smith	...do	14.00
19	9	William P. Trowbridge, jr	...do	15.50
20	10	John H. Hazelton	...do	18.40
20	11	L. B. Kendall	...do	40.00
20	12	Robert A. Farmer	Field expenses	45.55
20	13	Redick H. McKee	Traveling expenses	126.25
20	14	R. H. Chapman	Field expenses	6.50
20	15	H. E. Clermont Feusier	...do	44.40
22	16	E. M. Douglas	...do	43.29
22	17	...do	...do	49.75
22	18	P. V. S. Bartlett	...do	26.05
22	19	Tenny Ross	Travelingexpenses	19.75
22	20	C. S. Woodrow	Supplies	16.96
22	21	...do	...do	10.73
22	22	G. T. Nash	Supplies and material	157.90
22	23	Kennedy & Orr	Supplies	115.95
22	24	B. F. Acuff & Co	Subsistence	29.32
22	25	...do	Subsistence and supplies	24.61
22	26	W. H. Sanders	Supplies	20.00
22	27	S. C. Gallup	Supplies and material	252.10
22	28	C. C. Huddleston	Supplies	36.34
22	29	J. M. Killin & Co	...do	55.90
22	30	Wilson & Barnard	...do	108.40
22	31	Willard D. Johnson	Field expenses	128.71
22	32	...do	...do	138.19
24	33	Kennedy & Orr	Repairs and supplies	192.47
24	34	R. C. McKinney	Field expenses	29.95
24	35	William H. Herron	...do	68.95
24	36	Jno. W. Hays	...do	123.23
24	37	Charles Himrod	Subsistence	71.95
25	38	E. T. Perkins, jr	Traveling expenses	44.85
25	39	Robert J. Breckenridge	...do	22.25
25	40	Stuart P. Johnson	Field expenses	93.37
25	41	A. F. Dunnington	...do	39.53
25	42	Willard D. Johnson	...do	47.45
25	43	Redick H. McKee	...do	62.46
25	44	H. E. Clermont Feusier	...do	63.85
25	45	Nichols & Yager	Supplies	20.00
26	46	R. C. McKinney	Traveling expenses	26.50
26	47	T. E. Grafton	...do	26.50
26	48	W. B. Corse	...do	59.70
26	49	Jeremiah Ahern	...do	26.00
26	50	Frank E. Gove	...do	25.25
26	51	Jackson & Co	Forage	33.49
27	52	R. H. Chapman	Field expenses	27.85
27	53	William J. Peters	Traveling expenses	9.25
30	54	Pay roll	Services	1,037.20
30	55	...do	...do	364.16
30	56	...do	...do	260.93
30	57	...do	...do	334.72
30	58	...do	...do	280.56
30	59	E. T. Perkins, jr	...do	139.10
30	60	Sparks Bros	Field expenses	1,220.00
30	61	H. E. Clermont Feusier	Services	87.03

Abstract of disbursements made by H. C. Rizer, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Sept. 30	62	P. Hackett	Services	$47.90
30	63	Ah Moon	...do	40.00
30	64	H. C. Rizer	...do	191.36
30	65	...do	Traveling expenses	5.45
30	66	Perry Fuller	Services	78.29
30	67	W. B. Corse	...do	78.29
30	68	E. M. Douglas	...do	173.87
30	69	Pay roll	...do	316.03
30	70	...do	...do	273.01
30	71	...do	...do	231.52
30	72	...do	...do	171.19
30	73	...do	...do	126.19
30	74	...do	...do	324.02
30	75	...do	...do	227.33
30	76	...do	...do	369.20
30	77	...do	...do	227.80
30	78	...do	...do	231.20
30	79	...do	...do	502.10
30	80	...do	...do	366.51
30	81	C. H. Fitch	...do	156.58
30	82	William J. Peters	...do	130.40
30	83	Amos Scott	...do	31.87
30	84	Pay roll	...do	109.66
30	85	...do	...do	372.65
30	86	...do	...do	289.78
30	87	...do	...do	183.71
30	88	...do	...do	234.75
30	89	...do	...do	306.80
30	90	W. T. Griswold	...do	173.87
30	91	Paul Holman	...do	72.97
30	92	Marvin B. Seaman	...do	18.33
30	93	L. H. Cooper	...do	3.33
30	94	B. F. Buckner, jr	...do	3.33
30	95	Jeremiah Ahern	Field expenses	37.50
30	96	Charles F. Urquhart	...do	159.45
30	97	Frank Tweedy	...do	146.33
30	98	...do	...do	77.08
30	99	...do	Traveling	51.25
30	100	Bach, Corny & Co	Subsistence	125.54
30	101	J. H. McKnight & Co	Material	295.05
30	102	G. T. Nash	Supplies	35.44
30	103	R. U. Goode	Services	203.80
30	104	P. V. S. Bartlett	Field expenses	98.56
30	105	W. T. Griswold	...do	53.07
30	106	...do	...do	62.50
30	107	Willard D. Johnson	...do	138.18
30	108	R. B. Marshall	...do	64.50
30	109	R. C. McKinney	...do	70.83
30	110	Spratten & Anderson	Supplies	12.60
30	111	...do	Subsistence	22.59
30	112	...do	...do	61.25
30	113	...do	...do	81.32
30	114	S. C. Gallup	Supplies	80.00
30	115	Andrew McClelland	...do	95.26
30	116	B. F. Acuff & Co	Subsistence	52.95
30	117	...do	...do	45.88
30	118	...do	Supplies	10.36
30	119	Oppenlander & Rehm	Subsistence	23.98
30	120	Jul. Rehm & Co	...do	37.75
30	121	W. H. Hyde	Supplies	39.65
30	122	Lewis Corydon Leonard	Material	62.40
30	123	Frank Frates	Subsistence	57.37
30	124	Kinman & Rickey	...do	54.10
30	125	H. E. Clermont Feusier	Field expenses	40.77
30	126	J. B. Lippincott	...do	93.73
30	127	Gross, Blackwell & Co	Subsistence	79.83
30	128	T. M. Bannon	Services	
		Total		15,395.44

Abstract of disbursements made by Jno. D. McChesney, chief disbursing clerk, U. S. Geological Survey, during October, 1890.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890. Oct. 4	1	F. H. Newell	Services, August 30 to September 30, 1890.	$173.87
4	2	C. D. White	Traveling expenses	280.11
4	3	Cyrus C. Babb	Services, August 30 to September 30, 1890.	63.87
8	4	Joseph F. James	Traveling expenses	82.12
8	5	Callie A. O'Laughlin	Services, October 1 to 8, 1890	17.64
8	6	W. B. Young	...do	19.98
8	7	C. W. Dashiell	...do	23.22
9	8	George Ryneal, jr	Supplies	304.10
9	9	F. H. Knowlton	Services, September, 1890	114.20
9	10	The Humboldt Publishing Co	Publications	5.38
9	11	James M. Hamilton	...do	2.50
10	13	Chesapeake and Ohio R. R. Co	Transportation of assistants	14.00
10	14	The American Tool and Machine Co.	Laboratory supplies	3.60
9	15	National Press Intelligence Co	Newspaper clippings	16.45
10	16	Fanny Gresham	Services, Sept. 22 to Oct. 9, 1890	48.00
11	17	William D. Clark & Co	Laboratory supplies	14.40
11	18	Emil Greiner	...do	35.95
11	19	S. J. Haislett	Topographic supplies	26.00
11	20	E. J. Pullman	Geologic supplies	135.00
13	21	J. S. Bowen	Services, October 1 to 13, 1890	16.12
13	22	Pay roll of employés	...do	219.65
16	23	William M. Fontaine	Services, July, August, and September, 1890.	500.00
16	24	Pay roll of employés	Services, October 1 to 15, 1890	204.54
17	25	S. Ward Loper	Services, September 15 to 30, 1890	62.50
17	26	J. Bishop & Co	Repairs to laboratory material	18.31
17	27	Baker & Adamson	Laboratory supplies	41.54
17	28	Charles D. Walcott	Traveling expenses	145.56
17	29	F. H. Knowlton	...do	82.65
17	30	L. H. Schneider's Son	Supplies	28.62
17	31	L. Feuchtwanger & Co	Laboratory supplies	8.00
17	33	Pennsylvania R. R. Co	Transportation of assistants	263.15
17	34	Chicago and Northwestern R. R. Co.	...do	12.50
18	35	Eimer & Amend	Laboratory supplies	229.33
22	36	United States Express Co	Freight charges, August and September, 1890.	18.30
22	37	J. Stanley Brown	Traveling expenses	79.36
22	38	Henry S. Williams	Services, July 1 to Sept. 30, 1890	375.00
22	39	Wyckoff, Seamans & Benedict	Services, packing typewriter	1.00
22	40	Newman & Son	Repairing caligraph	4.00
22	41	The Eastman Co	Geologic supplies	4.36
22	42	Williams, Browne & Earle	...do	45.40
23	43	E. A. Schneider	Traveling expenses	41.62
23	44	C. A. White	...do	73.73
23	45	Northern Pacific R. R. Co	Transportation of assistants	38.00
29	47	Hubbell, Merwin & Co	Paleontologic supplies	110.95
29	48	Adams Express Co	Freight charges, July and August, 1890.	163.55
29	49	...do	Freight charges, September, 1890	120.41
31	50	Sam H. Scudder	Services, October, 1890	210.60
31	51	Ira Sayles	...do	117.90
31	52	J. Henry Blake	...do	151.60
31	53	William M. Fontaine	...do	168.50
31	54	F. H. Knowlton	...do	117.90
31	55	A. H. Storer	Supplies for mineral resources	9.00
31	56	C. C. Willard	Rent of office rooms	266.66
31	57	Pay roll of employés	Services, October, 1890	180.18
31	58	O. C. Marsh	...do	337.00
31	59	H. Gibb	...do	80.00
31	60	F. Berger	...do	80.00
31	61	O. A. Peterson	...do	65.00
31	62	J. B. Hatcher	...do	250.00
31	63	L. P. Bush	...do	50.00
31	64	W. H. Utterback	...do	55.00
31	65	George W. Shutt	...do	252.70
31	66	Cyrus C. Babb	...do	60.00
31	67	Pay roll of employés	...do	589.70
31	68	...do	...do	1,182.60
31	69	...do	...do	1,277.23
31	70	...do	...do	1,307.90
31	71	...do	...do	1,103.24
31	72	...do	...do	763.96
31	73	...do	...do	370.60
		Total		13,335.81

Abstract of disbursements made by Jno. D. McChesney, etc.—Continued.

APPROPRIATION FOR GEOLOGICAL MAPS OF THE UNITED STATES, 1891.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Oct. 9	1	George Ryneal, jr	Engraver's supplies	$1.60
11	2	William D. Clark & Co	...do	23.59
17	3	Robert Mayer & Co	...do	11.20
18	4	J. B. Hammond	...do	12.50
22	5	Andrew B. Graham	...do	5.00
29	6	Adams Express Co	Freight charges	1.15
31	7	Pay roll of employés	Services, October, 1890	843.10
		Total		898.14

Abstract of disbursements made by Anton Karl, special disbursing agent, U. S. Geological Survey, during October, 1890.

APPROPRIATION FOR UNITED STATES GEOLOGICAL SURVEY.

1890.				
Oct. 6	1	Philip Vasa Mohun	Traveling expenses	$25.60
11	2	Fred. A. Schmidt	Supplies	64.98
16	3	Henry Gannet	Traveling expenses	63.12
21	4	Lewis J. Battle	...do	13.48
21	5	Frank R. Hagner	...do	2.35
21	6	Ewing Speed	...do	7.48
21	7	R. A. Simmons	Field expenses	88.06
21	8	Lincoln Martin	...do	81.49
21	9	Frank Sutton	...do	170.29
21	10	William Kramer	Traveling expenses	22.41
21	11	...do	Field expenses	81.05
21	12	M. B. Lambert	...do	230.80
21	13	...do	Traveling expenses	5.89
21	14	Albert M. Walker	...do	3.24
21	15	...do	Field expenses	28.55
21	16	Glenn S. Smith	...do	180.51
21	17	...do	Traveling expenses	7.50
21	18	Robert D. Cummins	...do	24.47
21	19	...do	Field expenses	202.58
21	20	W. H. Lovell	...do	118.19
21	21	...do	Traveling expenses	12.90
21	22	A. F. Dudley	...do	30.30
21	23	...do	Field expenses	89.60
21	24	W. M. Beaman	...do	109.66
21	25	...do	Traveling expenses	12.24
21	26	Julien J. Mason	...do	11.77
21	27	...do	Field expenses	63.30
21	28	A. L. Tittle	Transportation	30.37
21	29	C. T. Reid	Services, September, 1890	68.40
21	30	Mrs. C. E. Smith	...do	25.00
21	31	Nannie M. Peyton	...do	25.00
21	32	Julius Ulke	...do	35.00
21	33	James W. Queen & Co	Instruments	162.00
21	34	...do	...do	3.11
21	35	Field & Jenkins	Subsistence	85.60
21	36	S. S. Fetterhoff	Subsistence and Transportation	51.25
21	37	J. S. Topham	Supplies	7.25
21	38	S. J. Haislett	Field supplies	25.00
21	39	Melville Lindsay	...do	2.70
21	40	Wyckhoff, Seamans & Benedict	Repairs	32.00
21	41	John W. Price	Pasturage	13.50
21	42	W. F. Fling	Forage	18.00
21	43	Henkel, Craig & Co	Storage	6.00
21	44	Benson Roux & Co	...do	6.00
21	45	J. C. Baker	Transportation	90.00
21	46	Z. N. Lockhard	...do	150.00
21	47	N. B. Dunn	...do	150.00
21	48	L. C. Fletcher	Field expenses	49.70
21	49	...do	...do	84.53
21	50	...do	...do	70.75
21	51	...do	...do	79.40
21	52	Charles E. Cooke	...do	90.04
21	53	R. Lee Longstreet	...do	82.95
21	54	A. E. Murlin	...do	78.57
21	55	M. Hackett	...do	372.87
21	56	Louis Nell	...do	141.02
21	57	E. C. Barnard	...do	290.17

Abstract of disbursements made by Anton Karl, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Oct. 21	58	John H. Renshawe	Traveling expenses	$63.31
21	59	....do	....do	61.11
21	60	R. O. Gordon	Field expenses	139.10
21	61	L. M. Hoskins	Traveling expenses	21.80
21	62	Van H. Manning, jr	Field expenses	128.75
21	63	....do	....do	65.25
21	64	H. B. Blair	....do	225.90
21	65	H. S. Wallace	....do	58.65
21	66	George T. Hawkins	....do	395.13
21	67	William J. Peters	....do	38.50
21	68	....do	....do	68.00
21	69	....do	....do	19.70
21	70	G. E. Hyde	....do	182.85
21	71	D. C. Harrison	....do	113.90
21	72	H. L. Baldwin, jr	....do	147.24
21	73	R. M. Towson	....do	176.25
21	74	Theo. Attemder & Sons	Instruments	19.20
21	75	George S. Harris & Sons	Maps	687.50
21	76	E. C. Barnard	Traveling expenses	59.67
21	77	W. O. Beall	....do	22.15
21	78	Julius Ulke	Services October	22.58
21	79	Benson, Roux & Co	Transportation	180.00
22	80	J. S. Topham	Supplies	18.75
21	81	William Odell	Field expenses	85.50
21	82	Henry J. Green	Instruments	166.00
31	83	Robert D. Cummin, pay roll	October	266.38
31	84	C. G. Van Hook	Services October	84.20
31	85	Louis Nell, pay roll	October	475.10
31	86	Frank Sutton, pay roll	....do	264.50
31	87	A. E. Murlin, pay roll	....do	348.70
31	88	Charles E. Cook, pay roll	....do	236.10
31	89	William Kramer, pay roll	....do	286.90
31	90	George T. Hawkins, pay roll	....do	302.90
31	91	Lewis J. Battle	Services October	60.00
31	92	John H. Renshawe	....do	210.60
31	93	G. E. Hyde	....do	75.80
31	94	Charles M. Yeates	....do	151.60
31	95	M. Hackett, pay roll	October	398.82
31	96	R. M. Towson, pay roll	....do	242.90
31	97	E. C. Barnard, pay roll	....do	407.40
31	98	L. C. Fletcher, pay roll	....do	491.60
31	99	Glenn S. Smith, pay roll	....do	155.80
31	100	H. B. Blair, pay roll	....do	363.99
31	101	S. S. Gannett	Services October	168.50
31	102	W. H. Lovell, pay roll	October	310.40
31	103	Van H. Manning, jr., pay roll	....do	161.10
31	104	D. C. Harrison, pay roll	....do	193.70
31	105	R. Lee Longstreet	Services October	101.10
31	106	Edward Kübel	Services August	171.20
31	107	....do	Services September	5.71
29	108	John H. Klemroth	Services October	126.09
21	109	W. & L. E. Gurley	Instruments	420.00
22	110	Marcus Baker	Traveling expenses	69.97
29	111	H. M. Wilson	....do	70.32
31	112	Anton Karl, pay roll	October	3,659.60
31	113	William H. Griffin	Traveling expenses	19.75
31	114	....do	Field expenses	11.88
		Total		17,557.39

Abstract of disbursements made by C. D. Davis, special disbursing agent, U. S. Geological Survey, during October, 1890.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

1890.				
Oct. 4	1	W. J. McGee	Traveling expenses	$110.90
4	2	Noah R. King	Services, July 21 to October 4, 1890.	152.00
4	3	Charles D. Loughry	....do	190.00
4	4	John B. Bean	Services, August 1, to September 30, 1890.	150.00
4	5	Edward C. Alderson	....do	110.00
4	6	James Forristell	Services, August 5 to October 5, 1890.	155.00
6	7	Frank Leverett	Services, August and September, 1890.	260.00

Abstract of disbursements made by C. D. Davis, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Oct. 6	8	A. C. Peale	Field expenses	$62.05
6	9	R. S. Tarr	Services, September 1 to 20, 1890	33.33
6	10	Gilbert van Ingen	Services, September, 1890	75.00
6	11	C. C. Dorsey	...do	96.00
6	12	Warren Upham	...do	97.80
6	13	Gilbert van Ingen	Traveling expenses	85.62
6	14	Lawrence C. Johnson	...do	61.10
6	15	N. H. Darton	...do	111.07
10	16	James M. Merrill	...do	28.40
10	17	R. S. Tarr	...do	77.30
10	18	Moritz Fischer	...do	49.73
10	19	R. E. Dodge	...do	54.36
10	20	C. R. Eastman	...do	123.58
10	21	Francis P. King	...do	66.92
10	22	S. F. Emmons	...do	153.90
10	23	Henry B. Hitz	...do	134.65
10	24	S. F. Emmons	Field expenses	10.00
10	25	C. W. Hayes	...do	123.76
10	26	Charles J. Moore	Services, August 14 to 30, 1890	150.00
10	27	Harry W. Wentworth	Services, September, 1890	90.00
10	28	Pay roll of employés	...do	252.80
13	29	Charles Oley	Services, September 1 to 18, 1890	54.00
13	30	George H. Barton	Services, August and September, 1890.	160.00
13	31	John B. Bean	Hire of transportation	767.75
13	32	James Forristell	...do	114.75
13	33	Edmund Jussen	Traveling expenses	36.25
13	34	George E. Luther	...do	30.85
13	35	Columbus Freeman	...do	18.00
14	36	Aug. F. Foerste	...do	40.08
14	37	...do	Services, September 1 to 25, 1890	63.33
16	38	James G. Bowen	Repairs to public property	10.60
16	39	A. Prescott Baker	Rent of office rooms	43.75
16	40	T. Nelson Dale	Services, September, 1890	147.93
16	41	Richard Bliss	...do	38.10
16	42	Benjamin K. Emerson	...do	100.00
16	43	W. S. Bayley	...do	125.00
16	44	Benjamin G. Palmer	...do	25.00
16	45	George W. Metcalfe	...do	19.33
16	46	...do	Traveling expenses	31.54
16	47	J. E. Wolff	Field expenses	4.89
16	48	...do	Services, September, 1890	95.11
16	49	Main & Winchester	Supplies	13.59
16	50	F. R. Hathaway	Services, September 1 to 13, 1890	9.50
16	51	T. Nelson Dale	Field supplies	9.03
16	52	G. K. Gilbert	Traveling expenses	186.32
16	53	W. S. Bayley	...do	147.43
16	54	F. R. Hathaway	...do	11.73
16	55	T. Nelson Dale	...do	53.69
17	56	J. E. Wolff	...do	71.36
17	57	Raphael Pumpelly	Services, September, 1890	326.00
17	58	Bailey Willis	Field expenses	167.30
17	59	William H. Hobbs	...do	15.94
17	60	...do	Traveling expenses	148.79
18	61	S. H. Davis	...do	99.47
18	62	...do	Services, July 8 to September 30, 1890.	55.48
18	63	M. A. Read	Traveling expenses	25.30
18	64	H. W. Turner	Field expenses	56.85
28	65	W. H. Dall	Traveling expenses	64.45
28	66	...do	...do	67.20
28	67	...do	...do	146.05
28	68	C. R. Van Hise	...do	437.33
28	69	R. D. Salisbury	...do	394.32
28	70	Heth. Canfield	Services, collecting	9.58
28	71	J. S. Diller	Field expenses	463.28
29	72	...do	Traveling expenses	86.40
29	73	C. R. Van Hise	Services, October, 1890	337.00
29	74	George E. Luther	...do	101.10
29	75	W. J. McGee	...do	252.70
29	76	A. B. Dawson	...do	36.68
29	77	A. C. Peale	...do	168.50
29	78	Edmund Jussen	Services, September 20 to October 31, 1890.	68.33
29	79	Pay roll of employés	Services, October, 1890	1,221.50
29	80	...do	...do	1,589.10
29	81	T. Nelson Dale	...do	151.60
29	82	Lawrence C. Johnson	...do	117.90

Abstract of disbursements made by C. D. Davis, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Oct. 29	83	Mark B. Kerr	Services, October, 1890	$151.60
29	84	W. Lindgren	...do	134.80
29	85	H. W. Turner	...do	134.80
29	86	G. F. Becker	...do	337.00
29	87	George H. Eldridge	Traveling expenses	130.40
29	88	Gilbert Van Ingen	Services, October, 1890	75.00
29	89	Benjamin G. Palmer	...do	25.00
29	90	A. P. Baker	Rent of office room	43.75
29	91	Raphael Pumpelly	Services, October, 1890	337.00
29	92	J. M. Safford	Services, September 2 to 4, 1890	14.67
29	93	Edward Storrs	Services, September 1 to October 2, 1890.	47.90
29	94	Warren Upham	Traveling expenses	20.50
29	95	Benjamin K. Emerson	Services, October, 1890	100.53
29	96	C. W. Hayes	...do	101.10
29	97	M. R. Campbell	...do	75.00
		Total		13,831.38

Abstract of disbursements made by Arnold Hague, special disbursing agent, U. S. Geological Survey, during October, 1890.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

1890.				
Oct. 16	1	Pay roll of employés	Services, August, 1890	$378.50
16	2	...do	Services, September, 1890	373.00
16	3	...do	Services, August, 1890	185.00
16	4	...do	Services, September, 1890	185.00
16	5	W. Preston Redmond	Traveling expenses	28.15
27	6	John S. Mendenhall	Subsistence stores	212.09
28	7	Louis V. Pirsson	Traveling expenses	28.00
31	8	Arnold Hague	Salary, August, 1890	337.00
31	9	Pay roll of employés	Salaries, September, 1890	399.40
31	10	...do	Salaries, October, 1890	732.90
		Total		2,859.04

Abstract of disbursements made by H. C. Rizer, disbursing agent, U. S. Geological Survey, during the second quarter of 1891, October 1 to November 19, 1890.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

1890.				
Oct. 7	1	R. A. Kirk	Field material	$11.87
7	2	Allen Moon & Co	Subsistence	93.13
7	3	Mart Buford & Burwell Co	Material	620.55
7	4	Great Northern Railway	Freight	111.52
8	5	E. M. Douglas	Field expenses	57.85
8	6	R. U. Parry	Feed and storage	33.85
9	7	Robert A. Farmer	Field expenses	21.30
8	8	William S. Post	...do	29.64
8	9	B. F. Buckner, jr	Traveling expenses	41.25
8	10	L. H. Cooper	...do	41.25
8	11	C. T. Reid	...do	25.75
8	12	T. M. Call	...do	9.50
8	13	H. H. Chumlea	...do	44.75
8	14	...do	Services	15.00
9	15	Gross & Eylers	Supplies	22.53
9	16	Stuart P. Johnson	Field expenses	46.52
11	17	E. M. Douglas	...do	57.56
11	18	...do	Traveling expenses	31.25
11	19	Burkhard & Oswald	Material	25.85
11	20	Morris Bien	Field expenses	67.48
13	21	...do	...do	90.00
13	22	H. F. Salyards	Material	100.00
13	23	A. Lietz & Co	Repairs	22.75
13	24	Redick H. McKee	Field expenses	84.18
13	25	R. H. Chapman	...do	60.63

Abstract of disbursements made by H. C. Rizer, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Oct. 13	26	A. F. Dunnington	Field expenses	$22.25
14	27	John Lee	Supplies	36.06
14	28	H. E. Clermont Feusier	Field expenses	117.50
16	29	R. H. Chapman	....do	27.65
17	30	Ione Coal and Iron Company	Pasturage	26.30
17	31	W. and L. E. Gurley	Material	2.10
17	32	Redick H. McKee	Field expenses	16.25
20	33	E. M. Douglass	....do	59.84
20	34	H. L. Baldwin, jr	....do	260.83
20	35	O. L. Houghton	Material	23.40
20	36	John McConn	Services	13.33
20	37	....do	Traveling expenses	17.95
20	38	C. D. Chinn	Forage	15.90
20	39	....do	Supplies	30.00
20	40	Charles Himrod	Subsistence	61.62
20	41	Acuff Bros	Supplies	35.79
20	42	A. Van Deusen	....do	11.38
20	43	Oppenlander & Rehm	Subsistence	16.00
20	44	B. F. Acuff & Co	....do	294.79
20	45	W. E. Hickman	Supplies	2.80
20	46	C. S. Woodrow	....do	14.15
20	47	Gross & Eylers	....do	23.33
20	48	Reeves & Co	....do	44.25
20	49	Pace & Crozur	Subsistence	97.20
20	50	W. B. Kimmel	Services	45.00
20	51	William J. Peters	Field expenses	34.50
20	52	....do	Traveling expenses	13.50
20	53	John Odell	....do	6.75
20	54	W. B. Corse	....do	47.50
20	55	Morris Bien	....do	69.63
20	56	....do	Field expenses	79.49
20	57	A. E. Wilson	....do	30.30
20	58	William S. Post	....do	29.24
20	59	William P. Trowbridge, jr	....do	81.91
20	60	Stuart P. Johnson, jr	....do	73.52
20	61	Samuel A. Foot	....do	27.95
20	62	....do	....do	9.35
20	63	....do	....do	37.50
20	64	L. B. Kendall	....do	135.80
20	65	A. P. Davis	....do	84.11
20	66	Robert A. Farmer	....do	52.06
20	67	....do	....do	73.20
20	68	John W. Hays	....do	26.68
20	69	F. H. Newell	....do	102.00
20	70	C. C. Bassett	....do	51.01
20	71	Alexander C. Barclay	....do	56.59
20	72	William H. Herron	....do	91.10
20	73	S. C. Gallup	Material	120.35
20	74	Willard D. Johnson	Traveling expenses	32.95
20	75	Paul Holman	....do	19.75
20	76	Frank Williams	Services	23.22
20	77	Fred. A. Schmidt	Supplies	23.40
20	78	William Malboeuf	Material	59.30
20	79	G. V. Bartlett	....do	125.00
20	80	W. B. Corse	Traveling expenses	28.75
20	81	C. L. Garland	....do	6.85
21	82	T. M. Brannon	....do	42.25
21	83	....do	Field expenses	112.50
21	84	William H. Herron	....do	20.20
21	85	Wm. S. Post	....do	70.91
21	86	Frank Tweedy	....do	41.88
21	87	Perry Fulter	....do	64.15
21	88	J. F. Farmer	Forage	33.60
21	89	L. Creps	Supplies	7.15
22	90	Morris Bien	Field expenses	110.18
22	91	Allan Tompkins	Board	148.45
22	92	M. J. Kieley	Pasturage	14.15
22	93	E. M. Douglas	Field expenses	71.20
22	94	F. M. Call	Services	8.00
22	95	F. H. Newell	Field expenses	97.79
23	96	Spratlen & Anderson	Subsistence	19.04
23	97	Bach Cory & Co	Supplies	93.40
17	98	Ed. B. Thomas	Material	60.00
24	99	Samuel A. Foot	Field expenses	158.05
24	100	Redick H. McKee	....do	83.41
27	101	L. B. Kendall	....do	164.25
27	102	F. H. Stewart	Labor	61.28
27	103	Robert A. Farmer	Field expenses	49.85
27	104	H. S. Wallace	....do	51.40

Abstracts of disbursements made by H. C. Rizer, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Oct. 27	105	J. T. Farmer	Foraging stock	$16.80
27	106	Acuff Brothers	Supplies	18.85
27	107	A. Deeter	Board	11.20
27	108	C. C. Huddleston	Supplies	8.35
28	109	William H. Herron	Field expenses	75.35
31	110	Willis P. Chapman	Services	23.20
31	111	C. T. Reid	...do	70.80
31	112	E. T. Perkins, jr	...do	134.80
31	113	Willard D. Johnson	...do	168.50
31	114	C. H. Fitch	...do	151.60
31	115	A. H. Thompson	...do	252.70
31	116	E. M. Douglas	...do	168.50
31	117	H. C. Rizer	...do	185.30
31	118	Pay roll	...do	317.90
31	119	...do	...do	315.10
31	120	...do	...do	217.95
31	121	...do	...do	335.00
31	122	...do	...do	630.30
31	123	...do	...do	230.80
31	124	...do	...do	533.15
31	125	...do	...do	220.80
31	126	...do	...do	125.80
31	127	...do	...do	316.29
31	128	...do	...do	375.40
31	129	...do	...do	286.90
31	130	...do	...do	113.53
31	131	...do	...do	125.80
31	132	...do	...do	143.40
31	133	R. U. Goode	Traveling expenses	92.44
31	134	...do	Services	210.60
31	135	Charles C. Bassett	...do	117.90
31	136	Pay roll	...do	145.80
31	137	...do	...do	225.80
31	138	...do	...do	170.80
31	139	...do	...do	303.50
31	140	A. F. Dunnington	Traveling expenses	102.00
31	141	...do	Services	151.60
31	142	Pay roll	...do	316.60
31	143	...do	...do	358.05
31	144	...do	...do	231.10
31	145	...do	...do	80.96
31	146	...do	...do	285.00
31	147	...do	...do	582.04
31	148	...do	...do	259.20
31	149	...do	...do	301.60
31	150	...do	...do	225.80
31	151	...do	...do	225.80
Nov. 3	152	A. F. Dunnington	Traveling expenses	18.25
3	153	Robert A. Farmer	Field expenses	61.20
3	154	...do	...do	40.07
3	155	A. Van Deusen	Supplies	6.60
3	156	Perkins Brothers	...do	2.00
3	157	Spratten & Anderson	...do	1.41
3	158	Stuart P. Johnson	Field expenses	17.25
3	159	...do	...do	80.82
3	160	W. T. Griswold	...do	53.35
3	161	Samuel McDowell	Supplies	300.00
3	162	P. V. S. Bartlett	Field expenses	130.80
3	163	C. C. Bassett	...do	113.64
3	164	John W. Hays	...do	129.30
3	165	Pay roll	Services	323.70
3	166	M. M. Myers	Supplies	71.64
3	167	Alexander C. Barclay	Field expenses	130.11
3	168	Paul Holman	...do	18.94
4	169	F. H. Newell	...do	91.00
4	170	W. B. Corse	...do	26.45
4	171	J. D. Reagan	Traveling expenses	16.75
4	172	R. C. McKinney	Field expenses	238.38
4	173	...do	...do	8.40
4	174	Henry Williams	Supplies	62.86
4	175	R. W. Parry	Forage	55.36
4	176	Andrew McClelland	...do	6.35
4	177	Pueblo Hardware Company	Material	9.95
4	178	Robert Patton	Board	8.00
4	179	A. McClelland	Supplies	39.40
4	180	Henry Darling	Board	19.37
4	181	Yard & Ashby	Labor	24.00
4	182	E. M. Douglas	Field expenses	163.09
4	183	E. T. Perkins, jr	...do	275.54

Abstract of disbursements made by H. C. Rizer, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Nov. 4	184	Morris Bien	Field expenses	$31.94
5	185	Redick McKee	....do	68.37
5	186	Robert A. Farmer	....do	62.31
5	187	William S. Post	....do	159.01
5	188	Perry Fuller	....do	53.05
5	189	R. B. Marshall	....do	147.80
5	190	S. S. Gannett	....do	36.40
5	191	....do	Traveling expenses	47.75
5	192	R. R. Kelly	Board	12.00
5	193	Gross & Eylers	Supplies	7.18
5	194	Handy & McGee	....do	49.00
5	195	Thomas W. Hayward	Subsistence	24.64
5	196	Gross, Blackwell & Co	....do	254.41
6	197	Willard D. Johnson	Field expenses	155.36
6	198	....do	....do	137.47
6	199	C. W. Kitchen	Board	38.00
6	200	L. H. Barnes	Livery	25.00
7	201	Samuel A. Foot	Field expenses	73.10
7	202	....do	....do	78.50
7	203	Coxhead & Harrel	Labor	15.05
7	204	....do	Feed and pasturage	30.28
7	205	Willard D. Johnson	Traveling expenses	31.45
7	206	George H. Lamar	....do	25.30
8	207	R. H. Chapman	Field expenses	54.50
8	208	L. B. Kendall	....do	47.12
8	209	Willard D. Johnson	....do	30.60
8	210	Paul Holman	....do	46.10
8	211	A. Deeter	Board	32.40
10	212	W. H. Anderson	Supplies	66.71
10	213	Jeremiah Ahern	Field expenses	29.04
10	214	T. M. Bannon	Services	75.00
10	215	Helfrich & Miller	Subsistence	52.47
10	216	M. Studzinski	Storage	7.50
10	217	E. T. Perkins, jr	Traveling expenses	25.30
10	218	E. M. Douglas	Field expenses	93.67
10	219	H. E. Clermont Feusier	....do	36.75
10	220	William J. Peters	....do	12.30
10	221	Robert A. Farmer	....do	47.50
10	222	Charles Stone	Transportation	12.00
10	223	A. McClelland	Forage	84.00
13	224	C. C. Bassett	Traveling expenses	50.75
13	225	Charles F. Urquhart	Field expenses	162.60
13	226	Ricketts Hord	Traveling expenses	41.25
13	227	J. A. Rogers	Supplies	28.52
13	228	Joseph Jacobs	Field expenses	9.70
14	229	P. V. S. Bartlett	....do	85.65
14	230	H. E. Clermont Feusier	....do	53.47
14	231	J. M. Dikeman	....do	37.50
14	232	W. H. Sanders	Repairs	10.25
14	233	J. M. Dikeman	Services	60.00
18	234	R. B. Cameron	Traveling expenses	61.55
18	235	A. E. Wilson	....do	61.55
18	236	E. McL. Long	....do	27.95
18	237	H. C. Rizer	....do	41.40
18	238	J. B. Lippincott	....do	51.00
18	239	....do	Field expenses	26.20
19	240	....do	....do	81.46
19	241	J. C. King	Subsistence	21.85
19	242	A. Deeter	Board	33.60
19	243	William H. Herron	Field expenses	92.15
19	244	H. S. Wallace	....do	42.54
19	245	....do	Traveling expenses	23.25
19	246	R. O. Gordon	....do	60.55
19	247	R. U. Goode	....do	31.56
19	248	Paul Holman	Field expenses	14.65
		Total		22,457.90

Abstract of disbursements made by Jno. D. McChesney, Chief Disbursing Clerk, U. S. Geological Survey, during November, 1890.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Nov. 5	1	Z. D. Gilman	Supplies	$179.14
5	2	Washington Gaslight Co	Laboratory supplies	39.38
5	3	William A. Wansleben	Services, November 1 to 4, 1890	16.81
10	4	...do	Services, November 5 to 9, 1890	26.79
8	5	J S. Smith	Services, November 7, 1890	1.72
8	6	W. Bauman	...do	1.72
17	7	F. H. Newell	Services, October 1 to 3, 1890	16.30
17	8	DeLancey W. Gill	Traveling expenses	14.20
18	9	E. & H. T. Anthony & Co	Supplies for illustrations	133.00
18	10	The Springer Torsion Balance Company.	Laboratory supplies	35.00
18	11	Whitall, Tatum & Co	...do	14.87
18	12	George E. Bailey	Paleontologic supplies	85.00
18	13	Henry Bufford	Services, November 3 to 8, 1890	12.00
18	14	William P. Rust	Services, October, 1890	108.00
18	15	Julius Bien & Co	Publications	20.00
18	16	Atlantic & Pacific R. R. Co	Transportation of assistant	25.70
18	17	John F. Stephenson	Freight charges	4.39
18	18	Columbia Phonograph Co	Phonographic services	49.82
18	19	E. Morrison	Library supplies	7.50
18	20	C. A. White	Traveling expenses	124.86
18	21	Adams Express Co	Freight charges, October, 1890	148.90
19	22	Pennsylvania R. R. Co	Transportation of assistants	27.00
19	23	Burlington and Mo. River R. R. in Nebraska.	...do	45.90
19	24	Chicago, Milwaukee and St. Paul R. R.	...do	11.50
19	25	Chicago, Burlington and Northern R. R.	...do	26.30
19	26	Cutter & Wood	Geologic supplies	27.50
19	27	H. B. Walker	Publications	20.00
20	28	Baltimore and Ohio R. R. Co	Transportation of assistants	249.95
20	29	...do	...do	276.30
20	30	Daniel Spriggs	Traveling expenses	3.50
24	31	Smithsonian Institution	Transportation of exchanges	1,033.10
24	32	Wyckoff, Seamans & Benedict	Repairing geologic material	2.50
24	33	Atchison, Topeka & Santa Fé R. R.	Transportation of assistants	51.00
24	34	Prescott and Arizona Central R. R.	...do	7.40
24	35	S. H. Davis	Pasturage	29.16
24	36	Eimer & Amend	Laboratory supplies	6.00
24	37	S. Ward Loper	Services, October 1 to November 13, 1890.	179.16
24	38	John S. Lengs, Son & Co	Laboratory supplies	2.18
25	39	T. W. Stanton	Traveling expenses	160.98
25	40	Chicago, Burlington and Quincy R. R.	Transportation of assistants	26.65
25	41	Emil Greiner	Laboratory supplies	4.05
25	42	Fred. A. Schmidt	Supplies	50.35
25	43	...do	...do	13.30
29	44	Ira Sayles	Services, November, 1890	114.20
29	45	Sam H. Scudder	...do	203.80
29	46	William M. Fontaine	...do	163.00
29	47	J. Henry Blake	...do	146.80
29	48	H. A. Otterback	Supplies for Mineral Resources	3.50
29	49	Baltimore and Ohio R. R. Co	Transportation of assistants	95.20
29	50	L. H. Schneider's Son	Supplies	13.84
29	51	James Storrs	Services, November 1 to 24, 1890	44.00
29	52	Marcus Baker	Services, November, 1890	244.60
29	53	O. C. Marsh	...do	326.00
29	54	Gus Craven	Services July 1 to November 15, 1890	675.00
29	55	W. H. Utterback	Services November, 1890	55.00
29	56	O. A. Peterson	...do	65.00
29	57	J. B. Hatcher	...do	250.00
29	58	F. Berger	...do	80.00
29	59	L. P. Bush	...do	50.00
29	60	H. Gibb	...do	80.00
29	61	C. C. Willard	Rent of office rooms	266.66
29	62	L. J. Yeager	Publications	24.00
29	63	Pay roll of employés	Services, November, 1890	570.60
29	64	...do	...do	1,275.12
29	65	...do	...do	1,163.93
29	66	...do	...do	1,251.40
29	67	...do	...do	1,116.33
29	68	...do	...do	847.80
29	69	...do	...do	358.80
29	70	United States Express Co	Freight charges, October, 1890	108.85
		Total		12,911.81

Abstract of disbursements made by Jno. D. McChesney, etc.—Continued.

APPROPRIATION FOR GEOLOGICAL MAPS OF THE UNITED STATES, 1891.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Nov. 5	1	Z. D. Gilman	Engravers' supplies	$13.10
18	2	Ernest Kübel	Copper plates	98.88
18	3	Adams Express Co	Freight charges, October, 1890	1.10
18	4	Fred A. Schmidt	Engravers' supplies	200.00
19	5	J. T. Walker & Sons	...do	1.50
24	6	Martin Wiegand	...do	18.75
24	7	Francis Miller	...do	2.25
29	8	Jno. D. McChesney	Traveling expenses	9.50
29	9	L. H. Schneider's Son	Engravers' supplies	1.60
29	10	Milton, Bradley & Co	...do	11.16
29	11	Pay roll of employés	Services, November, 1890	818.80
		Total		1,176.64

Abstract of disbursements made by Anton Karl, special disbursing agent, U. S. Geological Survey, during November, 1890.

APPROPRIATION FOR UNITED STATES GEOLOGICAL SURVEY.

1890.				
Nov. 10	1	A. E. Murlin	Field expenses	$54.91
10	2	A. E. Wilson	...do	54.35
10	3	L. C. Fletcher	...do	106.85
10	4	...do	...do	78.35
10	5	Van H. Manning, jr	Traveling expenses	51.35
12	6	G. C. Van Hook	Field expenses	31.30
12	7	...do	...do	75.05
13	8	L. C. Fletcher	...do	50.70
20	9	George E. Kennedy & Son	Subsistence	23.80
20	10	Chattanooga Saddlery Co.	Supplies	27.65
20	11	C. G. Van Hook	Field expenses	72.10
20	12	Charles M. Yeates	...do	170.08
19	13	L. C. Fletcher	...do	113.45
19	14	...do	...do	167.77
20	15	M. Hackett	Traveling expenses	35.01
20	16	...do	Field expenses	240.17
20	17	R. Lee Longstreet	...do	117.10
20	18	Charles E. Cooke	...do	136.86
20	19	E. C. Barnard	...do	171.70
20	20	...do	...do	171.90
20	21	A. E. Murlin	...do	83.45
20	22	Louis Nell	...do	149.50
20	23	...do	...do	116.66
20	24	...do	...do	78.02
20	25	G. E. Hyde	...do	60.95
20	26	...do	Traveling expenses	14.10
20	27	W. & L. E. Gurley	Instruments	13.00
20	28	W. W. Maxwell	Services, October	25.00
20	29	Van H. Manning, jr	Field expenses	83.66
20	30	...do	...do	157.83
20	31	H. B. Blair	...do	204.10
20	32	D. C. Harrison	...do	120.22
20	33	B. Peyton Legaré	Traveling expenses	35.63
20	34	John H. Renshawe	Field expenses	40.50
19	35	L. C. Fletcher	Traveling expenses	69.45
20	36	W. B. Moses & Sons	Furniture	38.00
20	37	W. E. Horton	Traveling expenses	10.68
20	38	W. R. Atkinson	...do	34.98
20	39	...do	Field expenses	133.00
20	40	Robert D. Cummin	...do	171.20
20	41	...do	Traveling expenses	15.06
20	42	J. J. Mason	...do	13.16
20	43	...do	Field expenses	94.75
20	44	Albert M. Walker	...do	73.55
20	45	...do	Traveling expenses	4.75
20	46	M. B. Lambert	...do	9.88
20	47	...do	Field expenses	114.47
20	48	William Kramer	...do	87.72
20	49	...do	Traveling expenses	25.00
20	50	Ewing Speed	...do	8.20
20	51	...do	Field expenses	46.05
20	52	A. F. Dudley	...do	93.00
20	53	W. H. Lovell	...do	91.00
20	54	Frank Sutton	...do	204.36

Abstract of disbursements made by Anton Karl, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Nov. 20	55	Lincoln Martin	Field expenses	$85.62
20	56	Glenn S. Smith	...do	160.90
20	57	W. M. Beaman	...do	125.75
19	58	L. C. Fletcher	...do	71.50
20	59	Fred. A. Schmidt	Paper	37.50
20	60	Thomas C. Nelson	Services, October	50.00
20	61	S. J. Haislett	Supplies	20.00
20	62	Frank Sutton	Field expenses	109.25
20	63	W. A. Lyon	Traveling expenses	4.55
20	64	H. M. Wilson	...do	51.02
20	65	William Kramer	Transportation	1.50
20	66	G. E. Hyde	Traveling expenses	46.68
22	67	H. W. Carpenter	...do	26.75
21	68	George T. Hawkins	Field expenses	211.57
24	69	Joseph W. Jones	Services, September	50.00
24	70	Nannie M. Payton	Services, October	25.00
24	71	Mrs. C. E. Smith	...do	25.00
26	72	Van H. Manning, jr	Field expenses	24.80
26	73	Clifford Arrick	Traveling expenses	53.75
28	74	L. C. Fletcher	Field expenses	73.25
28	75	H. L. Baldwin, jr	...do	8.50
28	76	William Smith	Traveling expenses	37.25
28	77	A. E. Murlin, pay roll	Services, November	307.75
28	78	M. Hackett	Field expenses	580.89
29	79	John B. Torbert	Services, November	81.60
29	80	S. S. Gannett	...do	163.00
29	81	B. Peyton Legare	Traveling expenses	18.39
29	82	Van H. Manning, jr	...do	40.31
29	83	C. G. Van Hook	Field expenses	66.50
29	84	...do	Services, November	81.60
29	85	Louis Nell, pay roll	...do	431.79
29	86	Anton Karl, pay roll	...do	3,249.28
29	87	Gilbert Thompson, pay roll	...do	1,009.60
29	88	Glenn S. Smith, pay roll	...do	235.00
29	89	E. C. Barnard, pay roll	...do	400.20
29	90	Charles M. Yeates	...do	146.80
29	91	Thomas C. Nelson	...do	50.00
29	92	M. Hackett, pay roll	...do	424.06
29	93	H. B. Blair, pay roll	...do	427.20
29	94	W. H. Lovell, pay roll	...do	327.00
29	95	John H. Renshawe	...do	203.80
29	96	William Kramer	...do	97.80
29	97	F. H. Clark	...do	9.00
29	98	W. W. Maxwell	...do	15.00
29	99	J. H. Hagerty	...do	25.50
29	100	R. M. Towson	...do	114.20
29	101	R. Lee Longstreet	Field expenses	91.66
29	102	...do	Traveling expenses	20.80
29	103	William Kramer	...do	23.95
29	104	...do	Field expenses	41.60
29	105	Louis Nell	Traveling expenses	39.25
29	106	A. B. Searle	...do	28.00
29	107	G. Unsell	Services, November	13.33
29	108	Isaac Crump	Forage and storage	44.83
29	109	George T. Hawkins	Traveling expenses	43.70
29	110	W. T. Quillin	...do	43.80
29	111	George Unsell	...do	10.85
29	112	Robert D. Cummin, pay roll	Services, November	338.20
29	113	...do	Field expenses	107.43
29	114	...do	Traveling expenses	17.43
29	115	Albert M. Walker	...do	6.33
29	116	...do	Field expenses	56.05
29	117	Ewing Speed	...do	50.00
29	118	...do	Traveling expenses	4.14
29	119	James Goode	...do	11.60
29	120	William D. Clark & Co	Material for mounting maps	39.92
		Total		15,310.61

Abstract of disbursements made by C. D. Davis, special disbursing agent, U. S. Geological Survey, during November, 1890.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Nov. 5	1	Benjamin K. Emerson	Traveling expenses	$236.32
5	2	Arthur Keith	Services, September 1 to October 31, 1890.	198.90
5	3	William B. Clark	Services, October, 1890	125.00
5	4	J. B. Woodworth	...do	50.00
5	5	N. S. Shaler	...do	270.00
5	6	Richard Bliss	...do	26.70
5	7	James Storrs	...do	55.00
5	8	R. H. Loughridge	...do	75.00
5	9	R. E. Dodge	...do	30.00
5	10	W J McGee	Traveling expenses	155.49
5	11	George H. Williams	Traveling expenses, August 1 to September 30, 1890.	130.00
3	12	Bailey Willis	Traveling expenses, October, 1890	252.70
10	13	W. S. Bayley	...do	80.00
10	14	Warren Upham	...do	101.10
10	15	Frank Leverett	...do	135.00
10	16	C. L. Whittle	Traveling expenses, September, 1890.	100.00
10	17	...do	Traveling expenses, October, 1890	100.00
10	18	R. S. Tarr	Traveling expenses	33.68
10	19	C. Whitman Cross	...do	375.32
10	20	C. R. Eastman	...do	23.95
10	21	R. E. Dodge	...do	29.20
10	22	G. K. Gilbert	...do	96.06
11	23	Cooper Curtice	...do	146.45
11	24	H. W. Turner	...do	55.75
11	25	...do	Field expenses	99.31
11	26	...do	...do	53.07
11	27	F. C. Boyce	Services, October, 1890	60.00
11	28	R. S. Tarr	...do	16.00
11	29	Seth C. Hathaway	...do	40.00
11	30	W. T. Turner	...do	50.00
11	31	Union Box Factory	Wooden boxes	9.00
12	32	James G. Bowen	Forage of public animals	22.52
12	33	J. T. Masten	Pasturage	27.27
13	34	S. H. Davis	...do	14.00
14	35	A. C. Peale	Field expenses	59.20
15	36	...do	Traveling expenses	125.50
17	37	R. H. Gaines	...do	8.25
18	38	J. H. Ropes	...do	72.49
18	39	...do	Services	61.72
18	40	J. E. Wolff	Services, October, 1890	45.65
18	41	...do	Field expenses	2.65
21	42	C. W. Hayes	...do	27.93
21	43	...do	Traveling expenses	144.92
21	44	Bailey Willis	...do	81.64
21	45	Thomas Parry	...do	19.75
21	46	F. Hollister	...do	26.17
21	47	M. R. Campbell	...do	88.94
21	48	T. Nelson Dale	Field expenses	8.95
22	49	W. H. Snyder	Services, August 1 to 15, 1890	24.19
22	50	The Eastman Company	Photographic prints	33.29
22	51	George H. Eldridge	Traveling expenses	134.76
25	52	Raphael Pumpelly	...do	120.44
25	53	...do	Field expenses	16.52
25	54	W. Lindgren	Services, November, 1890	130.40
25	55	Lawrence C. Johnson	...do	114.20
25	56	H. W. Turner	...do	130.40
29	57	A. Lutz & Co	Repairs to instruments	12.50
29	58	W. Lindgren	Field expenses	119.25
29	59	A. P. Brown	Rent of room	43.75
29	60	Moritz Fischer	Traveling expenses	28.98
29	61	R. E. Dodge	...do	18.44
29	62	I. C. Russell	...do	133.50
30	63	S. Ward Loper	Services, September 1 to 19, 1890	22.50
30	64	George E. Luther	Services, November, 1890	97.80
30	65	C. R. Van Hise	...do	326.00
30	66	Raphael Pumpelly	...do	326.00
30	67	W. B. Clark	...do	125.00
30	68	Benjamin G. Palmer	...do	25.00
30	69	T. Nelson Dale	...do	146.80
30	70	J. B. Woodworth	...do	50.00
30	71	R. E. Dodge	...do	30.00
30	72	P. M. Jones	Services, October 3 to 25, 1890	6.40
30	73	N. S. Shaler	Services, November, 1890	250.00
30	74	Fred. E. Morris	Services, November 1 to 22, 1890	53.80

Abstract of disbursements made by C. D. Davis, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Nov. 30	75	Pay roll of employés	Services, November, 1890	$1,752.60
30	76	....do	....do	443.00
30	77	....do	....do	1,792.10
		Total		10,554.17

Abstract of disbursements made by Arnold Hague, special disbursing agent, U. S. Geological Survey, during November, 1890.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

1890.				
Nov. 5	1	Louis V. Pirsson	Services, October, 1890	$25.00
7	2	Joseph P. Iddings	Field expenses	25.95
10	3	Louis V. Pirsson	Traveling expenses	29.30
10	4	Pay roll of employés	Services, October, 1890	149.98
17	5	J. C. McCartney	Hauling and storage	11.80
20	6	W. H. Weed	Field expenses	65.85
28	7	Arnold Hague	....do	64.16
30	8	Pay roll of employés	Services, November, 1890	717 40
		Total		1,089.44

Abstract of disbursements made by H. C. Rizer, disbursing agent, U. S. Geological Survey, during the second quarter of 1891.

TOPOGRAPHY WEST OF ONE HUNDREDTH MERIDIAN.

1890.				
Nov. 19	249	Reaser Bros	Subsistence	$22.77
20	250	F. H. Newell	Field expenses	80.00
20	251	....do	....do	172.50
20	252	A. E. Wilson	....do	57.75
20	253	Frank F. Smart	Traveling expenses	18.75
21	254	S. D. P. Baxter	Board	5.50
21	255	....do	Feed for team	3.00
21	256	William S. Post	Field expenses	61.36
21	257	William M. Heidenrich	Services	23.33
21	258	N. B. Stoneroad	Foraging stock	28.83
21	259	W. A. Farish	Services	75.00
21	260	John Ott	....do	8.33
22	261	R. O. Gordon	Field expenses	404.66
22	262	R. H. Chapman	....do	47.15
22	263	Samuel A. Foot	....do	181.90
22	264	K. V. Osborne Bartlett	Services	16.00
24	265	Charles B. Green	Traveling expenses	68.55
24	266	J. L. King	Registered package charges	.70
24	267	Pay roll	Services	183.16
26	268	R. H. Chapman	Field expenses	58.00
Dec. 1	269	A. F. Dunnington	Traveling expenses	18.00
1	270	L. B. Kendall	....do	6.00
1	271	....do	....do	41.80
1	272	Mark B. Kerr	Services	146.80
1	273	T. M. Bannon	....do	75.00
1	274	Pay roll	....do	799.20
1	275	....do	....do	106.93
1	276	....do	....do	212.00
1	277	....do	....do	329.35
1	278	....do	....do	38.66
1	279	....do	....do	597.54
1	280	....do	....do	194.07
1	281	....do	....do	176.60
1	282	....do	....do	271.60
1	283	....do	....do	143.40
1	284	....do	....do	196.80
1	285	....do	....do	129.67
1	286	....do	....do	231.60
3	287	....do	....do	297.60
3	288	....do	....do	303.80
3	289	....do	....do	44.16
3	290	....do	....do	289.80
3	291	....do	....do	252.80

Abstract of disbursements made by H. C. Rizer, etc.—Continued.

TOPOGRAPHY WEST OF ONE HUNDREDTH MERIDIAN—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Dec. 3	292	Pay roll	Services	$226.60
3	293	...do	...do	894.80
3	294	H. S. Pritchett	...do	200.00
3	295	Clayborn Brimhall	...do	40.00
3	296	Willard D. Johnson	...do	163.00
3	297	A. L. Bruce	...do	6.44
3	298	S. S. Gannett	Traveling expenses	53.50
3	299	Mark B. Kerr	...do	126.25
3	300	Gross, Blackwell & Co	Subsistence	126.81
3	301	...do	...do	40.71
5	302	Bach, Cory & Co	...do	53.83
5	303	Oppenlander & Rehm	...do	22.70
5	304	Samuel McDowell	Supplies	25.25
5	305	B. F. Acuff & Co	...do	18.04
6	306	Iseli & Milne	...do	35.50
4	307	W. P. Merrill	...do	16.15
4	308	J. H. McKnight & Co	Material	42.50
4	309	Denver Transit and Warehouse Co.	Storage	21.29
4	310	...do	...do	20.00
4	311	Cook & Dawson	Board	28.00
4	312	A. Dieter	...do	14.40
4	313	...do	...do	28.80
4	314	J. M. Bay	...do	42.00
4	315	Henry Klein	...do	11.25
4	316	Henry Darling	...do	20.00
4	317	R. W. Parray	Care of stock	28.70
4	318	A. J. Green	Hire of team	15.00
4	319	W. J. Millrap	...do	10.00
4	320	John W. Hays	Traveling expenses	35.05
4	321	Frank E. Gove	...do	94.00
4	322	Frank Tweedy	...do	37.47
4	323	Robert A. Farmer	Field expenses	94.65
4	324	John W. Hays	...do	25.90
4	325	Perry Fuller	...do	25.00
4	326	J. M. Dikeman	...do	45.95
4	327	Stuart P. Johnson	...do	96.77
4	328	William P. Trowbridge, jr	...do	273.63
4	329	E. M. Douglas	...do	74.11
4	330	A. P. Davis	...do	129.23
6	331	F. H. Newell	...do	89.00
8	332	Jeremiah Ahern	...do	61.70
8	333	S. S. Gannett	...do	175.30
8	334	Frank Tweedy	...do	103.97
8	335	...do	...do	148.45
8	336	William S. Post	...do	118.11
8	337	R. C. McKinney	Traveling expenses	47.95
8	338	C. H. Fitch	Services	146.80
8	339	Pay roll	...do	131.60
8	340	...do	...do	419.00
8	341	...do	...do	778.40
8	342	...do	...do	240.33
8	343	...do	...do	336.30
8	344	A. F. Mack	...do	50.00
8	345	W. C. Pierce	Traveling expenses	35.38
8	346	Charles F. Urquhart	...do	62.10
8	347	A. C. Swift	Board	11.25
8	348	G. W. Bond & Bro	Subsistence	35.13
8	349	Samuel A. Foot	Field expenses	20.00
8	350	W. A. Farish	...do	34.40
8	351	Robert A. Farmer	...do	119.70
8	352	Paul Hohnan	...do	37.35
8	353	H. L. Baldwin, jr	...do	364.01
8	354	Perry Fuller	...do	34.80
9	355	Samuel A. Foot	...do	191.16
9	356	R. H. Chapman	...do	109.76
9	357	Arthur P. Davis	...do	100.21
9	358	R. R. Kelly	Board	33.00
9	359	C. W. Kittredge	Supplies	132.03
9	360	F. M. Call	Services	60.00
9	361	Pay roll	...do	313.73
11	362	Nelson Morgan	...do	23.33
11	363	M. J. Davis	...do	22.50
11	364	J. W. Martin	Board	36.00
11	365	Henry Darling	...do	23.50
11	366	A. Deeter	...do	49.60
11	367	Cook & Dawson	...do	58.00
11	368	N. B. Stoneroad	Board of stock	33.00

Abstract of disbursements made by H. C. Rizer, etc.—Continued.

TOPOGRAPHY WEST OF ONE HUNDREDTH MERIDIAN—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Dec. 11	369	Coxhead & Hanel	Livery	$13.50
11	370	A. J. Green	Hire of horse	6.00
11	371	M. Studzinski	Storage	7.50
11	372	H. L. Baldwin, jr	Traveling expenses	43.29
11	373	...do	...do	60.06
11	374	R. C. McKinney	...do	9.85
11	375	George H. Lamar	...do	53.40
11	376	R. H. Chapman	...do	125.50
10	377	Andrew McClelland	Supplies	29.97
10	378	J. W. Miller	...do	21.21
10	379	A. C. Schmidt	Labor and supplies	126.15
10	380	Spratten & Anderson	Subsistence	51.40
10	381	Handy & McGee	...do	5.10
10	382	B. F. Acuff & Co	...do	39.65
10	383	Alex. C. Barclay	Field expenses	239.40
10	384	Joseph Jacobs	...do	43.12
10	385	P. V. S. Bartlett	...do	19.50
10	386	R. C. McKinney	...do	262.87
10	387	R. B. Marshall	...do	106.27
12	388	E. M. Douglass	...do	161.79
12	389	Samuel A. Foote	...do	49.35
12	390	R. H. Chapman	...do	7.50
12	391	C. R. Glass	...do	39.88
12	392	R. B. Marshall	...do	20.32
13	393	Stuart P. Johnson	...do	116.66
13	394	John W. Hays	...do	88.72
13	395	E. M. Dawson	Board	14.00
13	396	J. F. Jeffers		18.00
13	397	Robert J. Breckenridge, jr	Traveling expenses	71.55
15	398	B. F. Buckner	...do	44.00
15	399	Morris Bien	...do	11.70
15	400	...do	Field expenses	47.11
15	401	...do	...do	44.84
15	402	P. V. S. Bartlett	Services	81.60
15	403	Pay roll	...do	531.25
15	404	...do	...do	16.66
15	405	J. H. Hazelton	...do	24.15
16	406	C. T. Reid	Traveling expenses	37.25
15	407	A. L. Bruce	...do	12.50
15	408	P. V. S. Bartlett	...do	124.00
16	409	John Bowler	...do	26.90
17	410	John H. Hazelton	...do	77.15
15	411	William J. Peters	...do	25.00
16	412	Morris Bien	...do	25.00
16	413	W. B. Corse	...do	25.00
16	414	F. M. Smith	...do	33.00
15	415	W. T. Griswold	...do	65.25
15	416	A. P. Davis	Field expenses	41.41
16	417	W. B. Corse	...do	32.40
16	418	...do	...do	71.82
15	419	E. T. Perkins, jr	...do	67.95
17	420	...do	...do	182.10
17	421	W. T. Griswold	...do	56.93
17	422	...do	...do	51.40
18	423	F. M. Smith	...do	104.65
18	424	Pay roll	Services	142.80
18	425	L. H. Cooper	...do	11.28
18	426	...do	Traveling expenses	44.00
18	427	L. B. Kendall	...do	21.45
18	428	William J. Peters	Field expenses	94.26
18	429	...do	...do	26.40
19	430	W. T. Griswold	...do	54.70
19	431	Charles F. Urquhart	...do	157.63
		Total		18,735.55

Abstract of disbursements made by Jno. D. McChesney, chief disbursing clerk, U. S. Geological Survey, during December, 1890.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Dec. 8	1	Charles L. Keyes	Original drawings	$340.00
8	2	Alpheus Hyatt	Services, September 1 to October 31, 1890.	500.00
8	3	Chesapeake and Ohio Ry. Co.	Transportation of assistants	42.00
8	4	William P. Rust	Services, November 1 to 30, 1890	62.50
8	5	Denver and Rio Grande Ry. Co.	Transportation of assistants	12.00
8	6	Cleonora Manufacturing Co	Laboratory supplies	3.00
8	7	Penrhyn Slate Co	Services	10.00
8	8	R. A. Dinsmore	Publications	24.00
8	9	George E. Littlefield	...do	40.00
8	10	George Ryneal, jr	Supplies	66.87
8	11	Washington Gaslight Co	Laboratory supplies	59.13
8	12	Brentanos	Publications	4.60
8	13	...do	...do	5.00
10	14	Northern Pacific R. R. Co	Transportation of assistants	243.10
10	15	Castle & Henshawe	Geologic supplies	1.00
10	16	W. H. Morrison	Publications	171.30
10	17	E. H. King	Geologic supplies	24.00
11	19	William Wesley & Son	...do	36.49
11	20	Geological Society	Publications	10.22
11	21	Wash. B. Williams	Supplies	32.25
11	22	L. H. Schneider's Son	...do	17.66
11	23	Citizens' National Bank	Bills of exchange	.52
17	24	Emil Greiner	Laboratory supplies	27.03
17	25	Eimer & Amend	...do	67.82
17	26	Edward J. Hannan	Repairs, etc	10.90
17	27	Missouri Pacific Ry. Co	Transportation of assistants	27.90
17	28	Whitall, Tatum & Co	Laboratory supplies	11.30
17	29	Goodnow & Wightman	...do	8.68
17	30	William Earl Hidden	...do	15.00
17	31	Great Northern Ry. Co	Transportation of assistants	17.80
19	32	Williams, Browne & Earle	Repairs	1.75
19	33	Chicago, Milwaukee and St. Paul Ry.	Transportation of assistants	63.00
23	34	Victoria Essex	Services, December 2 to 23, 1890	38.00
23	35	Z. D. Gilman	Supplies	244.98
26	36	Great Northern Ry. Co	Transportation of assistants	17.80
26	37	Memphis and Charleston Ry. Co.	...do	16.55
26	38	Wyckoff, Seamans & Benedict	Repairs	4.75
26	39	Charles D. Walcott	Traveling expenses	138.65
26	40	E. E. Jackson & Co	Laboratory supplies	4.80
26	41	E. & H. T. Anthony & Co	Supplies for illustrations	140.00
24	42	J. B. Hammond	...do	24.50
26	43	William Ballantyne & Son	Supplies	3.65
26	44	H. Hoffa	Paleontologic supplies	8.09
26	45	Edward J. Hannan	Laboratory supplies	5.20
24	46	Springmann & Brother	Hauling	48.37
24	47	Mary C. Mahon	Services, December 6-23, 1890	29.00
30	48	Edward J. Hannan	Repairs to laboratory sink	11.20
29	49	C. S. Prosser	Services, November, 1890	97.80
30	50	Williams, Browne & Earle	Geologic supplies	36.00
31	51	William M. Fontaine	Services, December, 1890	168.50
31	52	Ira Sayles	do	117.90
31	53	Sam. H. Scudder	...do	210.60
31	54	J. Henry Blake	...do	151.60
31	55	Harriet Biddle	Services, October 1 to Dec. 31, 1890	30.00
31	56	O. C. Marsh	Services, December, 1890	337.00
31	57	R. W. Westbrook	Services, October 1 to Dec. 31, 1890	75.00
31	58	W. A. Washburne	...do	105.00
31	59	T. A. Bostwick	...do	250.00
31	60	A. Hermann	...do	250.00
31	61	L. P. Bush	Services, December, 1890	50.00
31	62	H. Gibb	...do	80.00
31	63	F. Berger	...do	80.00
31	64	O. A. Peterson	...do	50.00
31	65	Pay roll of employés	...do	842.40
31	66	...do	...do	480.10
31	67	...do	...do	1,287.30
31	68	...do	...do	986.60
31	69	...do	...do	988.43
31	70	...do	...do	1,390.40
31	71	...do	...do	1,153.50
31	72	...do	...do	775.00
31	73	David T. Day	...do	252.70
31	74	William A. Raborg	...do	117.90
31	75	Frank T. Smart	...do	101.10
		Total		13,157.19

Abstract of disbursements made by Jno. D. McChesney, etc.—Continued.

APPROPRIATION FOR GEOLOGICAL MAPS OF THE UNITED STATES, 1891

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Dec. 8	1	George Ryneal, jr	Engravers' supplies	$1.60
10	2	Donald Barr	Services, December 1-5, 1890	16.30
17	3	S. J. Kübel	Traveling expenses	19.15
17	4	Edward J. Hannan	Renovating sink	23.58
17	5	Z. D. Gilman	Engravers' supplies	18.75
26	6	Ernest Kübel	Copper plates	74.40
24	7	Springman & Bro	Hauling, etc	15.00
30	8	Pay roll of employés	Services, December, 1890	761.35
		Total		930.13

Abstract of disbursements made by Anton Karl, special disbursing agent, U. S. Geological Survey, during December, 1890.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

1890.				
Dec. 4	1	John H. Renshawe	Traveling expenses	$99.13
4	2	R. M. Towson	....do	50.71
4	3	Charles E. Cook, pay roll	Services, November	232.80
5	4	W. T. Quillin	....do	13.33
5	5	J. J. Mason	Traveling expenses	3.30
5	6	....do	Field expenses	103.25
5	7	W. M. Beaman	....do	101.44
5	8	M. B. Lambert	....do	99.46
5	9	....do	Traveling expenses	7.38
5	10	Glenn S. Smith	....do	4.75
5	11	....do	Field expenses	146.00
5	12	A. F. Dudley	....do	96.84
5	13	John H. Renshawe	Traveling expenses	82.05
5	14	A. E. Murlin	Field expenses	139.49
5	15	Castle & Henshaw	Supplies	15.00
9	16	D. C. Harrison	Field expenses	75.43
9	17	....do	Services, November	114.20
9	18	F. Howard Seely	....do	68.40
9	19	W. H. Lovell	Field expenses	77.38
9	20	J. J. Fawbush	Services, November	29.15
9	21	Urban Katsik	....do	21.00
9	22	Louis Nell	Field expenses	69.59
9	23	....do	....do	279.04
9	24	J. L. Bridwell	Traveling expenses	23.40
11	25	L. D. Brent	Services, November	73.40
11	26	A. F. Dudley	Traveling expenses	46.98
11	27	W. R. Atkinson	....do	11.45
11	28	Charles M. Yeates	....do	54.13
12	29	....do	....do	22.50
12	30	R. M. Towson	Field expenses	394.70
13	31	F. Howard Seeley	Traveling expenses	54.20
16	32	Charles M. Yeates	Field expenses	199.69
16	33	L. D. Brent	Traveling expenses	40.58
16	34	D. C. Harrison	....do	47.55
19	35	Nannie M. Peyton	Services, November	18.33
19	36	Mrs. C. E. Smith	....do	25.00
19	37	H. B. Blair	Field expenses	187.35
19	38	Hersey Munroe	Traveling expenses	17.05
19	39	....do	Field expenses	24.25
19	40	Thomas C. Nelson	Services	11.29
19	41	....do	Traveling expenses	20.20
19	42	C. G. Van Hook	Field expenses	67.60
19	43	Jeff. D. Reagan	Traveling expenses	41.95
19	44	Henry Ulke, jr	....do	36.30
19	45	H. C. Evans & Co	Maps	182.00
19	46	C. T. Reid	Traveling expenses	10.41
19	47	Fred. A. Schmidt	Supplies	2.81
19	48	William J. Peters	Field expenses	60.00
19	49	W. B. Moses & Sons	Furniture	13.00
19	50	L. H. Schneider's Son	Supplies	15.53
19	51	William D. Clark & Co	Material	38.83
19	52	Hume & Co	....do	2.00
19	53	E. E. Jackson & Co	Supplies	6.24
20	54	Lincoln Martin	Field expenses	83.62
22	55	Gilbert Thompson	Traveling expenses	15.30
22	56	A. E. Murlin	Field expenses	119.34
22	57	W. M. Beaman	....do	42.17
23	58	....do	Traveling expenses	34.99

Abstract of disbursements made by Anton Karl, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1891.				
Dec. 23	59	C. W. Goodlove	Traveling expenses	$4.75
23	60	E. C. Barnard	...do	107.35
23	61	W. H. Lovell	Field expenses	7.75
24	62	J. J. Mason	Traveling expenses	14.85
24	63	J. B. Hammond	Furniture	43.50
24	64	J. J. Mason	Field expenses	44.50
24	65	Albert M. Walker	...do	14.50
24	66	...do	Traveling expenses	11.06
26	67	Frank Sutton	......do	13.34
26	68	A. E. Murlin, pay roll	Services, December	354.43
29	69	W. H. Lovell	Traveling expenses	47.77
30	70	M. Hackett	...do	70.66
30	71	H. E. Williams	Services, November	65.00
30	72	M. Hackett, pay roll	Services, December	362.09
30	73	Charles E. Cook, pay roll	...do	236.10
30	74	C. G. Van Hook	...do	84.20
30	75	E. T. Brock	Storage	5.50
30	76	J. H. Hagerty	Forage	43.00
30	77	H. B. Blair	Services, December	134.80
30	78	G. W. & C. B. Colton	Maps	4.00
30	79	George S. Harris & Sons	...do	161.00
30	80	...do	...do	17.50
30	81	Edward Kübel	Supplies	11.25
30	82	E. C. Barnard	Field expenses	146.95
30	83	Lincoln Martin	...do	58.25
30	84	......do	Traveling expenses	35.05
30	85	E. C. Barnard	...do	26.00
30	86	...do	Field expenses	189.71
30	87	M. Hackett	...do	377.53
30	88	C. W. Goodlove	Traveling expenses	23.65
30	89	C. G. Van Hook	Field expenses	120.60
30	90	Basil Duke	Services, December	70.80
30	91	M. B. Lambert	Traveling expenses	16.36
31	92	...do	Field expenses	60.00
31	93	W. R. Atkinson	...do	168.99
31	94	...do	Traveling expenses	17.98
31	95	Robert D. Cummin	...do	21.86
31	96	F. P. Metzger	...do	40.10
31	97	H. B. Blair	...do	40.80
31	98	Robert D. Cummin	Field expenses	72.18
31	99	Office Specialty Manufacturing Company.	Topographic supplies	3.00
31	100	J. L. Bowdie	Services, December	25.80
31	101	John H. Renshawe	Pay roll, December	970.40
31	102		...do	1,621.80
31	103		...do	1,940.00
31	104	F. H. Clark	Services, December	25.16
31	105	W. & L. E. Gurley	Repairs	17.50
31	106	James L. Southard	Services, December	28.00
31	107	W. F. Fling	Pasturage	27.35
31	108	James Goode	Services, December	50.00
31	109	Julius Bien & Co	Maps	225.00
31	110	Isaac Crump	Forage and storage	69.00
31	111	Hinkel, Craig & Co	Storage	6.00
31	112	Hersey Munroe	Field expenses	143.75
31	113	...do	Services, December	84.20
31	114	George S. Harris & Sons	Maps	330.00
31	115	Pay roll	Services	848.30
		Total		13,944.83

Abstract of disbursements made by C. D. Davis, special disbursing agent, U. S. Geological Survey, during December, 1890.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

1890.				
Dec. 1	1	G. K. Gilbert	Traveling expenses	$32.23
2	2	C. L. Whittle	Services, November, 1890	100.00
4	3	Beckham & Corum	Forage, etc	13.75
5	4	W. P. Jenney	Services, September 1 to November 30, 1890.	544.10
5	5	N. H. Darton	Traveling expenses	74.94
6	6	W. Zensser & Co	Supplies	3.75
6	7	James G. Bowen	Forage of public animals	21.00

Abstract of disbursements made by C. D. Davis, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Dec. 6	8	Frank Leverett	Services, November, 1890	$120.00
6	9	Gilbert van Ingen	....do	75.00
6	10	George H. Williams	Services, October and November, 1890.	190.00
6	11	J. E. Wolff	Traveling expenses	4.15
8	12	J. F. Masten	Forage of public animals	30.00
8	13	F. M. Kinne	Services, November 1 to 11, 1890	13.50
8	14	R. S. Tarr	Services, November 1 to 7, 1890	12.00
8	15	J. E. Wolff	Services, November, 1890	45.65
8	16	Ben K. Emerson	....do	97.80
8	17	W. S. Bayley	....do	72.50
8	18	Fred. N. Honeywell	....do	63.00
8	19	Richard Bliss	....do	24.30
8	20	Joseph A. Holmes	Services, August 1 to December 1, 1890.	270.00
8	21	S. Ward Loper	Traveling expenses	15.75
8	22	R. S. Tarr	....do	25.52
9	23	Arthur Keith	....do	241.09
10	24	Warren Upham	Services, November 1 to 30, 1890	97.80
10	25	The Eastman Company	Field material	2.20
11	26	Lawrence C. Johnson	Traveling expenses	162.72
11	27	Henry Palmer	....do	10.75
14	28	Henry A. Clarke & Son	1 typewriter	85.00
18	29	E. L. Washburne	Supplies	3.87
18	30	N. B. Dunn	Pasturage, etc	28.60
22	31	Frank Leverett	Traveling expenses	53.95
22	32	J. B. Woodworth	....do	56.41
22	33	Sam C. Partridge	Photo. supplies	13.35
22	34	H. W. Turner	Traveling expenses	143.95
23	35	....do	Field expenses	31.25
23	36	R. A. F. Penrose, jr	Traveling expenses	8.38
27	37	T. Nelson Dale	Services, December, 1890	151.60
27	38	Cooper Curtice	Traveling expenses	111.90
27	39	C. L. Whittle	....do	328.99
27	40	W. P. Jenney	....do	52.20
27	41	....do	Field expenses	33.71
31	42	W. Lindgren	Services, December, 1890	134.80
31	43	Lawrence C. Johnson	....do	117.90
31	44	C. L. Whittle	Field expenses	26.87
31	45	S. Ward Loper	Services, November 23 to 27, 1890	7.50
31	46	....do	Services, December 1 to 14, 1890	27.82
31	47	George E. Luther	Services, December, 1890	101.10
31	48	Ben G. Palmer	....do	25.00
31	49	C. L. Whittle	....do	100.00
31	50	J. E. Wolff	....do	53.26
31	51	W. B. Clark	....do	125.00
31	52	N. S. Shaler	....do	270.00
31	53	Pay roll of employés	....do	1,934.40
31	54	....do	....do	389.40
31	55	....do	....do	1,499.60
31	56	C. R. Van Hise	....do	337.00
31	57	Raphael Pumpelly	....do	337.00
		Total		8,953.31

Abstract of disbursements made by Arnold Hague, special disbursing agent, U. S. Geological Survey, during December, 1890.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

1890.				
Dec. 2	1	Carver Mercantile Company	Field supplies	$30.07
9	2	Walter H. Weed	Incidental expenses	34.62
9	3	John S. Mendenhall	Field supplies	53.09
9	4	Pay roll of employés	Salaries, October, 1890	173.38
10	5	C. N. Sargent & Co	Field supplies	23.38
10	6	E. J. Owenhouse	Field expenses	30.55
		Total		345.09

Abstract of disbursements made by H. C. Rizer, disbursing agent, U. S. Geological Survey, during part of the second quarter of 1891.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Dec. 19	432	Idaho Saddlery Co	Supplies	$17.75
22	433	John Odell	Traveling expenses	5.00
22	434	Perry Fuller	Field expenses	16.90
22	435	...do	...do	48.75
23	436	Robert A. Farmer	...do	88.95
23	437	Stuart P. Johnson	...do	20.50
23	438	Samuel A. Foot	...do	31.50
23	439	...do	...do	83.35
24	440	Morris Bien	...do	69.82
24	441	E. M. Douglas	...do	18.50
24	442	Frank Tweedy	...do	30.00
24	443	W. T. Griswold	...do	70.00
24	444	Fred J. Knight	...do	189.84
24	445	...do	Traveling expenses	72.60
26	446	M. L. Wood	Livery expenses	36.00
26	447	Robert A. Farmer	Field expenses	48.50
27	448	A. F. Mack	...do	25.00
31	449	Pay roll, Thompson	Services, December	1,903.00
31	450	Pay roll, Goode	...do	1,210.80
31	451	Pay roll, Bien	...do	541.56
31	452	Pay roll, McKee	Services, November	259.40
31	453	Redick H. McKee	Services, December	134.80
31	454	H. E. Clermont Feusier	...do	101.10
31	455	E. T. Perkins, jr	...do	134.80
31	456	John Bowler	...do	11.30
31	457	Redick H. McKee	Field expenses	36.47
31	458	...do	...do	27.92
31	459	...do	...do	57.26
31	460	...do	...do	36.67
31	461	H. E. Clermont Feusier	...do	110.85
31	462	William H. Herron	...do	71.65
31	463	...do	...do	15.95
31	464	...do	...do	71.55
31	465	Frank Tweedy	...do	58.95
31	466	E. M. Douglas	Traveling expenses	123.50
31	467	Alex. C. Barclay	Field expenses	126.97
31	468	Paul Holman	...do	32.45
31	469	Samuel A. Foot	...do	37.80
31	470	Willard D. Johnson	...do	24.40
31	471	...do	Services, December	168.50
31	472	C. H. Fitch	...do	151.60
31	473	Philip Weiss	...do	20.32
31	474	W. J. Harrel	...do	24.67
31	475	William Davis	...do	24.67
31	476	F. M. Smith	...do	75.00
31	477	John McConn	...do	50.00
31	478	Pay roll, Foote	...do	119.03
31	479	Pay roll, Holman	...do	155.80
31	480	Pay roll, Barclay	...do	229.20
31	481	Pay roll, Hays	...do	317.63
31	482	Pay roll, Marshall	...do	301.10
31	483	Pay roll, Post	...do	255.77
31	484	Pay roll, Perry Fuller	...do	134.20
31	485	Pay roll, Johnson	...do	234.20
31	486	Pay roll, Farmer	...do	260.50
31	487	William P. Trowbridge	...do	100.00
31	488	J. M. Dikeman	...do	60.00
31	489	F. J. Knight	...do	151.60
31	490	T. M. Bannon	...do	75.00
31	491	Jeremiah Ahern	...do	117.90
31	492	...do	Traveling expenses	90.90
31	493	H. E. Clermont Feusier	...do	126.50
31	494	William H. Herron	...do	55.15
31	495	Redick H. McKee	...do	125.00
31	496	A. F. Mack	Field expenses	5.75
31	497	H. L. Baldwin, jr	...do	2.25
31	498	Redick H. McKee	...do	41.04
31	499	E. M. Douglas	...do	48.60
31	500	Samuel McDowell	Pasturage	60.00
31	501	A. R. Black	Forage	542.50
31	502	Denver Transit and Warehouse Co.	Storage	20.00
31	503	...do	...do	20.00
31	504	Samuel A. Foot	Field expenses	29.25
31	505	Coxhead & Harrel	Forage	9.00
31	506	...do	Storage	7.50
31	507	St. James Hotel	Subsistence	20.00

Abstract of disbursements made by H. C. Rizer, disbursing agent, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
Dec. 31	508	M. Studzinski	Storage	$7.50
31	509	Kennedy & Orr	Repairs	39.35
31	510	George A. Newton	Labor	48.00
31	511	John Hess	Forage	13.00
31	512	...do	Pasturage	10.00
31	513	John McConn	Traveling expenses	23.05
31	514	Charles Stone	Services	51.25
31	515	Eastman Bros	Board	53.50
31	516	J. R. Patterson	Services, December	50.00
31	517	Jeff. D. Reagan	...do	60.00
31	518	Michael Cogan	...do	40.32
31	519	Pay roll, McKinney	...do	284.80
31	520	Frank Frater	Pasturage	72.80
31	521	Andrew McClelland	Supplies	126.87
31	522	A. McClelland	...do	50.82
31	523	...do	...do	33.92
31	524	Willard D. Johnson	Field expenses	30.05
31	525	...do	...do	103.80
31	526	...do	...do	63.50
31	527	H. H. Hackett	Services, November	15.00
31	528	Ed. Boehme	Services, December	18.00
31	529	E. C. Kelsey	Services, October	45.00
		Total		11,473.27

Abstract of disbursements made by Jno. D. McChesney, chief disbursing clerk U. S. Geological Survey, during January, 1891.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

1891.				
Jan. 13	2	H. A. C. Hunter	Traveling expenses	$26.65
13	3	C. C. Willard	Rent of office December, 1890	266.66
14	4	Robert Beall	Publications	9.00
14	5	Richmond and Danville R. R.	Transportation of assistants	71.65
14	6	Baker & Adamson	Laboratory supplies	26.60
14	7	Missouri Pacific R. R. Co	Transportation of assistants	17.15
14	8	Atchison, Topeka and Santa Fé R. R.	...do	50.45
14	9	William P. Rust	Services, December, 1890	67.50
14	10	Chicago, Milwaukee and St. Paul R'y.	Transportation of assistants	31.50
14	11	James W. Queen & Co	Laboratory supplies	212.25
14	12	...do	Geologic supplies	78.37
14	13	National Press Intelligence Co	Newspaper clippings	7.80
14	14	Buffalo Dental Manufacturing Co.	Laboratory supplies	40.30
14	15	Washington Gaslight Co	...do	63.25
14	16	Melville Lindsay	...do	3.44
14	17	Wash. B. Williams	Supplies	56.00
15	18	Robert Leitch & Son	Topographic supplies	12.24
16	19	Fred. A. Schmidt	Supplies	8.45
16	20	William D. Clark & Co	Topographic supplies	.75
16	21	Smithsonian Institution	Transportion of exchanges	28.97
16	22	E. E. Jackson & Co	Supplies	17.03
16	23	Baltimore and Ohio R. R. Co	Transportation of property	15.12
16	24	Z. D. Gilman	Supplies	150.54
17	25	Smedley Brothers& Co	Transportation of property	84.15
17	26	Samuel Springmann	Freight charges and hauling	4.38
17	27	J. F. Sabin	Publications	4.00
17	28	David Williams	...do	10.00
17	29	N. D. C. Hodges	...do	7.00
17	30	Pennsylvania R. R. Co	Transportation of assistants	69.30
20	31	Atchison, Topeka and Santa Fé R. R.	...do	6.55
20	32	Charles L. Condit	Supplies for mineral resources	9.50
20	33	Gustav E. Stechert	Publications	18.72
20	34	...do	...do	97.55
22	35	W. Andrew Boyd	...do	25.00
22	36	J. Walther	Topographic supplies	48.00
22	37	Pennsylvania R. R. Co	Transportation of assistants	34.61
22	38	Frank Burns	Traveling expenses	36.95
26	39	George W. Knox	Freight charges and hauling	181.99
26	40	Wash. B. Williams	Topographic supplies	71.00
31	41	C. C. Willard	Rent of office, January, 1891	266.66
29	42	H. Hoffa	Paleontologic supplies	5.50

Abstract of disbursments made by Jno. D. McChesney, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1891.				
Jan. 29	43	George Ryneal, jr	Supplies	$401.28
29	44	Smedley Brothers & Co	Transportation of property	53.39
29	45	L. H. Schneider's Son	Supplies	79.98
29	46	Baltimore and Ohio R. R. Co	Transportation of property	76.15
29	47	Charles R. Keyes	Original drawings	150.00
29	48	Ira Sayles	Services, January, 1891	120.60
29	49	Sam. H. Scudder	...do	215.30
29	50	J. Henry Blake	...do	155.00
29	51	O. C. Marsh	...do	344.40
29	52	F. Berger	...do	80.00
29	53	L. P. Bush	...do	50.00
29	54	H. Gibb	...do	80.00
29	55	Great Northern Rwy Co	Transportation of assistant	67.50
29	56	Victoria Essex	Services, December 24 to 31, 1890	10.00
29	57	...do	Services, January, 1891	52.00
29	58	Mary C. Mahon	Services, January 2 to 31, 1891	52.00
29	59	Frank T. Smart	Services January, 1891	103.30
29	60	Pay roll of employés	...do	1,351.80
29	61	...do	...do	1,310.70
29	62	...do	...do	1,017.16
29	63	...do	...do	976.17
29	64	...do	...do	1,419.30
29	65	...do	...do	1,188.00
29	66	...do	...do	792.10
29	67	...do	...do	378.90
29	68	W. S. Hardesty	Services January 12 to 31, 1891	32.26
		Total		12,799.82

APPROPRIATION FOR GEOLOGICAL MAPS OF THE UNITED STATES, 1891.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1891.				
Jan. 14	1	Robert Mayer & Co	1 ruling machine	$58.00
16	2	William D. Clark & Co	Engraver's supplies	1.07
26	3	George W. Knox	Freight charges and hauling	29.38
29	4	L. H. Schneider's Son	Supplies	5.13
31	5	Pay roll of employés	Services, January, 1891	883.42
		Total		977.60

Abstract of disbursements made by Anton Karl, special disbursing agent, U. S. Geological Survey, during January, 1891.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1891.				
Jan. 31	1	Hersey Munroe	Field expenses	$106.95
31	2	R. Riggs	Veterinary services	10.00
31	3	James G. Bower	Stabling	6.00
31	4	C. G. Van Hook	Field expenses	7.10
31	5	Charles E. Cooke	...do	177.16
31	6	Savannah, Florida and Western R. R.	Transportation	40.60
31	7	R. B. Cameron	Services	72.30
31	8	...do	Traveling expenses	16.85
31	9	Savannah, Florida and Western R. R.	Transportation	103.60
31	10	Benson, Roux & Co	Repairs	42.25
31	11	Gainesville Furniture Manufacturing Co.	Field material	17.50
31	12	H. L. Baldwin, jr	Field expenses	354.17
31	13	H. B. Blair	...do	250.09
31	14	H. L. Baldwin, jr	...do	107.64
31	15	C. G. Van Hook	Traveling expenses	22.85
31	16	...do	...do	10.30
31	17	Charles M. Yeates, pay roll	Services, January	583.67
31	18	Ewing Speed	Services, December, 1890	50.00
31	19	Hersey Munroe, pay roll	Services, January	340.73
31	20	Henry Gannett	...do	1,922.00
31	21	John H. Renshawe, pay roll	...do	2,189.55
31	22	Gilbert Thompson, pay roll	...do	2,058.24
31	23	Benson, Roux & Co	Storage	56.00
31	24	Ira M. Buell	Services	14.00

Abstract of disbursements made by Anton Karl, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1891.				
Jan. 31	25	Rees Evans	Traveling expenses	$5.20
31	26	John Jennings	...do	3.45
31	27	O. L. Meadows	...do	4.35
31	28	...do	Services	4.85
31	29	I. M. Buell	Field expenses	13.14
31	30	George B. Taylor	Storage	3.30
31	31	John W. Price	Pasturage	34.50
31	32	J. M. Gibson	...do	77.56
31	33	N. B. Dunn	...do	77.58
31	34	Rees Evans	Services	9.03
31	35	John Jennings	...do	6.77
31	36	J. H. Hagerty	Forage	62.22
31	37	J. M. Fawbush	Pasturage	35.00
31	38	Louis H. Everts	Maps	10.00
31	39	James G. Reeves	Pasturage	12.66
31	40	Winchester Manufacturing Co.	Storage	4.78
31	41	S. J. Haislett	Field material	10.00
31	42	S. E. Cook	Traveling expenses	15.30
31	43	James Goode	...do	19.75
31	44	F. Howard Seeley	...do	38.45
31	45	Basil Duke	...do	31.70
31	46	E. Baird	Field expenses	55.50
31	47	Basil Duke	Traveling expenses	29.60
31	48	Hersey Munroe	Field expenses	165.15
31	49	J. D. Matheson	Material	46.80
31	50	H. St. George Tucker	Traveling expenses	10.20
31	51	...do	Services	11.29
31	52	Phillip Miller	Field expenses	168.90
31	53	A. M. Jackson	Traveling expenses	9.55
31	54	H. E. Williams	Services	65.00
31	55	L. C. Woodbury	...do	27.42
31	56	W. T. Quillin	...do	14.51
31	57	Duncan Hannegan	...do	62.25
31	58	Basil Duke	...do	75.17
31	59	F. Howard Seeley	...do	75.17
31	60	H. L. Baldwin, jr	...do	155.00
31	61	Albert M. Walker	...do	60.00
31	62	J. J. Mason	...do	50.00
31	63	James Goode	...do	50.00
31	64	A. E. Wilson	Traveling expenses	33.57
31	65	...do	Field expenses	12.50
31	66	Glenn S. Smith	Services	75.80
31	67	...do	Field expenses	54.10
31	68	...do	Traveling expenses	17.00
31	69	Ewing Speed	Field expenses	71.75
31	70	...do	Traveling expenses	19.71
31	71	J. M. Durnal	Services	34.83
31	72	W. E. Lackland	...do	72.30
31	73	...do	Traveling expenses	49.10
31	74	H. B. Blair	Field expenses	240.05
31	75	M. E. Kahler	Instruments	23.40
31	76	H. B. Blair	Field expenses	67.75
31	77	J. S. Topham	Material	27.70
31	78	Charles E. Cooke	Field expenses	132.18
31	79	...do	...do	42.43
31	80	...do	Traveling expenses	11.80
31	81	H. B. Blair	Field expenses	51.25
26	82	C. G. Van Hook	...do	37.42
31	83	H. E. Williams	Services	65.00
31	84	S. E. Cooke	...do	34.84
20	85	Charles R. Grandy	Traveling expenses	12.25
20	86	H. L. Baldwin, jr	...do	60.45
20	87	C. W. Goodlove	...do	11.25
20	88	J. J. Mason	...do	46.65
20	89	Albert M. Walker	...do	12.50
20	90	Hersey Monroe	Field expenses	74.15
20	91	Duncan Hannegan	Traveling expenses	12.50
20	92	F. Howard Seeley	...do	12.95
20	93	C. G. Van Hook	Field expenses	64.67
20	94	Lincoln Martin	Traveling expenses	16.25
20	95	J. L. Bridwell	...do	29.70
20	96	Thomas C. Nelson	...do	37.45
20	97	Charles M. Yeates	Field expenses	65.36
31	98	...do	Traveling expenses	32.50
9	99	J. M. Fawbush	Forage and storage	41.00
31	100	Office Specialty Manufacturing Co.	Office furniture	25.00
31	101	W. & L. E. Gurley	Instruments	26.00
		Total		11,925.75

Abstract of disbursements made by C. D. Davis, special disbursing agent, U. S. Geological Survey, during January, 1891.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1891.				
Jan. 5	1	W. P. Jenney	Services, December, 1890	$185.30
5	2	Gilbert van Ingen	....do	75.00
5	3	W. S. Bayley	....do	95.00
5	4	Frank Leverett	....do	130.00
5	5	P. M. Jones	Services, November, 1890	8.33
5	6	J. M. Safford	....do	24.46
5	7	Charles S. Merrick	Services, September 1 to December 19, 1890.	20.00
5	8	J. M. Safford	Field expenses	2.25
5	9	S. Ward Loper	Traveling expenses	9.63
5	10	....do	....do	25.00
5	11	Charles S. Merrick	....do	21.20
5	12	W. Lindgren	Field expenses	94.40
5	13	Main & Winchester	Field supplies	24.00
7	14	R. E. Dodge	Services, December, 1890	30.00
7	15	J. B. Woodworth	....do	50.00
8	16	Beckham & Corum	Forage, etc	10.00
9	17	James G. Bowen	....do	21.50
9	18	Warren Upham	Services, December, 1890	101.10
9	19	J. F. Masten	Pasturage	45.00
9	20	Isaiah Rendell	....do	74.50
9	21	P. J. Littlehale	Pasturage, etc	25.50
9	22	Raphael Pumpelly	Field expenses	5.91
10	23	Charles J. Moore	Services, October 1 to December 31, 1890.	540.00
12	24	Richard Bliss	Services, December, 1890	26.40
12	25	W. F. Fling	Pasturage	18.00
12	26	A. P. Baker	Rent of office	43.75
14	27	Wells, Fargo & Co	Expressage	9.10
14	28	William D. Clark & Co	Toweling	2.00
14	29	James M. McCammon	Pasturage	74.82
16	30	Ben K. Emerson	Traveling expenses	106.87
16	31	William I. Swinburne	Fuel	33.70
16	32	T. Nelson Dale	Field supplies	14.23
17	33	William B. Clark	Services, January 1-15, 1891	55.00
17	34	C. R. Van Hise	Field expenses	33.35
17	35	W J McGee	Traveling expenses	79.32
21	36	William Beals, jr	....do	153.08
21	37	J. M. Safford	....do	6.20
21	38	W. F. Fling	Pasturage	11.32
22	39	W. Lindgren	Traveling expenses	45.85
22	40	....do	Field expenses	48.50
22	41	George H. Eldridge	Traveling expenses	82.92
23	42	W. T. Turner	Services, November 1 to December 3, 1890.	27.42
26	43	C. W. Hall	Services, August 4 to December 31, 1890.	63.00
26	44	William J. Park & Sons	Stationery	15.31
26	45	C. C. Hayes	Care and forage of animals	10.00
27	46	E. C. van Diest	Services, October 1 to December 1, 1890.	50.00
27	47	A. P. Baker	Rent of rooms	43.75
27	48	Joseph H. Perry	Traveling expenses	27.18
27	49	....do	Services, September 1 to December 31,1890.	24.00
28	50	Charles S. Prosser	Traveling expenses	180.25
28	51	Lawrence C. Johnson	Services, January, 1891	120.60
28	52	T. Nelson Dale	....do	155.00
29	53	W. P. Jenney	....do	189.40
31	54	Edmund Jüssen	....do	50.00
31	55	W. Lindgren	....do	137.80
31	56	Pay roll of employés	....do	1,532.70
21	57	....do	....do	202.50
31	58	....do	....do	2,176.00
31	59	J. B. Woodworth	....do	50.00
31	60	R. E. Dodge	....do	30.00
31	61	J. E. Wolff	....do	70.00
31	62	W. S. Bayley	....do	90.00
31	63	George E. Luther	....do	103.30
31	64	W. N. Merriam	....do	85.00
31	65	N. S. Shaler	....do	270.00
31	66	Frank Leverett	....do	135.00
31	67	Ben. G. Palmer	....do	25.00
31	68	Raphael Pumpelly	....do	344.40
31	69	C. R. Van Hise	....do	344.40
31	70	Raphael Pumpelly	Traveling expenses	118.41
31	71	William H. Dall	....do	78.42
31	72	I. M. K. Southwick	Supplies	7.34

Abstract of disbursements made by C. D. Davis, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid	For what paid.	Amount.
1891.				
Jan. 31	73	S. H. Davis	Pasturage	$24.00
31	74	L. C. Johnson	Traveling expenses	74.97
31	75	N. S. Shaler	...do	179.74
31	76	Raphael Pumpelly	Field expenses	13.23
		Total		9,510.61

Abstract of disbursements made by Arnold Hague, special disbursing agent, U. S. Geological Survey, during January, 1891.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

Date.	Voucher.	To whom paid	For what paid.	Amount.
1891.				
Jan. 31	1	Pay roll of employés	Salaries, December, 1890	$741.30
31	2	...do	Salaries, January, 1891	757.70
		Total		1,499.00

Abstract of disbursements made by James W. Spencer, special disbursing agent, U. S. Geological Survey, during the month of January, 1891.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

Date.	Voucher.	To whom paid	For what paid.	Amount.
1891.				
Jan. 13	1	John McConn	Traveling expenses	$32.00
13	2	H. H. Chinulea	...do	59.75
13	3	Perry Fuller	...do	59.75
16	4	Mark B. Kerr	...do	124.00
16	5	F. E. Conrad & Co	Forage	65.27
16	6	Rockwell Bros	Pasturage	23.22
16	7	A. A. Rockwell	Services, November and December.	36.67
17	8	Frank Tweedy	Field expenses	30.00
19	9	Morris Bien	...do	11.50
19	10	E. M. Douglas	...do	48.50
19	11	L. B. Kendall	...do	110.27
19	12	T. E. Grafton	Traveling expenses	72.60
19	13	R. B. Marshall	...do	72.60
19	14	...do	Field expenses	49.16
19	15	William S. Post	...do	246.47
19	16	A. P. Davis	...do	60.00
21	17	A. Momahan	...do	30.75
21	18	William S. Post	Forage	25.14
21	19	Tenny Ross	Traveling expenses	61.75
21	20	L. B. Kendall	...do	72.35
23	21	Samuel A. Foot	...do	73.85
23	22	W. T. Griswold	Field expenses	37.50
23	23	E. H. Stone	Traveling expenses	71.85
26	24	E. M. Douglas	Field expenses	11.70
26	25	Spratlen & Anderson	Subsistence expenses	35.31
27	26	F. M. Call	Traveling expenses	14.85
27	27	Stuart P. Johnson	...do	72.85
31	28	Charles W. Howall	Services, January	60.00
29	29	R. C. McKinney	Field expenses	10.00
29	30	Alex. C. Barclay	...do	51.42
29	31	...do	Traveling expenses	71.85
29	32	...do	...do	4.90
29	33	...do	...do	8.00
29	34	W. A. Farish	...do	10.50
28	35	William S. Post	...do	61.75
29	36	Amos Scott	Services, December, 1890, and January, 1891.	120.00
30	37	John Jones	Repairs	4.00
30	38	N. J. Davis	Transportation	9.67
31	39	Robert A. Farmer	Traveling expenses	71.85
31	40	C. H. Fitch	Services, January	155.00
31	41	W. L. Wilson	...do	17.74
31	42	Arthur P. Davis	Field expenses	50.79
31	43	Pay roll, A. H. Thompson	Services, January	4,519.64
31	44	...do	...do	737.10
31	45	J. M. Dikeman	...do	60.00
31	46	George L. Robinson	Forage	55.00
		Total		7,688.87

Abstract of disbursements made by Jno. D. McChesney, chief disbursing clerk, U. S. Geological Survey, during February, 1891.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1891.				
Feb. 4	1	Charles G. Stott & Co	Supplies	$10.42
4	2	Adams Express Co	Freight charges, July and November, 1890.	147.00
4	3	....do	Freight charges, December, 1890	183.50
9	4	T. W. Stanton	Traveling expenses	50.72
9	5	Washington Gaslight Co	Laboratory supplies	54.63
9	6	E. J. Pullman	Supplies	357.11
9	7	The Wabash R. R. Co	Transportation of assistants	11.25
9	8	William Grunow, jr	Laboratory supplies	175.00
11	9	Ira Sayles	Traveling expenses	14.05
11	10	Emil Greiner	Laboratory supplies	14.30
11	11	Charles J. Cohen	Geologic supplies	41.20
11	12	Northern Pacific Ry. Co	Transportation of assistants	2.60
11	13	John C. Parker	Topographic supplies	10.05
11	14	John S. Leng's Son & Co	Laboratory supplies	6.00
12	15	W. P. Rust	Services, January, 1891	67.50
12	16	Baltimore & Ohio R. R. Co	Transportation of property	25.45
12	17	....do	....do	.98
13	18	William F. Porter	Publications	7.00
13	19	Ellen L. Cudlip and Fillmore Beall.	Supplies for illustrations	89.11
14	20	E. E. Jackson & Co	Supplies	203.05
14	21	Columbia Phonograph Co	Rent of graphophone	101.43
14	22	E. & H. T. Anthony & Co	Supplies for illustrating	6.50
14	23	The Eastman Company	Geologic supplies	13.50
14	24	Pennsylvania R. R. Co	Transportation of assistants	322.20
16	25	The Wabash R. R. Co	....do	41.25
16	26	International and Great Northern R. R.	....do	40.00
16	27	Great Northern Railway Line	....do	280.50
18	28	W. D. Doremus	Laboratory supplies	119.19
18	29	Atchison, Topeka and Sant Fé R. R.	Transportation of assistants	82.40
18	30	J. Bishop & Co	Repairs to laboratory material	9.40
20	31	Wash. B. Williams	Geologic supplies	20.00
25	32	Rio Grande Western Ry. Co	Transportation of assistants	25.00
25	33	....do	....do	24.00
25	34	L. Feuchtwanger & Co	Laboratory supplies	9.00
25	35	Fremont, Elkhorn and Missouri Valley R. R.	Transportation of property	14.36
25	36	Whitall, Tatum & Co	Laboratory supplies	17.38
25	37	American Tool and Machine Co	....do	27.50
25	38	James W. Queen & Co	....do	7.50
25	39	Eimer & Amend	....do	155.35
25	40	Buffalo Dental Manufacturing Co.	....do	29.80
25	41	T. M. Chatard	Traveling expenses	138.64
25	42	Samuel Springmann	Freight charges and hauling	9.41
25	43	L. H. Schneider's Son	Supplies	53.56
25	44	Fred. A. Schmidt	Topographic supplies	14.20
28	45	Mary C. Mahon	Services, February, 1891	39.00
28	46	Victoria Essex	....do	39.00
28	47	Samuel H. Scudder	....do	194.40
28	48	J. Henry Blake	....do	140.00
28	49	O. C. Marsh	....do	311.20
28	50	F. Berger	....do	80.00
28	51	L. P. Bush	....do	50.00
28	52	C. C. Willard	Rent of office	266.66
28	53	Leonard A. White	Services, January 29 to February 28, 1891.	54.84
28	54	Pay roll of employés	Services, February, 1891	1,221.40
28	55	....do	....do	1,208.60
28	56	....do	....do	805.80
28	57	....do	....do	901.60
28	58	....do	....do	1,400.20
28	59	....do	....do	1,066.90
28	60	....do	....do	765.80
28	61	....do	....do	342.20
		Total		11,920.59

Abstract of disbursements made by Jno. D. McChesney, etc.—Continued.

APPROPRIATION FOR GEOLOGICAL MAPS OF THE UNITED STATES, 1891.

Date.	Voucher.	To whom paid.	For what paid	Amount.
1891.				
Feb. 5	1	H. Holffa	Engraver's supplies	$18.00
11	2	Melville Lindsay	Printer's blanket	6.81
11	3	Ernest Kübel	Electrotyping, &c	43.48
11	4	Robert Mayer & Co	Engraver's supplies	15.00
12	5	James K. Cleary	...do	4.50
14	6	E. E. Jackson & Co	...do	108.73
14	7	E. G. Wheeler	...do	1.50
14	8	George Meier & Co	...do	58.90
14	9	R. Hoe & Co	...do	4.00
14	10	Robert Mayer & Co	...do	1.15
20	11	Wash. B. Williams	...do	71.00
20	12	U. S. Electric Lighting Co	Use of 4 horse-power currents	12.50
25	13	Charles Credner	Japanese vellum paper	19.65
25	14	Mount Holly Paper Co	Lithographic and plate paper	15.66
25	15	L. H. Schneider's Son	Engraver's supplies	4.80
28	16	Pay roll of employés	Services, February, 1891	960.37
		Total		1,346.05

Abstract of disbursements made by Anton Karl, special disbursing agent, U. S. Geological Survey, during February, 1891.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

1891.				
Feb. 20	1	H. L. Baldwin, jr	Field expenses	$200.52
20	2	...do	...do	147.50
20	3	Hersey Munroe	...do	142.50
20	4	Chas. M. Yeates	...do	105.62
28	5	Pay roll, Yeates		351.96
24–28	6	John H. Renshawe	Services	194.40
14–24	7	Robert D. Cummin	...do	124.40
28	8	H. M. Wilson	...do	194.40
28	9	Nat. Tyler, jr	Traveling expenses	73.55
28	10	Pay roll, Gannett		1,596.00
28	11	Pay roll, Gilbert Thompson		2,223.63
28	12	Pay roll		1,393.80
28	13	Duncan Hannegan	Services	65.40
28	14	Easton & Rupp	Office material	1.75
28	15	Pay roll, Hersey Munroe		333.40
28	16	Jules Leport	Services	19.29
28	17	L. C. Woodbury	...do	50.00
28	18	F. Howard Seely	...do	70.00
28	19	H. L. Baldwin, jr	...do	140.00
28	20	George Landry	...do	40.00
28	21	...do	...do	7.74
28	22	J. R. Carn	...do	6.77
28	23	...do	...do	30.00
28	24	Albert M. Walker	...do	60.00
28	25	James Goode	...do	50.00
11–28	26	R. B. Cameron	...do	65.40
28	27	Norman Scott	Traveling expenses	33.80
28	28	W. R. Atkinson	Services	93.40
28	29	R. Hoe & Co	Instruments	10.00
28	30	W. R. Atkinson	Field expenses	159.43
28	31	...do	Traveling expenses	14.05
28	32	Hersey Munroe	Field expenses	126.87
28	33	John W. Price	Pasturage	45.00
28	34	...do	...do	39.19
28	35	James McCammon	...do	6.45
28	36	N. B. Dunn	...do	68.08
28	37	Isaac Crump	...do	69.00
28	38	James G. Reaves	...do	10.00
28	39	W. F. Fling	...do	42.00
28	40	J. M. Gibson	...do	79.95
28	41	S. J. Haislett	Flags	7.00
28	42	William D. Clark & Co	Office material	39.45
28	43	Isaac Crump	Pasturage	69.00
28	44	H. L. Baldwin, jr	Field expenses	469.90
28	45	J. H. Means	Services	70.00
		Total		9,040.60

Abstract of disbursements made by C. D. Davis, special disbursing agent, U. S. Geological Survey, during February, 1891.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1891.				
Feb. 6	1	James G. Bowen	Forage, etc	$22.50
7	2	T. H. Hooper	Services	27.00
7	3	Paul M. Jones	Traveling expenses	2.60
7	4	...do	Services, December, 1890	4.80
7	5	J. M. Safford	...do	4.89
9	6	Beckham & Corum	Forage	8.00
10	7	J. T. Masten	...do	45.00
10	8	William Beals, jr	Traveling expenses	143.20
10	9	Richard Bliss	Services	25.50
12	10	Lawrence C. Johnson	Traveling expenses	121.30
12	11	George H. Williams	Services, December, 1890	75.00
12	12	...do	Services, January, 1891	30.00
12	13	J. E. Wolff	Traveling expenses	30.00
13	14	William Beals, jr	Specimens	9.00
13	15	Julius Bien & Co	Maps	43.00
16	16	W. B. Leonard	Horse	175.00
18	17	William H. Hobbs	Field expenses	31.73
19	18	C. L. Whittle	Services, January, 1891	100.00
19	19	Adams Express Co	Expressage	4.95
19	20	Theodore C. Schneider	Supplies	10.00
20	21	Ward & Howell	Specimens	217.50
20	22	Edmund Jüssen	Traveling expenses	53.85
20	23	E. B. Richardson	Hire of transportation	80.00
26	24	George H. Eldridge	Traveling expenses	213.07
28	25	T. Nelson Dale	Services, February, 1891	140.00
28	26	Warren Upham	Services, January, 1891	103.30
28	27	Lawrence C. Johnson	Services, February, 1891	108.80
28	28	J. B. Woodward	...do	50.00
28	29	R. E. Dodge	...do	30.00
28	30	C. L. Whittle	...do	100.00
28	31	W. P. Jenney	...do	171.20
28	32	C. E. Kloeber	...do	30.00
28	33	W. S. Bayley	...do	82.50
28	34	George E. Luther	...do	93.40
28	35	W. N. Merriam	...do	80.00
28	36	N. S. Shaler	...do	240.00
28	37	Edmund Jüssen	...do	50.00
28	38	J. M. Safford	Expressage	1.55
28	39	...do	Services, January, 1891	5.00
28	40	Raphael Pumpelly	Services, February, 1891	311.20
28	41	C. R. Van Hise	...do	311.20
28	42	Pay roll of employés	...do	1,383.40
28	43	...do	...do	319.40
28	44	...do	...do	1,965.50
		Total		7,054.34

Abstract of disbursements made by Arnold Hague, special disbursing agent, U. S. Geological Survey, during February, 1891.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

1891.				
Feb. 4	1	E. J. Owenhouse	Storage	$30.00
28	2	Pay roll of employés	Salaries, February, 1891	684.60
		Total		714.60

Abstract of disbursements made by James W. Spencer, special disbursing agent, U. S. Geological Survey, during the month of February, 1891.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

1891.				
Feb. 4	47	Paul Holman	Field expenses	$5.36
5	48	W. J. Lloyd	Traveling expenses	72.10
5	49	...do	Field expenses	50.00
6	50	John W. Hays	Traveling expenses	78.15
7	51	A. A. Rockwell	Services, January, 1891	20.00
7	52	Rockwell Bros	Pasturage	14.50

Abstract of disbursements made by James W. Spencer, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1891.				
Feb. 7	53	F. E. Conrad & Co	Forage	$247.50
7	54	Coxhead & Harrell	Field expenses	37.90
7	55	Joseph Jacobs	Subsistence and forage	74.55
9	56	Paul Holman	Field expenses	5.40
11	57	M. Maxwell	Forage	84.50
11	58	J. A. Falkenstrie	...do	70.00
13	59	Frank Tweedy	Field expenses	20.00
13	60	E. M. Douglas	...do	13.50
13	61	A. P. Davis	...do	50.00
24	62	...do	...do	19.93
24	63	W. T. Griswold	...do	37.50
24	64	...do	...do	27.00
19	65	Willard D. Johnson	...do	123.05
27	66	...do	...do	10.00
28	67	Amos Scott	Services, February, 1891	60.00
28	68	Charles W. Howell	...do	60.00
28	69	J. M. Dikeman	...do	60.00
28	70	D. H. Sager	Services, November, 1890	8.00
28	71	A. H. Thompson, pay roll	Services, February, 1891	4,533.20
28	72	...do	...do	850.40
		Total		6,632.48

Abstract of disbursements made by Jno. D. McChesney, chief disbursing clerk, U. S. Geological Survey, during March, 1891.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

1891.				
Mar. 6	1	Z. D. Gilman	Supplies	$244.55
6	2	Charles G. Stott & Co	...do	8.56
9	3	Washington Gaslight Co	Laboratory supplies	56.76
9	4	Melville Lindsay	...do	10.46
9	5	J. S. Newberry	Services July 1 to September 30, 1890.	900.00
9	6	Baker & Adamson	Laboratory supplies	21.90
9	7	S. Ward Loper	Services, February, 1891	96.00
9	8	Browne & Sharp M'f'g Co	Laboratory material	9.00
9	9	William P. Rust	Services, February, 1891	60.00
9	10	Pittsburgh, Cincinnati, Chicago and St. Louis Rwy.	Transportation of assistants	17.51
9	11	The E. S. Greeley & Co	Laboratory supplies	5.44
11	12	Missouri Pacific Rwy. Co	Transportation of assistants	43.90
11	13	Baltimore and Ohio Rwy. Co	...do	46.65
11	14	Montana Union Rwy. Co	Transportation of property	2.20
18	15	Burlington and Missouri River Railroad in Nebraska.	Transportation of assistants	30.65
18	16	Texas and Pacific R. R. Co	...do	82.60
18	17	Emil Greiner	Laboratory supplies	10.65
18	18	F. E. Willis	Illustrations for reports	18.00
18	19	Atchison, Topeka and Santa Fé R. R.	Transportation of assistants	39.75
18	20	Smithsonian Institution	Transportation of exchanges	676.92
18	21	Wyckoff, Seamans & Benedict	Supplies and repairs	68.00
18	22	John C. Parker	Supplies for mineral resources	1.50
20	23	Office Specialty M'f'g Co	Geologic supplies	42.00
20	24	Fred. A. Schmidt	Geologic and topographic supplies.	11.03
20	25	Charles L. Condit	Mercantile speller	1.75
20	26	Chicago and Northwestern Rwy.	Transportation of assistants	12.50
20	27	......do	...do	19.26
20	28	Pennsylvania R. R. Co	do	17.50
20	29	Spring Garden Metal Works	Laboratory supplies	17.83
20	30	The American Tool and Machine Co.	...do	15.00
20	31	John C. Entriken	Repairs to laboratory material	11.55
23	32	Robert Beall	Publications	65.00
31	33	Pay roll of employés	Services, March, 1891	1,351.80
31	34	...do	...do	1,310.70
31	35	...do	...do	887.10
31	36	...do	...do	809.50
31	37	...do	...do	1,436.60
31	38	...do	...do	1,177.70
31	39	...do	...do	842.10
31	40	...do	...do	378.90

Abstract of disbursements made by Jno. D. McChesney, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1891.				
Mar. 31	41	W. D. Doremus	Laboratory supplies	$8.00
31	42	Alpheus Hyatt	Services, November 1 to December 31, 1890.	500.00
31	43	H. S. Williams	Services, October 1, 1890, to March 31, 1891.	750.00
31	44	Samuel H. Scudder	Services, March, 1891	215.30
31	45	J. Henry Blake	...do	155.00
31	46	O. C. Marsh	...do	344.40
31	47	F. Berger	...do	80.00
31	48	L. P. Bush	...do	50.00
31	49	T. A. Bostwick	Services, January 1 to March 31, 1891.	250.00
31	50	A. Hermann	...do	250.00
31	51	Wells M. Sawyer	Services, March 11 to 31, 1891	52.50
31	52	C. C. Willard	Rent of office	266.66
31	53	Wisconsin Central Lines	Transportation of assistants	40.48
31	54	Jos. F. James	Services, March, 1891	103.30
		Total		13,924.46

APPROPRIATION FOR GEOLOGICAL MAPS OF THE UNITED STATES, 1891.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1891.				
Mar. 2	1	Washington Construction Co	Services and supplies	$13.25
6	2	Z. D. Gilman	Engravers' supplies	9.50
9	3	United States Electric Lighting Co.	Use of 4 horse-power current	25.00
9	4	Melville Lindsay	Engravers' supplies	.31
9	5	R. Hoe & Co	Steam lithographer's press	3,750.00
9	6	Shepherd & Hurley	Labor and material furnished	335.46
18	7	Mount Holly Paper Co	Engravers' supplies	12.40
18	8	Fuchs & Lang	...do	13.50
18	9	Robert Mayer & Co	...do	4.50
18	10	J. B. Hammond	Boxes for copper plates	23.10
18	11	R. F. Bartle	Engravers' supplies	35.00
18	12	Fred. A. Schmidt	...do	12.00
31	13	Pay-roll of employés	Services, March, 1891	1,129.02
		Total		5,363.04

Abstract of disbursements made by Anton Karl, special disbursing agent, U. S. Geological Survey, during March, 1891.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1891.				
Mar. 7	1	John H. Renshawe	Traveling expenses	$140.95
10	2	Charles M. Yeates	...do	13.55
10	3	...do	...do	71.34
13	4	...do	Field expenses	71.14
17	5	Basil Duke	Services	70.00
17	6	...do	Traveling expenses	36.20
17	7	W. T. Quillin	Services	50.00
17	8	C. E. Siebenthal	...do	65.00
17	9	H. E. Williams	...do	65.00
17	10	Duncan Hannegan	Traveling expenses	33.60
19	11	J. H. Hagerty	Forage	70.00
20	12	Thomas C. Nelson	Traveling expenses	44.35
23	13	James McCammon	Pasturage	5.00
23	14	N. B. Dunn	...do	63.00
23	15	Philip Miller	Subsistence	38.16
23	16	J. M. Gibson	Pasturage	79.95
23	17	J. B. Efferson	Subsistence	47.41
23	18	H. L. Baldwin, jr	Traveling expenses	70.75
23	19	J. M. Fawbush	Forage	35.00
23	20	W. F. Fling	Pasturage	32.00
23	21	James G. Reaves	...do	10.00
23	22	Pound & Tison	Transportation	105.00
23	23	Albert M. Walker	Traveling expenses	16.55
23	24	R. B. Cameron	...do	14.85

Abstract of disbursements made by Anton Karl, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1891.				
Mar. 25	25	Edward Kübel	Office material	$12.50
31	26	Isaac Crump	Pasturage	69.00
31	27	W. R. Atkinson	Services	103.30
31	28	Robert D. Cummins	...do	137.80
31	29	...do	Map case	4.50
31	30	H. L. Baldwin, jr	Services	155.00
31	32	R. B. Cameron	...do	72.30
31	33	Howard A. Graham	...do	72.30
31	34	A. E. Muslin	...do	137.80
31	37	Basil Duke	...do	77.50
31	38	W. T. Quillin	...do	50.00
31	39	J. J. Mason	...do	50.00
31	40	Duncan Hannegan	...do	72.30
31	41	Anton Karl (pay roll, Hersey Munroe).		625.88
31	42	H. L. Baldwin, jr	Field expenses	137.73
31	43	Hersey Munroe	...do	231.65
31	44	W. C. Frye	Traveling expenses	3.50
31	45	Anton Karl, pay roll		2,190.30
31	46	...do		1,968.70
31	47	...do		1,767.00
31	48	James McCammon	Pasturage	5.00
31	49	N. B. Dunn	...do	63.00
31	50	W. R. Atkinson	Traveling expenses	7.95
31	51	...do	Field expenses	172.37
31	52	W. T. Fling	Pasturage	32.00
31	53	E. T. Brock	Storage	9.00
31	54	George B. Taylor	...do	9.00
31	55	J. H. Hagerty	Forage	70.00
31	56	R. M. Harper	Storage	10.50
31	57	H. L. Baldwin, jr	Field expenses	184.99
31	58	John W. Price	Pasturage	50.00
31	59	Winchester Manufacturing Co	Storage	10.50
31	60	James G. Reaves	Pasturage	15.00
31	61	C. E. Siebenthal	Transportation	8.35
31	62	E. Root & Co	...do	102.50
31	63	Hersey Munroe	Field expenses	256.90
31	64	H. L. Baldwin, jr	...do	145.10
31	65	Pound & Tison	Transportation	62.25
31	66	H. L. Baldwin, jr	Field expenses	159.25
31	67	H. E. Williams	Transportation	5.85
17	68	J. J. Mason	Services	50.00
		Total		10,617.37

Abstract of disbursements made by C. D. Davis, special disbursing agent, U. S. Geological Survey, during March, 1891.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

1891.				
Mar. 2	1	A. H. Quarles	Services, February 18 to 28, 1891	$9.46
5	2	W. P. Jenney	Field expenses	6.65
5	3	George M. Dockray	Supplies	8.20
5	4	Newport Water Works	Water rent	9.00
5	5	Raphael Pumpelly	Field expenses	6.30
5	6	Ben. G. Palmer	Services, February, 1891	25.00
5	7	A. P. Baker	Rent of building	43.75
5	8	W. B. Moses & Sons	Office supplies	1.00
5	9	Frank Leverett	Services, February, 1891	120.00
5	10	Fred. A. Schmidt	Geologic supplies	6.72
6	11	George H. Eldridge	Field expenses	34.05
6	12	James G. Bowen	Forage	24.00
6	13	James Storrs	Pasturage	13.00
6	14	Warren Upham	Services, February, 1891	93.40
6	15	C. W. Hall	Traveling expenses	73.05
10	16	P. J. Littenhale	Pasturage	30.00
10	17	J. T. Masten	...do	45.00
10	18	Joseph A. Holmes	Services, Dec. 1, 1890 to Feb. 1, 1891.	95.00
12	19	Z. D. Gilman	Supplies	1.20
12	20	Fred. A. Schmidt	Rubber triangles	1.67
16	21	Richard Bliss	Services, February, 1891	24.30
25	22	George H. Eldridge	Traveling expenses	173.70
25	23	...do	Field expenses	5.75

Abstract of disbursements made by C. D. Davis, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1891.				
Mar. 25	24	W. P. Jenney	Traveling expenses	$300.90
25	25	Edmund Jüssen	...do	136.74
25	26	Elisha T. Jencks	Section cutter	56.00
25	27	T. H. Willard	Freight charges	33.40
26	28	Raphael Pumpelly	Traveling expenses	104.75
26	29	N. S. Norwood	...do	20.85
26	30	...do	...do	37.75
31	31	W. P. Jenney	Services, March, 1891	189.40
31	32	Edmund Jüssen	...do	50.00
31	33	C. E. Kloeber	...do	30.00
31	34	W. S. Bayley	...do	117.50
31	35	George E. Luther	...do	103.30
31	36	Beckham & Corum	Forage	16.00
31	37	L. C. Johnson	Services, March, 1891	120.60
31	58	N. S. Shaler	...do	260.00
31	39	William H. Norton	...do	20.00
31	40	T. Nelson Dale	...do	155.00
31	41	J. B. Woodworth	...do	50.00
31	42	R. E. Dodge	...do	30.00
31	43	C. L. Whittle	...do	100.00
31	44	W. N. Merriam	...do	105.00
31	45	Raphael Pumpelly	...do	344.40
31	46	C. R. Van Hise	...do	344.40
31	47	Pay roll of employés	...do	1,532.70
31	48	...do	...do	2,046.80
31	49	...do	...do	395.30
31	50	George H. Eldridge	...do	206.70
31	51	W. H. Wamsley	Supplies	9.00
		Total		7,786.69

Abstract of disbursements made by Arnold Hague, special disbursing agent, U. S. Geological Survey, during March, 1891.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

1891.				
Mar. 2	1	Elwood Hofer	Services as herder	$113.22
9	2	The Eastman Company	Photographic supplies	18.08
31	3	Pay roll of employés	Services, March, 1891	757.70
		Total		889.09

Abstract of disbursements made by James W. Spencer, special disbursing agent, U. S. Geological Survey, during March, 1891.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

1891.				
Mar. 3	73	Nephi Johnson	Services, January, 1891	$60.00
3	74	Joseph Jacobs	...do	60.00
3	75	J. F. Mitchell	Services, February, 1891	30.00
3	76	S. S. Mitchell	...do	50.00
3	77	William H. Otis	...do	50.00
3	78	George L. Robinson	Forage	55.00
3	79	Willard D. Johnson	Field expenses	5.61
6	80	Nephi Johnson	Services, February, 1891	60.00
6	81	Joseph Jacobs	...do	60.00
10	82	...do	Field expenses	40.66
10	83	Denver Transit and Warehouse Co.	Storage	20.00
10	84	...do	...do	20.00
14	85	William Kronig	Forage	147.56
14	86	Fauth & Co.	Repairs	5.75
17	87	J. F. Farmer	Transportation	5.50
17	88	R. C. McKinney	Field expenses	5.55
19	89	J. F. Mitchell	Services, March 1 to 16, 1891	15.48
23	90	E. M. Douglas	Field expenses	13.50
23	91	Frank Tweedy	...do	15.00
23	92	Easton & Rupp	Office supplies	1.90
24	93	Willard D. Johnson	Field expenses	10.00

Abstract of disbursements made by James W. Spencer, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1891.				
Mar. 25	94	A. P. Davis	Field expenses	$40.00
25	95	W. T. Griswold	....do	48.00
25	96	M. J. Kiely	Pasturage	24.92
27	97	Frank Tweedy	Forage	162.00
28	98	Sparks Bros	Forage, etc	108.45
28	99	Coffin & Seeton	....do	17.95
28	100	Roberts & Co	Subsistence	7.10
31	101	J. W. Dobbins	Services, March, 1891	30.00
31	102	Amos Scott	....do	60.00
31	103	J. M. Dikeman	....do	60.00
31	104	Charles W. Howell	....do	60.00
31	105	William H. Otis	....do	50.00
31	106	S. S. Mitchell	....do	50.00
31	107	J. F. Mitchell	Services, March 21 to 31, 1891	11.00
31	108	E. G. Amick	Storage	40.00
31	109	J. W. Maloney	....do	8.00
31	110	Joseph Jacobs	Services, March, 1891	60.00
31	111	James Shumway	....do	50.00
31	112	....do	Services, February, 1891	16.07
31	113	Rich Shumway	Services, March, 1891	50.00
31	114	Pay roll "A. H. T"	....do	5,008.40
31	115	....do	....do	894.80
31	116	J. W. Dobbins	Subsistence	14.40
31	117	George L. Robinson	Forage	55.00
31	118	Wright, Peck & Co	Storage	45.00
31	119	H. M. Wilson	Traveling expenses	268.40
31	120	....do	Field expenses	23.21
31	121	F. H. Newell	Field supplies	4.25
31	122	Eva Shuster	Services, March, 1891	40.00
		Total		8,038.46

Abstract of disbursements made by H. C. Rizer, disbursing agent, U. S. Geological Survey, during the third quarter of 1891.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

1891.				
Jan. 6	1	Arthur P. Davis	Traveling expenses	$50.80
6	2	William P. Trowbridge	....do	127.07
6	3	Pay roll	Services	543.81
7	4	Charles W. Howell	....do	60.00
7	5	Mark B. Kerr	....do	25.00
7	6	E. T. Perkins, jr	Traveling expenses	65.25
7	7	William P. Trowbridge	Field expenses	11.75
7	8	C. D. Chinn	Feed	23.35
7	9	....do	....do	28.65
7	10	Charles Himrod	Subsistence	80.01
7	11	R. R. Marshall	Field expenses	230.73
8	12	Spratlen & Anderson	Supplies	45.90
8	13	....do	Subsistence	84.45
8	14	....do	....do	100.00
8	15	A. Deeter	....do	12.00
8	16	....do	....do	24.00
8	17	....do	....do	33.50
8	18	....do	....do	40.80
8	19	....do	....do	26.80
8	20	....do	....do	23.20
8	21	B. F. Acuff & Co	Forage	77.53
8	22	....do	....do	82.86
8	23	....do	Subsistence	37.58
8	24	....do	Forage	24.50
8	25	....do	Storage	5.00
8	26	Acuff Bros	Field supplies	6.79
8	27	....do	....do	52.46
9	28	A. L. Bruce	Traveling expenses	1.50
9	29	J. T. Farmer	Forage	22.90
9	30	....do	Transportation	14.00
9	31	Corhead & Harrel	Forage	20.15
9	32	....do	....do	30.25
9	33	....do	....do	11.25
9	34	....do	....do	14.00
9	35	....do	....do	4.66
9	36	T. M. Call	Field expenses	68.05
9	37	J. W. Martin	Subsistence	58.50

Abstract of disbursements made by H. C. Rizer, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1891.				
Jan. 9	38	J. W. Martin	Subsistence	$118.00
9	39	C. L. Wall	Material	41.80
9	40	S. C. Gallup	...do	39.00
9	41	A. C. Swift	Subsistence	7.25
9	42	Jul. Rehm	...do	27.33
9	43	E. P. Slattery	Forage	60.99
9	44	Ricketts Hord	Traveling expenses	69.72
9	45	R. C. McKinnney	...do	69.72
9	46	George L. Robinson & Co	Forage	50.08
10	47	R. Planderleith	...do	21.70
10	48	W. J. Davis	Use of team	75.00
10	49	Reeves & Co	Forage	51.38
10	50	H. Halthuse	...do	24.15
10	51	C. L. Garland	Traveling expenses	1.75
10	52	Jeff. D. Reagan	...do	16.10
10	53	Robert A. Farmer	Field expenses	77.25
10	54	C. D. Baldwin	...do	10.35
10	55	W. H. Sanders	...do	21.25
10	56	Kennedy & Orr	...do	9.00
10	57	Stuart P. Johnson	...do	11.26
10	58	...do	...do	30.80
10	59	G. T. Nash	Supplies	18.06
10	60	L. Creps	...do	21.68
10	61	T. G. McCarthy	...do	13.95
10	62	W. H. King	Transportation	8.00
10	63	Donald Harold	Field expenses	12.50
10	64	William S. Post	...do	73.07
10	65	...do	...do	65.00
10	66	...do	Traveling expenses	35.19
10	67	Paul Holman	Field expenses	37.75
10	68	...do	...do	36.65
16	69	Fred Lawrence	Services	24.19
16	70	Jeff. D. Reagan	...do	61.29
16	71	Joseph Jacobs	Field expenses	54.20
16	72	A. P. Davis	...do	60.50
16	73	W. T. Griswold	...do	77.50
16	74	A. Deeter	Board	5.60
16	75	C. F. Wheeler	Subsistence	29.60
16	76	Nephi Johnson	Services	60.00
16	77	Joseph Jacobs	...do	60.00
16	78	Thomas O'Toole	...do	11.29
16	79	J. T. Mitchell	...do	18.87
16	80	William Davis	...do	8.70
16	81	P. H. Cosgrove	...do	19.35
16	82	J. W. Botts	...do	13.06
17	83	C. R. Glass	...do	29.03
17	84	...do	Field expenses	39.00
17	85	...do	...do	20.50
17	86	W. A. Farrish	...do	37.08
19	87	B. A. Chambers	Services	28.50
19	88	C. C. Martin	...do	20.30
19	89	Robert A. Farmer	Field expenses	26.73
19	90	...do	...do	14.95
19	91	R. R. Kelley	Board	19.00
19	92	J. F. Farmer	Livery	13.00
19	93	...do	Care of stock	22.80
19	94	Jno. W. Hays	Traveling expenses	16.25
19	95	...do	Field expenses	55.93
19	96	R. C. McKinney	...do	99.37
19	97	Jno. W. Hays	...do	35.69
20	98	R. B. Marshall	...do	40.72
20	99	Perry Fuller	...do	88.25
20	100	...do	...do	5.25
20	101	Grant Hackworth	Services	20.96
20	102	William B. Lane	...do	20.96
20	103	S. C. Gallup	Material	13.75
20	104	C. R. Glass	Field expenses	70.50
20	105	Arthur P. Davis	...do	142.55
20	106	Fred. C. Lawrence	Traveling expenses	16.00
20	107	Ezra T. Hatch	Services	24.18
20	108	O. L. Houghton	Material	9.20
21	109	Gross, Blackwell & Co	Subsistence	233.22
21	110	William Malboeuf	Supplies	22.75
21	111	A. C. Schmidt	Repairs	20.95
21	112	Willard D. Johnson	Field expenses	10.00
21	113	A. Deeter	Board	9.70
21	114	...do	...do	35.00
21	115	...do	...do	22.40

Abstract of disbursements made by H. C. Rizer, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1891.				
Jan. 23	116	E. R. Kindle	Services	$31.92
24	117	E. A. Cormich	...do	17.42
24	118	Hallie W. Bram	...do	16.12
24	119	J. W. Dobbins	...do	38.70
26	120	Thomas W. Haywood	Subsistence	20.62
31	121	Pay roll	Services	269.06
31	122	Paul Holman	...do	72.30
31	123	F. H. Kelsey	...do	24.83
31	124	William H. Otis	...do	50.00
31	125	S. S. Mitchell	...do	50.00
31	126	H. C. Rizer	...do	189.40
31	127	W. H. King	Forage	30.00
Feb. 10	128	William Kronig	...do	183.78
10	129	Paul Holman	Traveling expenses	125.10
9	130	Frank Fuqua	Storage	24.00
14	131	B. F. Buckner	Services	11.29
16	132	Willard D. Johnson	...do	172.20
16	133	...do	Field expenses	89.24
18	134	A. Deeter	Board	19.50
24	135	W. E. Carpenter	Supplies	14.94
25	136	A. J. Woodward	Services	14.51
26	137	R. R. Kelley	Board	10.00
28	138	H. C. Rizer	Services	171.20
Mar. 7	139	Willard D. Johnson	Traveling expenses	59.50
31	140	H. C. Rizer	Services	189.40
31	141	Rich Shumway	...do	25.00
		Total		6,933.43

Abstract of disbursements made by Jno. D. McChesney, Chief Disbursing Clerk, U. S. Geological Survey, during April, 1891.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

1891.				
Apr. 6	1	DeLancey W. Gill	Traveling expenses	$13.25
6	2	Leonard A. White	Services, March, 1891	50.00
10	3	People's Dispatch and Transfer Co.	Freight charges and hauling	7.76
11	4	Victoria Essex	Services, March 2 to 31, 1891	52.00
11	5	Mary C. Mahon	Services, March 2 to 14, 1891	24.00
11	6	T. W. Stanton	Traveling expenses	117.19
11	7	Washington Gaslight Co	Laboratory supplies	61.13
11	8	J. W. Powell	Traveling expenses	12.18
11	9	Marcus Baker	...do	12.28
13	10	Columbia Phonograph Co	Rent of graphophones, etc	77.50
13	11	Charles D. Walcott	Traveling expenses	90.78
13	12	A. H. Storer	Supplies for mineral resources	9.00
13	13	S. Ward Loper	Services, March, 1891	104.00
13	14	William P. Rust	...do	65.00
13	15	John M. Gurley	Services, March 1 to 18, 1891	30.00
13	16	Harriet Biddle	Services, January 1 to March 31, 1891	30.00
13	17	International and Great Northern Ry.	Transportation of assistant	10.70
13	18	Denver and Rio Grande Ry. Co	...do	19.35
13	19	Pennsylvania R. R. Co	Transportation of property	2.37
13	20	Burlington and Missouri Valley R. R. in Nebraska.	Transportation of assistants	44.90
13	21	Chicago and Alton R. R	...do	9.40
13	22	Savannah, Florida and Western R. R.	...do	27.80
13	23	William Grunow, jr	Laboratory supplies	51.00
13	24	National Press Intelligence Co	Newspaper clippings	6.80
13	25	United States Express Co	Freight charges	399.05
14	26	Charles C. Darwin	Traveling expenses	40.90
14	27	W. H. Morrison	Publications	82.70
16	28	Wash. B. Williams	Geologic supplies	35.00
16	29	Robert Boyd	Supplies	29.70
16	30	Emil Greiner	Laboratory supplies	10.00
16	31	Pennsylvania R. R. Co	Transportation of assistants	48.70
16	32	David Williams	Publications	5.00
16	33	L. H. Schneider's Son	Supplies	76.44
17	34	Edward J. Hannan	Supplies for illustrations	55.00
17	35	George Ryneal, jr	Supplies	199.07
17	36	Albert L. Pitney	Paleontologic supplies	12.70

Abstract of disbursements made by Jno. D. McChesney, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1891.				
Apr. 17	37	Wyckoff, Seamans & Benedict..	Supplies and repairs	$20.55
17	38	Atchison, Topeka and Santa Fé R. R.	Transportation of assistants	12.65
17	39	Fremont, Elkhorn and Missouri Valley R. R	....do	17.42
18	40	Annie E. Hendley	Services, April 1 to 18, 1891	30.00
20	41	D. Skutsch	Services, February 1 to 8, 1891	28.50
21	42	Hall & Sons	Laboratory material	24.00
21	43	Scientific Publishing Co	Publications	4.00
21	44	James D. & E. S. Dana	....do	7.50
21	45	John C. Parker	Supplies for Mineral Resources	90.00
21	46	Cutter & Wood	Geologic supplies	21.45
21	47	Charles Scribner's Sons	Publications	118.92
21	48	J. W. Bonton	....do	1.50
21	49	Daniel Appleton & Co	....do	6.00
23	50	Baltimore and Ohio R. R. Co	Transportation of assistants	46.65
23	51	Unexcelled Paper Tube Co	Topographic supplies	27.00
23	52	Eimer & Amend	Laboratory supplies	103.57
23	53	E. E. Jackson & Co	Supplies	112.63
23	54	Wash. B. Williams	Paleontologic supplies	95.00
23	55	Richmond and Danville R. R. Co.	Transportation of assistants	275.55
24	56	E. J. Pullman	Illustration supplies	180.37
24	57	M. G. Copeland & Co	Topographic field material	48.71
24	58	Newman & Son	Repairing typewriter	2.00
27	59	U. S. custom-house	United States duties on instrument..	94.00
28	60	Fred. A. Schmidt	Supplies	33.54
28	61	M. W. Beveridge	....do	9.94
28	62	Great Northern Ry. Co	Transportation of property	12.60
28	63	Charles R. Keyes	Services, April 18 to 23, 1891	20.00
28	64	R. R. Bowker	Publications	3.50
28	65	Charles Scribner's Sons	....do	3.73
28	66	Emil Greiner	Laboratory supplies	3.00
28	67	Baltimore and Ohio R. R. Co	Transportation of property	32.87
30	68	Wash. B. Williams	Topographic supplies	55.00
30	69	J. Henry Blake	Services, April, 1891	148.30
30	70	Samuel H. Scudder	....do	206.00
30	71	O. C. Marsh	....do	329.70
30	72	F. Berger	....do	80.00
30	73	L. P. Bush	....do	50.00
30	74	C. C. Willard	Rent of office, April, 1891	266.66
30	75	H. C. Rizer	Services, April, 1891	181.30
30	76	Leonard A. White	....do	50.00
30	77	Pay roll of employés	....do	1,293.85
30	78	....do	....do	1,265.40
30	79	....do	....do	851.20
30	80	....do	....do	754.73
30	81	....do	....do	1,478.00
30	82	....do	....do	1,119.90
30	83	....do	....do	882.40
30	84	....do	....do	362.65
		Total		12,784.89

APPROPRIATION FOR GEOLOGICAL MAPS OF THE UNITED STATES, 1891.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1891.				
Apr. 10	1	People's Dispatch and Transfer Company.	Freight charges	.30
13	2	U. S. Electric Lighting Co	Use of 4 horse-power current	$25.00
13	3	Bernhard Meiners	Engravers' supplies	11.25
13	4	United States Express Co	Freight charges	1.25
16	5	George Meier & Co	Engravers' supplies	97.07
16	6	Peter Adams Co	....do	72.00
16	7	J. E. Entwistle	....do	51.50
16	8	Robert Boyd	....do	4.43
16	9	L. H. Schneider's Son	....do	1.00
23	10	George Meier & Co	....do	3.75
23	11	E. E. Jackson & Co	....do	21.00
28	12	Ernest Kübel	Resurfacing copper plates	31.25
28	13	Fred. A. Schmidt	Engravers' supplies	107.50
28	14	M. W. Beveridge	....do	.68
28	15	Robert Mayer & Co	....do	3.00
	16	Pay roll of employés	Services, April, 1891	1,319.71
		Total		1,750.69

Abstract of disbursements made by Anton Karl, special disbursing agent, U. S. Geological Survey, during April, 1891.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1891.				
Apr. 16	2	Rhees Evans	Salary	$4.00
21	3	H. L. Baldwin, jr	Field expenses	63.15
30	4	...do	...do	498.19
30	5	Duncan Hannegan	Services	69.20
30	6	F. Howard Seely	Traveling expenses	89.40
30	7	...do	Salary	74.20
30	8	A. M. Walker	Traveling expenses	54.20
30	9	...do	Services	60.00
30	10	Basil Duke	...do	74.20
30	11	H. W. Elmore	...do	72.00
30	12	C. F. Trill	...do	32.00
30	13	Howard Graham	...do	69.20
30	14	Frank Sutton	...do	131.90
29	15	C. W. Goodlove	Traveling expenses	38.25
29	16	J. J. Mason	...do	53.25
28	17	Basil Duke	...do	53.25
28	18	...do	...do	16.60
21	19	Fred. A. Schmidt	Stationery	45.00
21	20	W. A. Balch	Services	32.00
18	21	J. N. Goode	...do	50.00
18	22	A. M. Walker	...do	60.00
18	23	George Landrey	...do	40.00
18	24	J. R. Carn	...do	30.00
23	25	J. M. Gibson	Pasturage	79.95
23	26	J. M. Fawbush	...do	35.00
23	27	J. H. Means	Services	70.00
23	28	H. E. Williams	...do	65.00
23	29	C. E. Siebenthal	...do	65.00
23	30	Pay roll, Renshawe		1,606.00
30	31	Pay roll, Gannett		1,608.80
30	32	Pay roll, Thompson		2,232.80
30	33	Hersey Munroe	Field expenses	225.90
30	34	...do	Pay roll	543.10
30	35	Isaac Crump	Forage	69.00
30	36	E. Root & Co	Transportation	127.00
30	37	Pound & Tison		45.00
30	38	C. E. Siebenthal	Services	65.00
30	39	J. H. Means	...do	70.00
30	40	H. E. Williams	...do	65.00
30	41	J. H. Hagerty	Forage	70.00
30	42	Robert D. Cummin	Services	131.90
30	43	Glenn S. Smith	...do	74.20
30	44	R. B. Cameron	...do	69.20
30	45	L. D. Brent	...do	74.20
30	46	H. L. Baldwin, jr	...do	148.30
30	47	C. W. Goodlove	...do	74.20
30	48	H. L. Baldwin, jr	Traveling expenses	82.75
		Total		9,407.29

Abstract of disbursements made by C. D. Davis, special disbursing agent, U. S. Geological Survey, during April, 1891.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

1891.				
Apr. 3	1	James G. Bowen	Forage, etc	$29.9[illegible]
3	2	W. P. Jenney	Supplies	115.98
3	3	N. H. Darton	Traveling expenses	66.64
4	4	Frank Leverett	Services, March, 1891	130.00
4	5	Benjamin C. Palmer	...do	25.00
4	6	A. P. Baker	Rent of rooms	43.75
7	7	James H. Wilson	Services	6.00
9	8	Robert D. Coggeshall	Supplies	8.50
9	9	J. S. Diller	Traveling expenses	26.52
9	10	Benjamin French & Co	Supplies	93.72
9	11	T. Nelson Dale	...do	9.52
9	12	Bent & Co	...do	10.00
9	13	J. F. Maston	Pasturage	45.00
9	14	George H. Eldridge	Supplies	5.50
9	15	...do	Traveling expenses	140.25
9	16	W. S. Bayley	...do	46.65
13	17	Edmund Jüssen	...do	53.90
14	18	George H. Williams	Services, February 1 to March 31, 1891	85.00

Abstract of disbursements made by C. D. Davis, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1891.				
Apr. 16	19	Benjamin K. Emerson	Field expenses	$16.19
17	20	W. H. Dall	...do	47.25
17	21	Richard Bliss	Services, March, 1891	28.50
23	22	Benj. French & Co	Supplies	4.59
23	23	...do	...do	57.91
24	24	William Beals, jr	Services, August 2 to December 10, 1890.	214.52
24	25	Frank Burns	Traveling expenses	103.60
24	26	W. P. Jenney	...do	94.25
24	27	...do	Field expenses	155.43
25	28	W. Lindgren	Traveling expenses	60.00
25	29	J. E. Wolff	Services, February, 1891	77.78
25	30	...do	Services, March, 1891	97.22
27	31	W. P. Jenney	Services, April, 1891	181.30
30	32	C. E. Kloeber	...do	30.00
30	33	C. Willard Hayes	...do	115.40
30	34	Edmund Jüssen	...do	67.73
30	35	Lawrence C. Johnson	...do	115.40
30	36	T. Nelson Dale	...do	148.30
30	37	W. Lindgren	...do	131.90
30	38	H. W. Turner	...do	131.90
30	39	George H. Eldridge	...do	197.80
30	40	R. D. Salisbury	Services, September 10, 1890, to April 30, 1891.	155.00
30	41	Pay roll of employés	Services, April, 1891	1,467.05
30	42	...do	...do	1,776.06
30	43	...do	...do	190.93
30	44	H. W. Turner	Traveling expenses	50.25
30	45	J. E. Wolff	...do	38.92
30	46	S. H. Davis	Pasturage	24.00
30	47	P. J. Littlehale	Pasturage, etc	53.25
30	48	Daniel S. Martin	Supplies	10.00
30	49	C. L. Whittle	Services, April, 1891	100.00
30	50	N. S. Shaler	...do	260.00
30	51	R. E. Dodge	...do	30.00
30	52	J. B. Woodworth	...do	50.00
30	53	Raphael Pumpelly	...do	329.70
30	54	C. R. Van Hise	...do	329.70
30	55	George E. Luther	...do	98.90
		Total		7,981.66

Abstract of disbursements made by Arnold Hague, special disbursing agent, U. S. Geological Survey, during April, 1891.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

1891.				
Apr. 6	1	Elwood Hofer	Services as herder	$77.14
30	2	Pay roll of employés	Services. April, 1891	725.20
		Total		802.34

Abstract of disbursements made by James W. Spencer, special disbursing agent, U. S. Geological Survey, during April, 1891.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

1891.				
Apr. 8	1	R. W. Parry	Storage	$10.83
8	2	Charles Swanson	Transportation	7.50
8	3	Frank Tweedy	Traveling expenses	59.85
8	4	William Kronig	Forage	89.50
11	5	William H. Otis	Field expenses	18.55
13	6	Joseph Jacobs	Subsistence and forage	61.29
13	7	Roberts & Co	...do	13.30
13	8	Rockwell Brothers	Forage	68.50
13	9	A. A. Rockwell	Services, February and March	40.00
13	10	Jeremiah Ahem	Field expenses	15.00
13	11	Willard D. Johnson	...do	10.00

Abstract of disbursements made by James W. Spencer, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1891.				
Apr. 13	12	A. P. Davis	Field expenses	$60.00
13	13	E. M. Douglas	...do	13.50
18	14	E. T. Perkins, jr	...do	84.50
20	15	H. W. Koen	Forage	240.00
21	16	Samuel McDowell	...do	147.50
21	17	W. T. Griswold	Traveling expenses	119.50
22	18	H. W. Koen	Forage	150.00
22	19	Western Union Telegraph Co	Message	2.35
24	20	Willard D. Johnson	Field supplies	2.00
24	21	W. H. Hyde	Repairs	22.50
24	22	J. W. Dobbins	Field expenses	22.30
24	23	George A. Newton	Field supplies	24.52
24	24	Eyelet Tool Co	Office supplies	12.00
24	25	Fred A. Schmidt	Map material	29.75
27	26	F. H. Newell	Supplies	8.00
30	27	P. & S. Bartlett	Services, April	82.40
30	28	Amos Scott	...do	60.00
30	29	Charles W. Howell	...do	60.00
30	30	William H. Otis	...do	50.00
30	31	S. S. Mitchell	...do	50.00
30	32	J. F. Mitchell	...do	30.00
30	33	J. M. Dikeman	...do	60.00
30	34	Frank Tweedy	...do	148.30
30	35	...do	Field expenses	21.95
30	36	...do	Traveling expenses	79.80
30	37	T. M. Bannon	...do	79.80
30	38	Joseph Jacobs	Field expenses	5.00
30	39	J. W. Dobbins	...do	26.70
30	40	...do	Services, April	30.00
30	41	A. Van Duesen	Field supplies	5.04
30	32	William Kronig	Forage	75.77
30	43	George L. Robinson	...do	55.00
30	44	Theod. Heyck	Storage	45.00
30	45	Frank Fuqua	...do	18.00
30	46	H. E. Clermont Feusier	Traveling expenses	35.75
30	47	Pay roll, Thompson	Services, April	4,542.25
30	48	...do	...do	629.50
30	49	W. T. Griswold	...do	164.80
30	50	Jeremiah Ahern	Field expenses	20.00
30	51	Willard D. Johnson	...do	10.00
		Total		7,717.80

Abstract of disbursements made by Jno. D. McChesney, chief disbursing clerk, U. S. Geological Survey, during May, 1891.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

1891.				
May 2	1	John C. Parker	Supplies for mineral resources	$128.00
2	2	...do	Supplies	9.35
8	3	George W. Knox	Freight charges and hauling	63.44
8	4	Washington Gaslight Co	Laboratory supplies	67.64
8	5	William D. Clark & Co	Topographic supplies	39.06
8	6	Robert Leitch & Sons	...do	3.23
8	7	Melville Lindsay	...do	9.68
8	8	Browning & Middleton	...do	1.75
8	9	E. Morrison	Supplies	14.53
8	10	J. Baumgarten & Son	Topographic supplies	1.75
8	11	Charles R. Keyes	50 drawings	125.00
8	12	Victoria Essex	Services, April, 1891	52.00
8	13	S. Ward Loper	...do	104.00
8	14	W. H. Warner	Topographic supplies	52.38
8	15	Jacksonville, St. Augustine and Halifax River R. R. Co.	Transportation of assistants	44.30
8	16	The Eastman Company	Services and postage	6.04
8	17	W. & L. E. Gurley	Topographic supplies	49.50
8	18	Prosch Manufacturing Co	Repairs	1.50
8	19	Goodnow & Wightman	Laboratory material	1.25
8	20	John C. Entriken	...do	12.09
8	21	Kansas City, Fort Scott and Memphis R. R.	Transportation of assistant	9.65
11	22	Robert Beall	Publications	35.25
11	23	George Ryneal, jr	Topographic supplies	6.00
11	24	William P. Rust	Services, April, 1891	65.00

Abstract of disbursements made by Jno. D. McChesney, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1891.				
May 11	25	James W. Queen & Co	Laboratory supplies	$6.12
11	26	Pennsylvania R. R. Co	Transportation of property	1.85
11	27	W. H. Morrison	Publications	43.80
12	28	W. D. Doremus	Laboratory supplies	2.50
12	29	John C. Parker	Topographic supplies	6.00
12	30	Wyckoff, Seamans & Benedict	....do	2.50
13	31	J. S. Topham	....do	18.80
13	32	E. J. Pullman	Supplies for illustrations	60.83
13	33	Royce & Marean	Geologic supplies	3.95
13	34	Baltimore and Ohio R. R. Co	Transportation of assistant	10.00
13	35	Richards & Co (limited)	Laboratory supplies	4.40
14	36	Ira Sayles	Traveling expenses	24.64
14	37	R. R. Bowker	Publications	5.00
14	38	Fremont, Elkhorn and Missouri Valley R. R.	Transportation of property	49.35
14	39	Samuel Springmann	Freight charges and hauling	22.70
16	40	Franklin R. Carpenter	Services, April 14–30, 1891	60.00
16	41	Fremont, Elkhorn and Missouri Valley R. R.	Freight	67.60
16	42	Baltimore and Ohio R. R. Co	....do	6.13
16	43	R. C. Jones	Publications	6.00
19	44	W. H. Lowdermilk	....do	295.10
20	45	Frances B. Johnston	Paleontologic supplies	77.30
20	46	E. J. Pullman	Supplies for illustrations	3.12
20	47	Melville Lindsay	Geologic supplies	2.10
20	48	W. & L. E. Gurley	3 Philadelphia rods	60.00
20	49	Whitall Tatum & Co	Laboratory material	18.20
20	50	Chicago, Rock Island and Pacific R. R.	Transportation of assistants	25.00
20	51	Carson and Colorado R. R. Co	....do	60.00
20	52	Virginia and Truckee R. R. Co	....do	2.75
20	53	Pennsylvania R. R. Co	....do	66.05
20	54	Wilmington and Weldon R. R	....do	9.45
20	55	Williams, Browne & Earle	Geologic supplies	5.00
31	56	Samuel H. Scudder	Services, May, 1891	213.00
31	57	J. Henry Blake	....do	153.40
31	58	Ira Sayles	....do	119.20
31	59	O. C. Marsh	....do	340.60
31	60	T. A. Bostwick	Services, April and May, 1891	167.60
31	61	L. P. Bush	Services, May, 1891	50.00
31	62	F. Berger	....do	80.00
31	63	Edward W. Parker	Services, May 16–31, 1891	87.91
31	64	Chas. G. Stott & Co	Topographic supplies	41.44
31	65	....do	Library supplies	53.79
31	66	C. C. Willard	Rent of office rooms	266.66
31	67	Leonard A. White	Services, May, 1891	50.00
31	68	Pay roll of employés	....do	1,337.30
31	69	....do	....do	1,299.13
31	70	....do	....do	877.60
31	71	....do	....do	762.20
31	72	....do	....do	1,414.80
32	73	....do	....do	1,106.20
31	74	....do	....do	910.20
31	75	....do	....do	374.70
		Total		11,634.16

APPROPRIATION FOR GEOLOGICAL MAPS OF THE UNITED STATES, 1891.

1891.				
May 8	1	William D. Clark & Co	Engraver's supplies	$7.50
8	2	J. Baumgarten & Son	Rubber stamp	5.00
8	3	George W. Knox	Freight charges and hauling	16.24
11	4	D. McMenamin	Engraver's supplies	5.92
11	5	William H. Arneth	....do	7.00
12	6	George Meier & Co	... do	18.50
13	7	U. S. Electric Lighting Co	Use of 4 H. P. current (April, 1891)	25.00
13	8	J. S. Topham	Engraver's supplies	3.25
14	9	Irwin N. Megargee	....do	466.38
20	10	Henry Lindenmeyer	....do	198.00
31	11	Pay roll of employés	Services, May, 1891	1,365.00
		Total		2,117.79

Abstract of disbursements made by Anton Karl, special disbursing agent, U. S. Geological Survey, during May, 1891.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1881.				
May 31	1	W. R. Atkinson	Field expenses, April	$182.20
31	2	....do	Services, April, 1891	98.90
12	3	Lincoln Martin	Field expenses, May, 1891	37.30
13	4	A. E. Wilson	....do	81.15
16	5	H. M. Wilson	....do	46.45
16	6	L. C. Fletcher	....do	357.71
13	7	Glenn S. Smith	Field expenses, April, 1891	29.25
13	8	....do	Traveling expenses, April, 1891	18.44
13	9	Hersey Munroe	Traveling expenses, May, 1891	75.85
31	10	Charles T. Trask	Forage, etc	119.20
31	11	W. E. Lackland	Services, May, 1891	71.60
16	12	Hersey Munroe	Field expenses, April and May	251.26
16	13	L. C. Fletcher	Field expenses, May	108.15
18	14	J. L. Bridwell	....do	114.36
18	15	....do	Traveling expenses, May	53.60
31	16	Van H. Manning	....do	39.25
31	17	B. Peyton Legare	....do	38.25
19	18	S. S. Gannett	Field expenses, May	62.28
16	19	L. C. Fletcher	....do	53.83
31	20	R. B. Cameron	Traveling expenses, March to May	53.25
31	21	Duncan Hannegan	....do	53.60
31	22	L. C. Woodbury	Services, April	50.00
31	23	George Landry	....do	40.00
31	24	H. L. Baldwin, jr	Field expenses, April	155.70
31	25	W. T. Quillin	Traveling expenses, April	12.15
31	26	James U. Goode	Services, April	50.00
31	27	....do	Traveling expenses, April	29.85
31	28	Pay roll (in part)	Salaries, April	169.23
31	29	George T. Hawkins	Traveling expenses, April	19.00
31	30	....do	Field expenses, April and May	128.67
31	31	J. R. Carn	Services, April	20.00
31	32	Ed. Gandin	....do	9.00
31	33	W. R. Atkinson	Traveling expenses, April	8.35
31	34	J. J. Mason	Services, April	50.00
31	35	John Boler	Traveling expenses, May	34.80
31	36	Jules Leforte	Services, April	30.00
11	37	L. C. Woodbury	Traveling expenses, April	24.90
20	38	J. H. Jennings	Traveling expenses, May	20.85
12	39	G. E. Hyde	....do	16.94
31	40	W. Cooper Talley	Services, May	22.86
31	51	George T. Hawkins	Field expenses, May	90.85
31	52	....do	Traveling expenses, April and May	52.95
29	58	Pay roll	Salaries, May	695.40
31	59	....do	....do	2,682.60
31	60	....do	....do	1,355.80
31	61	L. C. Woodbury	Services, May	16.00
31	62	Frank Sutton	....do	136.20
31	63	Frank Sutton (in part)	Field expenses, May	60.00
31	64	Ewing Speed	Services, May	50.00
31	65	....do	Traveling expenses, May	7.72
31	66	D. C. Harrison	....do	81.85
31	67	....do	Services, May	119.20
31	68	G. E. Hyde	....do	102.20
31	69	Pay roll	Salaries, May	493.63
31	71	H. B. Blair	Services, May	136.20
31	72	Pay roll (in part)	Salaries, May	117.74
31	74	William Kramer	Services, May	102.20
31	75	F. Howard Seeley	....do	76.60
31	76	Richmond and Danville R. R	Transportation	23.25
		Total		9,238.57

Abstract of disbursements made by C. D. Davis, special disbursing agent, U. S. Geological Survey, during May, 1891.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

1891.				
May 4	1	Benjamin G. Palmer	Services, April, 1891	$25.00
4	2	A. P. Baker	Rent of rooms, April, 1891	43.75
6	3	Lawrence C. Johnson	Traveling expenses	60.28
6	4	....do	....do	80.45
6	5	W. Lindgren	Field expenses	67.03
6	6	W. O. Rew	Hire of steam launch	232.50

Abstract of disbursements made by C. D. Davis, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1891.				
May 6	7	J. E. Wolff	Services, April, 1891	$123.63
6	8	Frank Leverett	....do	130.00
7	9	Ben. K. Emerson	....do	100.00
7	10	J. T. Master	Forage	45.00
7	11	Warren Upham	Services, March, 1891	103.30
9	12	....do	Services, April, 1891	98.90
8	13	George H. Eldridge	Traveling expenses	98.93
8	14	....do	Supplies, etc	101.13
8	15	....do	Field expenses	25.00
8	16	James G. Bowen	Hire and care of public animal	45.50
8	17	G. K. Gilbert	Traveling expenses	19.42
11	18	Goldberg, Bowen & Co	Supplies	23.95
11	19	Pay roll of employés	Services, April, 1891	138.90
11	20	Charles J. Moore	Services, February 1 to April 15, 1891	360.00
11	21	M. R. Campbell	Subsistence	55.00
11	22	....do	Traveling expenses	30.45
11	23	G. C. Temple	....do	16.25
12	24	Bailey Willis	....do	247.54
12	25	Raphael Pumpelly	Supplies	6.05
12	26	Beckham & Corum	Forage, etc	9.00
12	27	George H. Williams	Services, April, 1891	75.00
12	28	David White	Traveling expenses	17.25
12	29	Gilbert D. Harris	....do	17.70
13	30	J. E. Wolff	....do	31.62
13	31	W. P. Jenney	....do	220.30
13	32	....do	Supplies	103.05
13	33	....do	Photographic supplies	32.24
13	34	Richard Bliss	Bibliographic work	25.50
13	35	W. N. Merriam	Services, April, 1891	65.00
13	36	W. S. Bayley	....do	67.50
13	37	G. F. Becker	Traveling expenses	140.10
13	38	....do	Field expenses	344.30
16	39	George M. Dockray	Supplies	12.63
16	40	New York and Boston Dispatch Express Co.	Expressage	4.25
16	41	George E. Luther	Traveling expenses	62.32
16	42	Mary A. Lloyd	Services	10.00
18	43	T. Nelson Dale	Supplies	10.43
19	44	I. C. White	Traveling expenses	25.95
19	45	....do	Services	503.40
19	46	F. H. Newell	Traveling expenses	17.70
19	47	Eugene Dietzgen & Co	Supplies	63.53
20	48	Lawrence C. Johnson	Traveling expenses	73.81
21	49	C. M. Harlan	Pasturage	31.00
23	50	C. R. Van Hise	Traveling expenses	163.68
23	51	Raphael Pumpelly	....do	62.81
23	52	Arthur Keith	Supplies	18.75
23	53	Parker & Starbird	Camera, etc	64.00
23	54	G. P. Putnam's Sons	Specimen bags	66.65
26	55	C. C. Hayes	Pasturage, etc	18.16
26	56	E. B. Richardson	Stabling, etc	31.66
26	57	George H. Eldridge	Grabbing tongs	3.94
26	58	....do	Traveling expenses	137.85
30	59	Edmund Jüssen	....do	163.40
31	60	J. B. Woodworth	Services, May, 1891	50.00
31	61	R. E. Dodge	....do	30.00
31	62	W. A. Croffut	....do	255.50
31	63	Edmund Jüssen	....do	76.60
31	64	George H. Eldridge	....do	204.40
31	65	W. Lingren	....do	136.20
31	66	H. W. Turner	....do	146.20
31	67	T. Nelson Dale	....do	153.40
31	68	C. L. Whittle	....do	100.00
31	69	N. S. Shaler	....do	260.00
31	70	W. R. Herbert	Typewriter	16.00
31	71	Benjamin French & Co	Material	4.75
31	72	W. S. Bayley	Traveling expenses	11.45
31	73	W. A. Hallock	....do	49.00
31	74	Pay roll of employés	Services, May, 1891	182.20
31	75	....do	....do	1,515.90
31	76	....do	....do	1,791.80
31	77	Raphael Pumpelly	....do	340.60
31	78	J. S. Diller	Traveling expenses	49.34
31	79	W. S. Hummell	....do	32.79
		Total		10,398.57

Abstract of disbursements made by Arnold Hague, special disbursing agent, U. S. Geological Survey, during May, 1891.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1891. May 31	1	Pay roll of employés	Services, May, 1891	$749.60

Abstract of disbursements made by James W. Spencer, special disbursing agent, U. S. Geological Survey, during May, 1891.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

1891. May 4	52	James S. Topham	Supplies	$5.00
4	53	C. Becker	...do	14.00
4	54	Pay roll, Jacobs	Services, April	160.00
4	55	Joseph Jacobs	Field expenses	69.59
4	56	Roberts & Co.	Subsistence	22.60
4	57	Fred A. Schmidt	Paper	15.60
4	58	C. E. Crawford	Labor	135.00
5	59	C. H. Fitch	Field expenses	13.50
5	60	A. P. Davis	...do	50.00
6	61	C. D. Baldwin	Field supplies	11.95
6	62	M. Strain	...do	4.95
6	63	B. F. Acuff & Co	...do	45.24
6	64	...do	Subsistence	55.11
6	65	Thomas L. Denny	Services	10.15
6	66	Edward Biby	...do	40.00
6	67	Coxhead & Harrel	Field expenses	12.25
6	68	...do	Storage	14.00
6	69	...do	Field expenses	45.50
6	70	Vanorsdale & Everett	Subsistence	19.80
6	71	Oppenlander & Rehm	...do	17.00
6	72	John M. Killan & Co	Supplies	6.60
6	73	S. C. Gallup	...do	105.69
6	74	G. T. Nash	Repairs	2.00
6	75	C. C. Huddleston	Field supplies	74.50
7	76	W. T. Griswold	Field expenses	22.00
7	77	William P. Trowbridge, jr	...do	74.50
8	78	J. W. Dobbins	...do	9.90
9	79	T. M. Bannon	Services, April	75.00
11	80	E. T. Perkins, jr	Traveling expenses	45.45
11	81	Wayson & Harbin	Field supplies	6.75
12	82	Kruffel & Esser Co	Instruments	30.00
12	83	John Chatillon & Sons	...do	9.75
13	84	Frank Tweedy	Traveling expenses	98.35
13	85	...do	Field expenses	67.40
13	86	Fred A. Schmidt	Paper	3.90
13	87	Coffin & Seaton	Forage	37.25
13	88	P. V. S. Bartlett	Traveling expenses	44.00
16	89	Fred A. Schmidt	Paper	35.40
16	90	J. W. Dobbins	Field expenses	29.10
16	91	...do	...do	7.35
16	92	Wurdeman & Co	Instruments	5.25
18	93	R. H. McKee	Traveling expenses	42.25
18	94	B. F. Acuff & Co.	Subsistence	22.05
18	95	Decker & Co	...do	12.90
18	96	Vanorsdale & Everett	...do	10.40
18	97	Stebbins Mercantile Co	...do	103.43
18	98	Frank Tweedy	Field expenses	129.14
18	99	E. J. Owenhouse	Storage	16.00
18	100	W. & L. E. Gurley	Instruments	104.00
19	101	J. B. Lippincott	Traveling expenses	51.50
19	102	E. T. Perkins, jr	Field expenses	126.93
19	103	B. F. Acuff & Co	Forage	10.84
19	104	Stuart P. Johnson	Traveling expenses	19.50
19	105	T. E. Grafton	...do	19.50
20	106	L. B. Kendall	...do	41.00
21	107	W. & L. E. Gurley	Instruments	84.00
21	108	R. U. Goode	Traveling expenses	65.50
21	109	Charles F. Urquhart	...do	22.75
21	110	H. S. Wallace	...do	22.75
21	111	T. M. Bannon	...do	130.40
22	112	J. B. Hamilton	Forage	5.75
23	113	Wayson & Harbin	Supplies	2.70
23	114	W. T. Griswold	Field expenses	29.79
23	115	S. C. Gallup	Field supplies	54.50
23	116	Fred L. Leonard	...do	32.35
23	117	M. Strain	...do	4.02

Abstract of disbursements made by James W. Spencer, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1891.				
May 23	118	Decker & Co	Subsistence	$37.22
23	119	Spratlen & Anderson	...do	22.75
23	120	Oppenlander & Rehm	...do	24.48
23	121	W. H. Hyde	Repairs	13.50
23	122	A. Van Deusen	Lumber	15.03
23	123	James McCauley	Board	41.00
23	124	E. Andrews	...do	63.12
23	125	R. O. Gordon	Traveling expenses	21.25
23	126	Charles B. Green	...do	21.25
25	127	Alex. C. Barclay	Services, May	85.20
25	128	C. H. Stone	Traveling expenses	18.75
25	129	C. H. Fitch	...do	18.75
16	130	J. B. Lippincott	Services, May	119.20
28	131	R. H. Chapman	...do	136.20
29	132	E. M. Douglas	Traveling expenses	50.75
29	133	Morris Bien	...do	29.25
29	134	Dave Chandler	Services, May	50.00
29	135	P. V. S. Bartlett	...do	85.20
29	136	J. M. Dikeman	...do	60.00
29	137	Pay roll. Perkins	...do	387.19
29	138	W. J. Lloyd	Traveling expenses	17.50
29	139	Robert A. Farmer	...do	66.55
29	140	E. McL. Long	...do	74.20
29	141	Pay roll. Thompson	Services, May	3,976.30
29	142	James W. Spencer	...do	136.20
		Total		8,286.17

Abstract of disbursements made by Jno. D. McChesney, chief disbursing clerk, U. S. Geological Survey, during June, 1891.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

1891.				
June 5	1	Sophie C. Harrison	Services, May 18 to 29, 1891	$22.00
5	2	Victoria Essex	Services, May 1 to 29, 1891	50.00
8	3	George Ryneal, jr	Supplies	250.35
8	4	Z. D. Gilman	...do	617.18
8	5	Adams Express Company	Freight charges	426.90
8	6	John C. Parker	Geologic supplies	1.00
8	7	Melville Lindsay	Illustration supplies	3.60
8	8	Washington Gaslight Co	Laboratory supplies	53.14
8	9	J. W. Powell	Traveling expenses	51.95
8	10	William D. Clark & Co	Topographic supplies	39.06
8	11	Northern Pacific R. R. Co	Transportation of assistants	70.00
8	12	Central Vermont R. R. Co	...do	19.30
8	13	Chesapeake and Ohio R. R. Co	...do	109.75
8	14	The Eastman Company	Geologic supplies and repairs	7.27
8	15	Chicago, Milwaukee and St. Paul R. R.	Transportation of property	1.51
8	16	Denver and Rio Grande R. R. Co.	Transportation of assistants	34.30
8	17	John M. Gurley	Services, May 2 to 31, 1891	50.00
8	18	S. H. Zahn & Co	Publications	1.00
8	19	Norman W. Henley & Co	...do	48.34
8	20	Baltimore and Ohio R. R. Co	Transportation of assistants	557.55
10	21	Hume & Co	Topographic supplies	.60
10	22	J. Baumgarten & Son	Supplies	.90
10	23	Charles H. Elliott	Services, December 26, 1890 to January 26, 1891.	26.00
10	24	W. D. Castle	Geologic supplies	6.25
13	25	L. H. Schneider's Son	Supplies	63.56
13	26	Robert Beall	Publications	49.00
13	27	Atchison, Topeka and Santa Fé R. R.	Transportation of assistant	26.80
13	28	William P. Rust	Services, May 1 to 31, 1891	78.00
15	29	George H. McKeehan	Services May 1 to 4, 1891	7.74
19	30	Edward J. Hannan	Laboratory repairs	11.65
19	31	H. S. Williams	Services, April 1 to May 15, 1891	185.41
19	32	Henry J. Green	Geologic and topographic supplies	163.90
19	33	E. R. Klippart	Publications	18.75
19	34	Chicago, St. Paul and Kansas City R. R.	Transportation of assistant	14.20
19	35	Savannah, Florida and Western R. R.	...do	22.65

Abstract of disbursements made by Jno. D. McChesney, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1891.				
June 19	36	Fremont, Elkhorn and Missouri Valley R. R.	Transportation of property	$34.31
19	37	...do	...do	41.93
20	38	J. B. Hammond	Geologic supplies	118.00
25	39	Atlantic and Pacific R. R. Co	Transportation of property	74.43
25	40	Pennsylvania R. R. Co	Transportation of assistants	191.65
25	41	Northern Pacific R. R. Co	...do	75.05
25	42	William Grunow	Laboratory material	35.00
25	43	Andrew Renz	Geologic hammers and repairs	15.75
25	44	Herbert J. Browne	Publications	110.00
25	45	E. J. Pullman	Geologic supplies	231.10
25	46	George W. Knox	Freight charges and hauling	4.79
25	47	James S. Topham	Geologic supplies	10.00
25	48	Fred. A. Schmidt	Illustration supplies	3.00
25	49	E. De Puy	Supplies	4.00
27	50	Missouri Pacific Ry. Co	Transportation of assistants	24.50
27	51	George H. Rigby	Publications	12.00
27	52	Emil Greiner	Laboratory supplies	2.25
27	53	Melville Lindsay	...do	8.12
27	54	People's Dispatch and Transfer Co.	Freight charges and hauling	3.94
27	55	John C. Parker	Supplies for mineral resources	3.03
30	56	Ira Sayles	Services, June, 1891	115.40
30	57	Harriet Biddle	Services, April 1 to June 30, 1891	30.00
30	58	J. Henry Blake	Services, June, 1891	148.30
30	59	Samuel H. Scudder	...do	206.00
30	60	...do	Traveling expenses	12.85
30	61	O. C. Marsh	Services, June, 1891	329.70
30	62	T. A. Bostwick	...do	82.40
30	63	C. A. White	...do	222.50
30	64	F. H. Newell	Services, May 31 to June 30, 1891	170.29
30	65	Leonard A. White	Services, June, 1891	50.00
30	66	Pay roll of employés	...do	906.55
30	67	...do	...do	1,303.73
30	68	...do	...do	1,577.60
30	69	...do	...do	1,290.20
30	70	...do	...do	1,071.90
30	71	...do	...do	882.40
30	72	...do	...do	527.45
30	73	T. W. Stanton	...do	82.40
30	74	C. C. Willard	Rent of offices, June, 1891	266.66
30	75	Washington Gaslight Co	Laboratory supplies	48.75
30	76	Sophie C. Harrison	Services, June, 1891	51.00
30	77	Victoria Essex	...do	52.00
		Total		13,520.54

APPROPRIATION FOR GEOLOGICAL MAPS OF THE UNITED STATES, 1891.

1891.				
June 8	1	Adams Express Co	Freight charges	$6.30
8	2	Z. D. Gilman	Engraver's supplies	33.30
8	3	William D. Clark & Co	...do	51.21
8	4	Mt. Holly Paper Co	...do	57.00
8	5	Milton Bradley Company	...do	12.15
9	6	George S. Harris & Sons	Engraving maps	1,080.00
10	7	United States Electric Lighting Co.	Use of 4 horse power current (May, 1891).	25.00
13	8	L. H. Schneider's Son	Engraver's supplies	2.75
13	9	Bureau Engraving and Printing	...do	1.00
19	10	Edward J. Hannan	...do	7.12
25	11	George W. Knox	Freight charges and hauling	7.81
27	12	The John Ryan Company	Supplies	35.00
30	13	Pay roll of employés	Service, June, 1891	1,330.00
		Total		2,648.64

Abstract of disbursements made by Anton Karl, special disbursing agent U. S. Geological Survey, during June, 1891.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1891.				
June 3	1	S. S. Gannett	Field expenses, May	$60.32
May 31	2	R. B. Cameron	Services, May	71.60
29	3	J. J. Mason	...do	50.00
29	4	S. S. Gannett	...do	170.40
31	5	C. F. Trill	...do	104.00
31	6	H. W. Elmore	...do	100.00
31	7	Howard A. Graham	...do	71.60
29	8	George H. McKeehan	...do	30.96
31	9	Glenn S. Smith	...do	76.60
June 10	10	...do	Traveling expenses, May	13.87
10	11	...do	Field expenses, May	97.35
10	13	Pay-roll	Salaries, May	236.20
12	23	S. S. Gannett	Field expenses, May	29.90
2	24	...do	Traveling expenses, May and June.	64.97
9	25	W. R. Atkinson	Services, May	102.20
12	27	M. Hackett	Field expenses, June	8.25
13	28	H. M. Wilson (in part)	Services for May	105.00
13	29	Howard A. Graham	Services, June	30.00
		Total		1,423.22

Abstract of disbursements made by C. D. Davis, special disbursing agent U. S. Geological Survey, during June, 1891.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

1891.				
June 1	1	Eugene A. Smith	Collecting for report	$300.00
3	2	C. W. Hall	Services, January 1 to April 30, 1891.	45.00
3	3	W. S. Bayley	Services, May, 1891	76.25
3	4	P. M. Jones	Services, April, 1891	5.81
3	5	George E. Luther	Services, May, 1891	102.20
3	6	W. N. Merriam	...do	30.00
3	7	Frank Leverett	...do	130.00
3	8	C. R. Van Hise	...do	340.60
3	9	J. M. Safford	Services, April, 1891	14.82
3	10	...do	Traveling expenses	3.66
3	11	T. Nelson Dale	...do	37.05
3	12	John Gallaher	Tents	32.50
3	13	William D. Hiestand	Material	22.50
3	14	C. W. Hall	Field expenses	28.90
3	15	James G. Bowen	Hire of transportation	67.70
3	16	F. C. Boyce	Services, April 20 to May 31, 1891	86.66
3	17	W. T. Turner	...do	53.33
3	18	W. Young	...do	53.33
3	19	Main & Winchester	Supplies	8.75
3	20	Goldberg, Bowen & Co.	...do	43.60
3	21	W. Lindgren	Field expenses	51.95
4	22	M. R. Campbell	...do	74.99
4	23	Benjamin G. Palmer	Services, May, 1891	25.00
5	24	C. L. Whittle	Traveling expenses	146.05
5	25	A. P. Baker	Rent of rooms	43.75
5	26	George A. Lake	Field material	12.25
6	27	S. H. Davis	Pasturage	3.00
8	28	W. P. Jenney	Services, May, 1891	187.40
8	29	W. S. Norwood	Services, February 16 to May 31, 1891.	207.86
8	30	P. M. Jones	Traveling expenses	1.70
8	31	C. E. Kloeber	Services, May 1 to June 1, 1891	38.00
8	32	Warren Upham	Services, May, 1891	102.20
8	33	R. D. Salisbury	Services, April and May, 1891	160.00
8	34	J. E. Wolff	Services, May, 1891	118.68
8	35	Thomas S. Kinsey	Services	84.50
8	36	Raphael Pumpelly	Field expenses	15.31
8	37	Keuffel & Esser	Supplies	3.05
8	38	New England Phonograph Co	...do	42.00
8	39	Charles Louch	...do	344.73
8	40	J. E. Wolff	Traveling expenses	31.98
8	41	H. W. Turner	...do	66.00
9	42	S. Ward Loper	...do	67.24
9	43	...do	Services, May, 1891	75.00
9	44	Gilbert van Ingen	Services, January, 1891	75.00
11	45	...do	Freight charges	2.25
11	46	...do	Traveling expenses	119.85
13	47	Lawrence C. Johnson	...do	112.49

Abstract of disbursements made by C. D. Davis, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1891.				
June 13	48	G. K. Gilbert	Traveling expenses	$25.70
13	49	W. P. Jenney	...do	166.25
13	50	...do	Field expenses	56.83
15	51	C. Willard Hayes	Services, May, 1891	119.20
16	52	I. M. K. Southwick	Rent of stoves	8.00
16	53	United States Express Co	Expressage	3.45
16	54	I. Steininger & Co	Field supplies	29.31
16	55	F. B. Furbish	Field cases	15.00
16	56	Raphael Pumpelly	Field supplies	18.28
16	57	Gilbert van Ingen	Services, February 1 to 25, 1891	66.96
16	58	W. H. Hobbs	Services, May, 1891	100.00
16	59	Ben. K. Emerson	...do	100.00
16	60	George H. Williams	...do	125.00
16	61	William J. Swinburne	Coal	30.95
17	62	Lawrence C. Johnson	Services, May, 1891	119.20
19	63	C. E. Ketcham	Specimen bags	24.00
19	64	F. Kroedel	Compasses	50.00
19	65	William Orr, jr	Services	7.00
19	66	...do	Traveling expenses	9.20
19	67	H. W. Turner	Field expenses	53.55
19	68	Richard Bliss	Services, May, 1891	24.60
19	69	Cooper Curtice	Traveling expenses	35.05
19	70	...do	Services, June 1 to 15, 1891	75.00
19	71	T. Nelson Dale	Traveling expenses	43.57
19	72	Wilson Davidson	Collecting	48.35
19	73	A. P. Breckinridge	Harness	35.00
20	74	E. P. Hough	Traveling expenses	37.94
22	75	C. L. Whittle	Field expenses	172.68
23	76	Raphael Pumpelly	Traveling expenses	76.45
23	77	...do	...do	63.42
23	78	L. G. Westgate	Services, May, 1891	12.90
23	79	William Hallock	Traveling expenses	18.70
24	80	Isaiah Rendell	2 mules	255.00
24	81	...do	Forage, etc	37.60
24	82	...do	Pasturage	112.60
24	83	C. M. Harlan	Forage	13.50
24	84	Main & Winchester	Harness, etc	38.80
24	85	Goldberg, Bowen & Co	Field supples	34.61
24	86	J. F. Masten	Pasturage	14.00
27	87	Charles D. Walcott	Traveling expenses	82.37
27	88	Ira Sayles	...do	148.31
27	89	G. K. Gilbert	...do	131.63
27	90	Gilbert D. Harris	...do	43.20
27	91	Edwin G. Paul	...do	48.45
27	92	J. S. Diller	...do	95.20
29	93	P. M. Jones	...do	2.00
29	94	...do	Expenses	1.50
29	95	...do	Services, May, 1891	1.60
30	96	James M. Safford	...do	9.89
30	97	J. B. Woodworth	Services, June, 1891	50.00
30	98	N. S. Shaler	...do	260.00
30	99	H. B. Hitz	Services, June 1 to 19, 1891	46.98
30	100	W. Lindgren	Services, June, 1891	131.90
30	101	H. W. Turner	...do	131.90
30	102	W. A. Holmes	...do	45.00
30	103	J. D. Rose	...do	45.00
30	104	T. Nelson Dale	...do	148.30
30	105	W. T. Turner	...do	40.00
30	106	Edwin G. Paul	...do	50.00
30	107	Lawrence C. Johnson	...do	115.40
30	108	C. Willard Hayes	...do	115.40
30	109	J. S. Diller	...do	197.80
30	110	A. C. Peale	...do	164.80
30	111	C. R. Van Hise	...do	329.70
30	112	Raphael Pumpelly	...do	329.70
30	113	W. H. Hyatt	Hire of horses, etc	12.00
30	114	John S. Mendenhall	Supplies	110.72
30	115	J. D. Bohn & Co	...do	28.90
30	116	J. B. Bean	Hire of transportation	63.00
30	117	T. Nelson Dale	Traveling expenses	31.41
30	118	W. J. McGee	...do	304.75
30	119	Arthur Keith	...do	47.37
30	120	New York and Boston Despatch Express Co.	Freight	8.25
30	121	W. Lindgren	Field expenses	70.85
30	122	Will Q. Brown	Services, June, 1891	75.00
30	123	Noah R. King	...do	16.00
30	124	C. D. Loughrey	...do	26.00
30	125	W. P. Redwood	...do	10.80

Abstract of disbursements made by C. D. Davis, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
June 30	126	James Forristell	Services, June, 1891	$18.00
30	127	George E. Luther	...do	98.90
30	128	Ben. G. Palmer	...do	25.00
30	129	W. Young	...do	40.00
30	130	F. C. Boyce	...do	65.00
30	131	George H. Shields, jr	...do	26.66
30	132	W. A. Croffut	...do	247.25
30	133	G. F. Becker	...do	329.70
30	134	I. C. Russell	...do	197.80
30	135	George H. Eldridge	...do	197.80
30	136	Pay roll of employés	...do	576.95
30	137	...do	...do	1,687.85
30	138	...do	...do	195.57
30	139	J. E. Wolff	...do	148.30
30	140	C. L. Whittle	...do	100.00
30	141	W. & L. E. Gurley	...do	50.00
30	142	Keuffel & Esser	Instruments	20.00
30	143	M. M. J. Vea	Services, June, 1891	34.67
30	144	Collier Cobb	...do	50.00
30	145	L. G. Westgate	...do	18.33
30	146	Edmund Jüssen	Field expenses	54.15
30	147	J. E. Wolff	Traveling expenses	66.37
30	148	L. G. Westgate	...do	56.84
30	149	C. L. Whittle	...do	24.65
30	150	M. M. J. Vea	...do	13.25
		Total		13,886.66

Abstract of disbursements made by Arnold Hague, special disbursing agent, U. S. Geological Survey, during June, 1891.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

1891.				
June 30	1	E. J. Owenhouse	Storage	$30.00
30	2	T. Woody	Pasturage	135.00
30	3	Pay roll of employés	Salaries, June, 1891	725.20
		Total		890.20

Abstract of disbursements made by James W. Spencer, special disbursing agent, U. S. Geological Survey, during June, 1891.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY.

1891.				
June 1	143	Paul Holman	Services, May	$71.60
1	144	Pay roll, Holman	...do	57.42
1	145	Paul Holman	Traveling expenses	18.25
1	146	...do	Field expenses	32.55
1	147	A. F. Dunnington	...do	67.55
1	148	W. T. Griswold	...do	64.10
1	149	...do	Pasturage	62.20
1	150	Pay roll, Urquhart	Services, May	129.66
1	151	Robert J. Breckenridge	...do	50.00
1	152	Robert A. Farmer	...do	85.20
1	153	James T. Storrs	Services, April	11.00
1	154	Pay roll, Gove	Services, May	156.92
1	155	Pay roll, McKee	...do	450.80
1	156	Pay roll, Gordon	...do	151.42
1	157	Pay roll, Wallace	...do	135.94
1	158	Pay roll, Griswold	...do	312.33
1	159	A. A. Rockwell	...do	29.68
1	160	Rockwell Bros	Forage	20.77
1	161	Stuart P. Johnson	Field expenses	15.00
2	162	Samuel R. Sprecher	Services, May	21.77
2	163	A. H. Thompson	Traveling expenses	107.00
3	164	H. H. Chumlea	...do	22.50
3	165	Frank E. Gove	...do	45.50
3	166	Perry Fuller	...do	19.75

Abstract of disbursements made by James W. Spencer, etc.—Continued.

APPROPRIATION FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1890.				
June 3	167	R. B. Marshall	Traveling expenses	$74.52
3	168	....do	Field expenses	27.71
4	169	R. H. Chapman	....do	32.67
4	170	Morris Bien	....do	41.63
4	171	W. B. Corse	....do	19.25
4	172	H. E. Clermont Feusier	....do	34.35
5	173	George O. Glavis, jr	Traveling expenses	21.25
5	174	R. H. Chapman	....do	38.75
5	175	R. C. McKinney	....do	21.25
5	176	Jeff. D. Reagan	....do	16.60
5	177	C. C. Bassett	....do	40.00
5	178	Alex. C. Barclay	....do	40.75
5	179	....do	Field expenses	7.00
6	180	J. F. Mitchell	Services, April	13.06
6	181	....do	Services, May	21.29
6	182	D. H. Sager	....do	38.70
6	183	Pat Cosgrove	....do	37.09
6	184	J. W. Dobbins	....do	60.00
6	185	H. H. Hackett	....do	8.75
6	186	W. F. Coxhead	....do	50.00
6	187	T. M. Bannon	....do	75.00
6	188	William S. Post	....do	102.20
6	189	Pay roll, Fuller	....do	29.03
6	190	Pay roll, Johnson	....do	113.69
6	191	Pay roll, Trowbridge	....do	191.93
6	192	Pay roll, Tweedy	....do	398.38
6	193	Stuart P. Johnson	Field expenses	50.04
6	194	E. M. Douglas	....do	65.50
6	195	Morris Bien	....do	26.40
6	196	T. E. Grafton	....do	21.44
6	197	Redick H. McKee	....do	30.89
6	198	....do	....do	8.85
6	199	A. F. Dunnington	....do	125.02
6	200	....do	Traveling expenses	40.00
9	201	Arthur P. Davis	....do	48.25
9	202	William S. Post	....do	74.10
9	203	William H. Herron	....do	32.25
9	204	John McConn	....do	80.30
9	205	R. U. Goode	....do	19.90
9	206	....do	Field expenses	87.39
9	207	J. M. Gregory	....do	33.25
9	208	H. E. Clermont Feusier	....do	15.45
9	209	Perry Fuller	....do	6.55
9	210	William H. Otis	....do	7.21
9	211	J. B. Lippincott	....do	55.45
9	212	Charles F. Urquhart	....do	36.95
9	213	R. H. Chapman	....do	12.39
9	214	P. H. Grady	....do	200.05
9	215	Nichols & Yager	....do	73.50
9	216	John Stromburg	....do	205.74
9	217	Redick H. McKee	....do	45.16
9	218	A. F. Dunnington	....do	21.25
9	219	E. Ritchie & Sons	Repairs	17.50
9	220	O. T. Triplett	Transportation	13.00
9	221	....do	Forage	6.00
9	222	Pat Kelley	....do	30.00
9	223	William Kronig	....do	41.80
9	224	Frank Given	....do	53.50
9	225	A. W. Koen	....do	65.25
9	226	George L. Robinson	....do	55.00
9	227	I. B. Hamilton	....do	6.75
9	228	Philip Crawshaw	Board	19.02
9	229	Jackson & Co	Lumber	30.63
9	230	Charles E. Clark	Field supplies	13.25
9	231	E. A. Palm	....do	10.49
9	232	....do	....do	13.36
9	233	C. D. Baldwin	....do	7.50
9	234	Frank Frates	....do	45.71
9	235	S. C. Gallup	....do	17.00
9	236	....do	....do	7.75
9	237	Ed. S. Hughes & Co	....do	180.33
9	238	John R. Brennan	Subsistence	120.00
9	239	O'Neill & Co	....do	279.06
9	240	Daniel Graham	....do	26.00
9	241	A. McKinney	....do	49.38
9	242	Spratlen & Anderson	....do	95.85
9	243	E. Andrews	....do	32.50
9	244	J. C. Page	....do	24.15

Abstract of disbursements made by James W. Spencer, etc.—Continued.

APPROPRIATIONS FOR U. S. GEOLOGICAL SURVEY—Continued.

Date.	Voucher	To whom paid.	For what paid.	Amount.
1891.				
June 9	245	Charles Himrod	Subsistence	$72.09
9	246	Plonmoy Bros	Supplies	693.89
9	247	S. S. Mitchell	Services, May	50.00
9	248	William H. Otis	...do	60.00
9	249	C. C. Martin	...do	40.00
10	250	C. C. Bassett	Field expenses	113.01
10	251	...do	...do	76.30
11	252	Joseph Jacobs	...do	49.15
11	253	E. T. Perkins, jr	...do	75.93
11	254	...do	...do	50.50
11	255	R. C. McKinny	...do	63.90
11	256	E. A. Stuart & Co	Subsistence	45.30
11	257	Coffin & Seeton	Forage	28.35
12	258	George Morrison	Field expenses	13.50
12	259	Frank Tweedy	...do	402.51
12	260	Holcomb & Whitney	Field supplies	9.75
15	261	Paul Holman	Field expenses	17.75
15	262	W. B. Corse	Traveling expenses	30.25
15	263	Pay roll, Jacobs	Services, May	160.00
16	264	Pat Cosgrove	Services, June	18.33
16	265	Fred. J. Knight	Field expenses	168.00
16	266	Philip Crawshaw	Subsistence	22.00
16	267	Frank Tweedy	Field expenses	43.25
16	268	R. H. Chapman	...do	39.05
16	269	J. W. Hugus & Co	...do	8.50
16	270	Andrew McClelland	Forage	6.09
16	271	E. M. Kennedy	Subsistence	5.00
16	272	Jackson & Co	Forage	32.25
16	273	W. T. Griswold	Field expenses	86.42
17	274	Iseli & Milne	...do	125.32
17	275	H. E. Clermont Feusier	...do	38.40
17	276	E. M. Douglas	...do	74.00
17	277	Stebbins Mercantile Co	Field supplies	80.40
17	278	James McCauley	Subsistence	31.88
17	279	George Berry	Forage	68.62
17	280	E. G. Amick	Storage	30.00
17	281	Philip Crawshaw	...do	6.00
17	282	J. H. Frisbie	Services, May	50.00
17	283	L. C. Woodbury	...do	19.35
18	284	C. D. Baldwin	Field supplies	26.60
18	285	John M. Killen & Co	...do	19.00
18	286	M. Strain	...do	3.40
18	287	W. H. Sanders	Field expenses	114.90
18	288	R. R. Kelley	Subsistence	4.50
18	289	T. L. Denny	...do	3.75
18	290	Vanorsdal & Everett	...do	29.20
18	291	H. M. Wilson	Traveling expenses	17.15
18	292	Coffin and Northrop Co	Field supplies	39.25
18	293	J. P. Chinn	...do	8.95
18	294	C. Jacobs	Storage	81.60
18	295	Redick H. McKee	Field expenses	62.58
19	296	Thomas Othet	Forage	42.50
19	297	E. T. Perkins	Field expenses	66.40
20	298	T. E. Grafton	Traveling expenses	12.30
20	299	...do	...do	8.25
20	300	Stuart P. Johnson	...do	10.60
20	301	...do	...do	12.30
20	302	J. W. Dobbins	Field expenses	29.95
20	303	J. H. Frisbie	Services, June	16.66
20	304	William H. Herron	Field expenses	71.20
22	305	H. E. Clermont Feusier	...do	33.35
22	306	...do	...do	33.00
22	307	W. T. Griswold	...do	44.30
22	308	A. F. Dunnington	...do	122.98
22	309	William S. Post	...do	50.92
22	310	Joseph Jacobs	...do	16.20
22	311	Goldberg, Bowen & Co	Subsistence	350.54
22	312	A. Lietz & Co	Instruments	25.00
23	313	Morris Bien	Traveling expenses	122.62
23	314	Perry Fuller	Field expenses	27.50
23	315	Stuart P. Johnson	...do	23.90
24	316	George O. Glavis, jr	Services, May	25.80
24	317	T. S. Clark	Services, June	50.00
25	318	A. H. Thompson	Traveling expenses	204.50
25	319	Frank Frates	Pasturage	615.85
25	320	...do	Forage	250.00
25	321	Sperry & Co	...do	197.75
25	322	Coffin & Seeton	...do	233.15

Abstract of disbursements made by James W. Spencer, etc.—Continued.

Date.	Voucher.	To whom paid.	For what paid.	Amount.
1891.				
June 25	323	J. P. Waldron	Forage	$27.50
25	324	E. A. Stuart	Field supplies	316.60
25	325	Krakaner, York & Moze	...do	153.70
25	326	W. H. Shelton	...do	317.30
25	327	Gross, Blackwell & Co	...do	133.92
25	328	C. C. Huddleston	...do	74.22
25	329	B. F. Acuff & Co	...do	55.40
25	330	...do	...do	333.76
25	331	F. A. Jones	Subsistence	141.95
25	332	A. Deeter	...do	52.00
25	333	Elliott & Co	...do	48.43
25	334	S. Ecker	...do	133.75
25	335	H. S. Ballou	...do	40.27
25	336	J. C. King	Field expenses	78.47
25	337	T. L. Minor	...do	134.60
25	338	William P. Trowbridge, jr	...do	125.82
25	339	Coxhead & Harrell	...do	103.37
25	340	George Ryneal, jr	Instruments	137.35
25	341	William P. Trowbridge, jr	Traveling expenses	36.50
26	342	C. C. Bassett	Field expenses	356.06
26	343	Willard D. Johnson	...do	43.05
26	344	Overpeck Bros	Field supplies	79.80
26	345	Torn, Sweeney Hardware Co	...do	62.40
26	346	O'Neill & Co	...do	43.17
26	347	...do	Subsistence	13.50
26	348	...do	Forage	42.00
26	349	Humburgh & Masgott	...do	205.97
26	350	Spratlen & Anderson	Subsistence	146.20
26	351	R. P. Conant	Forage	35.88
26	352	E. A. Palm	...do	29.04
27	353	...do	Field supplies	11.89
27	354	Ah Sam	Services, June	17.33
27	355	H. H. Hackett	...do	52.50
27	356	J. M. Dikeman	...do	60.00
27	357	P. V. S. Bartlett	...do	82.40
27	358	Pay roll, Griswold	...do	264.80
27	359	Pay roll, Trowbridge	...do	350.00
27	360	Pay roll, Chapman	...do	291.90
27	361	Pay roll, Feusier	...do	143.90
27	362	Pay roll, McKee	...do	272.90
29	363	Pay roll, Douglas	...do	610.50
29	364	Pay roll, Perkins	...do	394.30
		Total		18,545.66
		Grand total		616,515.83

ANALYSIS OF DISBURSEMENTS.

Under the following heads appear the total expenditures under the various appropriations for the fiscal year ending June 30, 1891:

1. Salaries, office of the Director	$34,721.00
2. Salaries of scientific assistants	66,587.53
3. Skilled laborers and various temporary employés	14,991.78
4. Topography	299,837.48
5. Geology	100,966.28
6. Paleontology	39,559.08
7. Chemical and physical researches	16,652.87
8. Preparation of illustrations	13,699.14
9. Mineral Resources of the United States	5,625.42
10. Books for library	3,397.74
11. Geological maps of the United States	19,643.75
12. Rent of office rooms	2,933.26
Total	618,615.33

RECAPITULATION.

	Geological survey.	Salaries, office of Director.	Geological maps of the United States.	Total.
Appropriation fiscal year ending June 30, 1891..	$613, 900. 00	$35, 540. 00	$70, 000. 00	$719, 440. 00
Expended as per detailed statement herewith ..	562, 151. 08	34, 721. 00	19, 643. 75	616, 515. 83
Bonded railroad accounts:				
Freight $388. 05				
Transportation of assistants 1, 711. 45	2, 099. 50	....	....	2, 099. 50
Balance on hand..........................	49, 649. 42	819. 00	50, 356. 25	100, 824. 67

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, 1891.

THE ORIGIN AND NATURE OF SOILS.

BY

NATHANIEL SOUTHGATE SHALER.

CONTENTS.

ILLUSTRATIONS.

THE ORIGIN AND NATURE OF SOILS.

By N. S. Shaler.

PREFATORY NOTE.

The object of this report is to set before the general reader a somewhat popular account of the origin and nature of soils; to show the importance of their relations not only to the well being of men but their influence on the course of the physical and organic events which have determined the geologic history of the planet. It is also intended to show that this slight superficial and inconstant covering of the earth should receive a measure of care which is rarely devoted to it; that even more than the deeper mineral resources it is a precious inheritance which should be guarded by every possible means against the insidious degradation to which the processes of tillage ordinarily lead.

The peculiar order of the relations of civilized men to the soil are now the subject of serious discussion. More clearly than ever before it is perceived that the roots of our society, like those of a tree, strike deep into the fertile earth and draw thence the nurture which maintains all its springs of life. The way in which the soil may best be made to support the state, the laws by which it can most effectively secure this need, the measure of governmental interference with the ownership of the fields and forests, are now all matters of serious debate. In the consideration of these problems it it desirable that the nature of the matter under discussion should be well understood. We should as far as possible obtain a clear notion as to the way in which the varied soils stand related to the needs of our people. It is of importance, for instance, to know how much tillable land still remains in the unused reserves of the inundated and arid districts of this country and how far these may provide for the necessities of the generations to come. It is equally desirable for us to know the extent to which the fertility of this superficial coating of the earth needs the peculiar care which men give to their personal property, but which they rarely if ever devote to goods which are not endeared to them by absolute possession. The discussion of these and many other correlated questions demands a certain amount of knowledge which in order to meet the need must be separated from the special learning or at least the special phases of the several sciences of geology, physics, chemistry, and botany, which are applied to the inquiries relating to the constitution and economy of the soil.

It is a somewhat remarkable fact that while the scientific treatises on soils are very numerous constituting, indeed, a tolerably rich literature, the general essays on the subject are few in number and are, moreover, almost without exception, devoted either to the conditions of some particular region or to a particular class of questions which demand in the reader who is to obtain profit from their pages a considerable amount of training in chemical science. So far as I have learned there is no work in our own or in any other language which will give the reader who has not had special technical training in the subject any connected story concerning soil problems, which will in familiar phrase tell him the leading and most important facts concerning the chemistry, physics, and geologic history of these deposits. The farmer who imperatively needs to know something as to the part of the earth with which he is dealing is, in the main, compelled to rely upon personal or traditional experience as the guide of his conduct. This body of inherited learning is doubtless of great value; it is indeed in the best sense scientific as well as practical, for it rests, as all true science does, on a series of experiments; yet it is necessarily limited, for the reason that it is derived from contact with the conditions of a small field. For its best use it needs the enlargement of view which comes from an understanding of the general aspect of the subject and a knowledge of the experience of other men in other regions who are dealing with the same class of problems.

Where the people who till a particular soil have dwelt for centuries upon the same ground, the mass of learning concerning it which is gathered in tradition is usually very great, and in most cases provides better guidance for the husbandman than any more recondite science can afford him. The folk who have summered and wintered with their fields for many generations know in most cases the effects of diverse means of tillage in a very complete way. The effect of this ancestral experience in such immemorially cultivated land is commonly shown in the preservation of the original fertility of the earth or even in the enhancement of its returns by the skillful treatment which it has received. The people have in these cases learned how to husband and augment the soil resources, and a sound public opinion commands a large measure of care in agriculture. In these countries the owner has himself struck root in the soil; he has come to love it as the source of his own life and to look forward to the time when it will nurture his descendants. He may appear to the eye as a stupid peasant, but he is in most cases learned in all that relates to his acres from his own experience and the body of information which has come down to him from the past.

It is otherwise in this new world of America. Save here and there in the parts of the country longest settled, the traditions concerning the soil of any district are comparatively meager. It is indeed rare to find a farm which has been tilled for as much as a century by the members of one family. The larger part of the land, particularly that of the Northern States, has been occupied but a few years by the people who now possess it. A great portion of our agriculturists have but recently come upon the fields which they cultivate. Thus among the farmers of the continent there is no extended experience in the conditions of the soil they till. Left to such lessons, it will require generations to gain that information which the history of other fields might readily and immediately supply. It is in this way that science can best help in practical affairs such as agriculture and mining, viz, by presenting the results which have been gathered over a wide area of ground for the guidance of laborers in a particular field.

One of the greatest improvements in modern agriculture consists in the use of various mineral manures which within the lifetime of many active men have been made elements of commerce. Although the profit of these resources is in most cases to be quickly and cheaply determined by actual trial, it is, nevertheless, important that those who are interested in farming should know something concerning the nature and origin of these geologic fertilizers in order that they may be prepared to discover them in their own districts. There can be no question that at a great number of as yet undiscovered localities in this country there are deposits which will serve well as sources of materials for the refreshment of the soils. As far as seems practicable within the limited scope of this essay, care is taken to point out the conditions in which such materials may be expected to occur.

Although it is hoped that the practical needs of many persons may be served by this essay, the main intent of it is to afford a clear, simple and connected idea of the place of the soil in the economy of nature. So far as this can be done it will tend to ennoble the conception of all those relations with the earth on which the daily life of mankind depends, and on which the whole future of our civilization must rest. To obtain this end it will be necessary to devote the larger part of the essay to a study of the origin and nature of soils, showing how they originate, and the steps by which they are continually reformed. Only by a careful discussion of these points can the true nature and importance of this covering be made plain.

NATURE AND ORIGIN OF SOILS.

Many of the most noteworthy features of this world are, by their ever present nature, in a way concealed from us. The starry depths of the heavens afford a spectacle which would overwhelm the minds of men if they were revealed to us but once in a generation, but from the familiarity of the vision they nightly pass unregarded. In a like manner the soil beneath our feet, because we have been accustomed to its phenomena for all our lives, appears to us commonplace and uninteresting; it seems a mere matter of course that it should everywhere exist and that from it should spring the manifold forms of life; that into it the dust of all things should return to await the revival of the impulse which lifted them into the living realm. Now and then a poetic spirit, anticipating with the imagination the revelations of science, has spoken of the earth as the mother of all; but the greater part of mankind, those who are well instructed as well as the ignorant, look upon the soil as something essentially unclean, or at least as a mere disorder of fragmentary things from which seeds manage in some occult way to draw the sustenance necessary for their growth. Any chance contact with this material fills them with disgust, and they regard their repugnance as a sign of culture.

It is one of the moral functions of science to change this attitude of men to the soil which has borne them; to bring men to a clear recognition of the marvel and beauty of the mechanism on which the existence of all the living beings of the earth intimately depends. This end it attains through the clear views which it opens into the structure and history of the earth by removing the dull conception of mere chance which we almost instinctively apply to the phenomena of nature, and in its place giving an understanding of those processes which lead to the order and harmony of the universe. In no part of this great work of ordering and ennobling nature in our understanding is modern learning doing a better or more profitable work than in removing the veil of the commonplace with which long and ignorant familiarity has wrapped this earth, hiding its dignified meaning from the understandings of men. Though this task is but begun, enough has been accomplished to insure in those who have an appetite for such truths a nobler conception of this sphere, a new and imposing sense of the relations which they themselves and all their living fellows bear to the earth which has nurtured them.

This view of the moral relations of men to the earth is attained by the method of science in a simple way; following step by step the history of the earth's features and noting the processes by which they have taken form, there gradually develops in the mind a sense of the activities and the relations between the forces which have shaped its growth. No sooner is this inquiry begun than the mind ceases to look upon this sphere as a dull matter-of-course. Every event in the history is seen to have been determined by well adjusted modes of action. Each of these events blends its influence with every other so that the whole sphere moves forward in the process of its evolution, a vast array of forces perfectly ordered in their ongoing, steadfastly winning successes in organization and bringing all of its activities to a higher plane of existence.

It is beyond the compass of the human mind at once to conceive the course of the many different fields of this earth's progressive activities.

We have to limit our inquiries to some particular part of the vast realm in order that the number of the considerations may fall within the compass of our understanding. The student of the earth may select any one of the dominions of its mechanism and from the study win an exalted conception of the wisdom and beauty of its processes. On many accounts the soil covering is the best field for the beginner of such inquiries. The facts with which he has to deal are in general of a simpler and more evident nature than those which are afforded by the concealed portions of the globe. They are everywhere presented and are to a great extent open to the light of day, while the student of the earth's successive periods or of its mineral deposits is compelled to seek beneath the surface and in many different lands for the phenomena he deals with. The observer of the soils everywhere finds the part of nature with which he is concerned close about him and accessible to his inquiry, as are no other parts of the geologic field. All that is needed is an interest in the problem and an easily acquired training in certain simple methods of observation to fit any one for the study of the more evident phenomena of soils.

As the greater part of the soils of the earth in their natural condition are forest clad, we shall begin our inquiry with the portions of the earth which are covered with woods. The reader should, however, bear in mind the fact that a large portion of the lands are destitute of timber, and are either covered by a luxuriant growth of lowly plants, as in the case of the prairies, or in arid districts may present a very scanty growth of vegetation. In certain very rare cases the surface bears a true soil which does not support any vegetation whatever; but in such instances we may be sure that a recent climatal change has led to the destruction of a vegetable coating which originally existed in the district.

In beginning a study of the soil covering it is well to gain an idea as to the nature of this substance of which it is ordinarily composed. In this first step it will be useful to select a handful of ordinary soil from any convenient place, taking care that it is from within an inch or two of the surface and from a place where it has not been disturbed for a century. It is best it should be virgin soil; that is, unaffected by the processes of tillage. The naked eye commonly shows us that the mass is composed of two distinct kinds of materials. In part it is made up of decayed vegetable matter, portions of which so far retain their living shape that we can easily see that they are derived from leaves or twigs. From these discernible bits, by progressive decay, the vegetable matter shades down to less and less distinguishable form until it appears as an unorganized blackish mold. Mingled with this dark waste of rotted vegetation there are more or less distinct fragments of a stony nature in the form of sand or pebbly matter. If the sample has been taken from an old forest bed these bits of rock may be so rare as to escape observation; taken from a lower part of the soil they will always be evident, if not to the eye, at least under a simple microscope, or, if that is not convenient, they may be felt between the teeth as gritty particles. Observing them closely we find that, however small, they are more or less angular fragments of rock, generally a good deal decayed on the surface, often so much changed that they fall into dust at a touch. The magnifying glass shows that the process of decay is fracturing all these fragments along their structural planes, joints, or cleavages, and this indicates that some action is at work which serves to break up the stony matter of the soil into an ever finer state of division. That this action is in a way peculiar to the soil is shown by the fact that if we take a sample of finely divided rock, as for instance from any soft sandstone or other like deposit lying at a considerable depth below the soil, we find that its grains do not exhibit this progressive decay. We shall hereafter note how this breaking up of the stony matter is brought about.

In order to see in a clear manner that the soil is not a mere mixture of decayed organic matter and of broken-up rock it will be well for the observer to make two small experiments which will throw much light upon this problem. In one experiment, a sufficient quantity of the rock lying below the original soil at such depth as to preserve it from the chemical influence of the superficial materials should be taken and reduced to a state of division like that of the stony matter of the soil. In this seeds of some grain-bearing plant, such as wheat, should be sprouted and kept duly moistened with distilled or rain water. It will be observed that while the seeds readily germinate and enter on the process of growth the plants soon become stunted and fail to produce their fruit. If we then take decayed woody matter, such as forms the other component of the soil, carefully excluding all mineral materials from the mass and, as before, sow it with grain, we find that there also the plants grow for a time sustained by the nutriment contained in the seed and the trifle of sustenance they find in the materials about their roots, but they likewise fail to come to full maturity. It is not indeed necessary, to perform these experiments artificially. We may often observe them in the fields. On the storm-blown places where the natural soil has been removed by the wind and bare sand exposed we may observe that the seeds of the tough wild grasses, which lodge upon this material, sprout as in the suggested experiment with powdered rock, but die before they blossom. In other places we may see where some deep mossy bog has been recently drained and an effort made to reduce it to cultivation. Hardly any flowering plants will ripen their seeds upon it, the pure vegetable mold evidently being unfit for this nurture. It is necessary to remove this swamp deposit by burning or by allowing it to decay until it is so thin that the plow can mingle the humus with the rocky matter which lies beneath the layer before any green crops can flourish upon it.

Although it is in general true that decayed organic matter is necessary to fit a soil for the uses of vegetation, it should be remarked that in certain instances the earth may yield its mineral stores to vegetation even where there is no trace of decayed organisms in the mass. This condition occurs most commonly in arid lands which by irrigation have been made fit for tillage. Such soils, even where destitute of organic matter in a state of decay, often have a relatively large proportion of their mineral ingredients in a state in which they may be assimilated by the roots. The reason for this exceptional condition is perhaps as follows, viz: Even in the desert districts there is a small amount of rainfall, enough to provide the soil at certain times of the year with a share of water. This water effects the decomposition of the mineral matter in a slow way, but as the substances made ready for solution are not removed by plants, nor to any extent carried away by underground movements of water, they remain stored in the earth and are ready for the use of vegetation when the field is provided with water.

In some parts of the Southern States, notably in Florida, soils which contain scarcely a trace of organic waste at the depth of say an inch below the surface will nourish vegetation. In this case the solution of the mineral substances is probably in good part effected through the action of the water which, in its course through the thin layer of decayed vegetation, takes up the acids which facilitate, though they are not absolutely necessary to, the decay of the rocky matter.

These artificial or natural instances appear to show us that true fertilized soils are not usually made of either stony matter or vegetable materials alone; that what is needed is a mixture of the two substances. Similar experiments, or, in their place, observation in the field, will indicate that some time must elapse after the mineral and vegetable materials are mingled together before the soil becomes adapted to the growth of plants which produce fruits important to man; it in general requires a year or more for the results of the mixture to be evident. The general meaning of this evidence is plain; it is clearly to the effect that true fertilized soils, at least those from the point of view of human interests and needs, are the result of some reaction between the decayed organic matter and the broken-up bits of the solid earth with which it is commingled in varying proportions according to the circumstances of its development. Before we proceed to consider the natural history of soils, in which task we shall endeavor to show the way in which this commingling of their organic and inorganic components has been brought about and the chemical influences arising therefrom, it will be best for us to examine in a brief way into the effects of this mixture of these decayed materials derived from the remains of forms which were once living and from the lifeless rocks. In this way we shall see something, at least, of the importance of the questions with which we are to deal, and shall at the same time have a chance to note the problems which in our further inquiries we should seek to solve.

One of the most noteworthy features of soils is their wide extension over the surface of the lands. It is only in a very small portion of the land area that they are absent. The nature and origin of these fragmentary and on the whole insignificant soilless areas should be noted, for the facts are very instructive. We observe in the first place that soils are wanting on those surfaces of the bed rocks which are swept by moving water in such manner that the detrital materials can not remain in their natural position. The shores of the existing sea and of some ancient sea margins within the section beaten by the waves, the rocky beds of rivers and torrents, the steep parts of mountains where the rain urged downward by gravity clears everything before it until it flows on the bed-rock, are instances of this action (see Pl. II). Also, where rocks are steeply inclined, the effect of frequent earthquake shocks is to urge all loose materials in a sliding motion to the base of the declivity. Again, in regions from which glacial ice has recently disappeared it happens that occasional patches of bed-rock are left without any of the detrital coating which is usually deposited on such surfaces (see Pl. III). In regions overflowed by lavas derived from recent volcanic eruptions we now and then find that the once fluid but now solid rock has not yet become soil covered (see Pl. XXI). Lastly, in certain places where the soil at times when the wind blows violently is very dry and maintains at best but a scanty vegetation, the moving air may sweep it away. Notwithstanding this considerable list of conditions which may lead to a soilless earth, at least nineteen-twentieths of the land areas are occupied by a coating of commingled rocky and organic matter of sufficient thickness and fertility to afford sustenance to a varied vegetation and in a greater or less measure, if carefully tilled, to contribute to the necessities of mankind.

However these soils may differ in their character we shall find that they all have the common feature above noted of containing an admixture of materials derived from the decay of the firm-set underlying earth and similarly decayed fragments of plants and animals; the animal remains are less evident and important, but they are present in all soils and in many of them are a considerable element in their composition. On the adjustment in the proportions of these diversely originating materials depends to a great extent the fitness of the earth in the particular region to bear an abundant vegetation, whether planted by nature or by art. The variations in this regard largely depend on the operation of the natural agents which serve to bring about and maintain this association of the two elements, the organic and the inorganic, which compose the soil.

The extension of the soil coating of the earth is not more widespread or more evident than its importance to the organic life of the land. Nearly the whole of the plants other than those of the sea and the lichens and mosses require as the first condition of their existence that there shall be a soil beneath them from which they may derive the mineral or ashy parts of their bodies and the water of their sap. On the arid soilless lands of the desert or on lava rocks we may find a variety of the

VIEW ON THE EASTERN SHORE OF CAPE ANN, MASSACHUSETTS, SHOWING SHORE LINE STRIPPED OF SOIL MATERIALS BY WAVE ACTION.

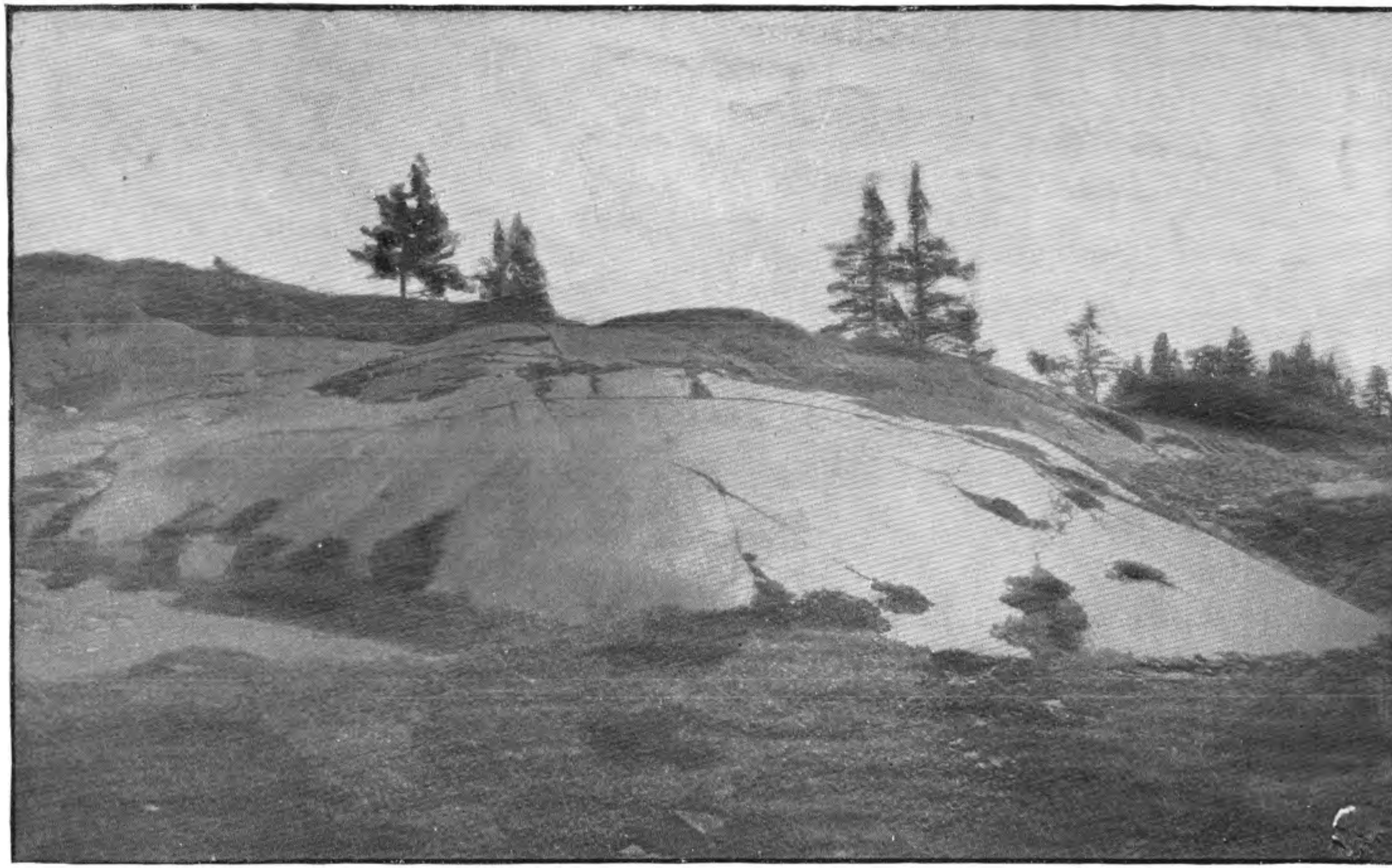
rootless non-flowering plants such as the "tripe de roche," a species of lichen, or the "poverty grass," another similar plant of the sandier fields of New England, but unless there be a distinct though it may be thin soil, none of the higher plants, especially those of importance to man, will grow there. So, too, on the bogs where the vegetable mold is deep and the plants can not strike their roots through it to the under earth and where the deposit is so placed that mineral matter can not be washed in from the land or blown on by the winds, we find the vegetation to consist of species which, like the water-loving mosses, have but a small amount of mineral matter in their composition. This mineral matter they give, when they decay, to the swamp water, whence it is returned to the growing forms. No plants having nutritious seeds or fruits, none yielding strong fibers or endowed with other qualities making them immediately valuable to man or useful to him because they serve the needs of food for his domesticated animals, will flourish in these swamps, where the depth and purity of the vegetable mold excludes the roots from the advantages of a true soil. It is by such observations made plain that were it not for the peculiar conditions which are afforded by this admixture of the débris of the underearth and of organic bodies, the higher plants which afford sustenance to man and to all the higher animals as well would have no place on this sphere.

A little consideration of the relations of the higher animals to plants makes it clear that all the advance of the earth's life above its simpler forms depends upon the existence of moderately fertile soils such as produce food fit for the nurture of the higher forms. They could not have developed if the world had afforded no better provision for them than the lichens of the rocks or the mosses of the peat swamps. We thus see that the soil is really the immediate source not only of the superior kind of plants which feed in the soil, but also of the animals which depend upon them. If the plants, such as those which produce fruits, grains, or nutritious herbage, had not had this field for their development there would have been no chance for the evolution of the series of animals which have led life up to the estate of man to find a place upon the earth. Important as the effects of the soil are to more advanced beings, they have been almost as important to many of the lower orders of life. Of the vast array of insects existing on the earth, the species of which are to be numbered by the hundred thousand, the greater part likewise depend for their nutrition either on the food they obtain from the soil nurtured on higher plants or on other animals which themselves feed on such vegetation; only a few lowly forms can subsist on plants which do not require true roots for their support. The bees and ants, nearly all the butterflies and moths, in fact all but a trifling remnant of the insect world, need the conditions which the soils bring about quite as much as does man or his kindred among the mammals.

It is not alone on the relations of the soil to the life of the land, however, that we must look for its action in the economy of the world; those relations, though most important and apparent, are not the most far-reaching of the consequences which arise from the mingling of decayed organisms with the stony matter of the earth. To perceive these we must look in succession at the conditions of the seas and of the rocks which lie in the depths of the earth. We shall find that on these apparently remote realms the influence of the soils is felt in many and interesting ways.

On the floors of the seas there is no soil coating; there is on these surfaces a quantity of detritus worn from the land, cast into the seas by volcanoes or laid upon their bottoms by the decay of organic bodies, the whole forming a layer which in many ways resembles the soil covering of the lands, but it serves no purpose in nourishing vegetation. The true algæ or seaweeds have no roots; they absorb through the surface of their bodies the materials which ordinary plants procure by these processes. As the waters of the sea, and in a less considerable way the fresh waters in our lakes and streams, contain a considerable amount of mineral matter which they readily yield to these aquatic plants, this lowly vegetation has not been compelled to invent the special underground structures which take the ashy material necessary for their growth from the soil waters. When plants originating in water forms were by the course of their development transferred to the land, they found in the rain which fell upon their leaves no mineral materials to serve their needs, and therefore the parts of their surfaces above ground abandoned the function of absorbing mineral matter and only the under earth parts retained those absorbing functions which were common to the whole of the seaweed, and these roots performed the office for the whole plant. As we shall see hereafter, it is in a considerable degree to the penetration of the roots that we owe the characteristic features of the soil; therefore, while the materials accumulated on the sea floor resemble in their fragmentary and unorganized form those of the land surface, they really differ from them in a distinct and important way.

There are other differences in the constitution of the sea-floor deposits which separate them from the true soils; thus on the ocean bottom there is no current of water through the detritus; none of that alternate wetting and drying which is of very great importance in the economy of soils. Only a few of the root-bearing plants have accustomed themselves to draw nourishment from the débris deposited on the sea floor, and these, like the mangrove tree, can do so only in the marine mud next the shore, which is in large measure composed of waste washed in from the neighboring land. Furthermore, though there is generally a soft layer of a muddy or sandy nature lying on the floor of the water areas, this matter is always passing from the incoherent to the compact state, while on the surface of the lands the process is exactly reversed, the change being from the solid condition of the rocks to the loose state of



GLACIATED ROCK SURFACE FROM WHICH THE THIN SOIL HAS BEEN SWEPT AWAY, EASTERN MASSACHUSETTS.

the soil materials. In a word, the marine conditions are those in which the rocks are being integrated or built up, while on the land the state is that of disintegration. It happens that these two contrasted processes alike for a time afford materials of a somewhat similar appearance, though in fact the state of the respective deposits are essentially dissimilar.

In the processes which go on beneath the surface of the soil of the land and below the pseudo-soil or growing bed of the sea floor, we find widely contrasted phenomena. Thus below the soil and thence indefinitely downward we find that the rain-water finds its way through the innumerable crevices of the earth, carrying agents of change along with it. In this manner it produces the ordinary caverns of our limestone rocks and has a large share in the formation of mineral veins and other alterations in the original character of the rocks. In many cases these soil effects are propagated downward for hundreds if not thousands of feet; in many parts of the world, in all portions of the land, indeed, where the surface has not recently arisen from the sea or been in late ages scraped away by the glaciers, this downward-going influence of the soil is clearly marked to a great depth, producing in general a profound decay of the rocks, which often become so much softened that beds originally hard granite or tough mica schist may easily be cut into with a miner's pick. No such effects arise from the presence of the detritus of the sea floor, for the reason that here is no opportunity for the waters to penetrate downward from that level in the manner which occurs beneath the land.

This contrast between the conditions of the sea floor and those of the land in all that pertains to the effects of the detrital layer, if we consider it well, points to the obvious and important general conclusion which will be enforced by all that we shall have hereafter to consider, viz, that the life of the land in a singular way depends upon the destructive processes acting on the portions of the air-bathed parts of the earth's crust. It is to the ceaseless wearing down of the land that we owe the formation and preservation of the wonderful mixture of decayed rock and organic matter which forms our soil. This is one of the most beautiful and significant facts of nature; it shows us that the processes, which from a short-sighted view we term destructive and associate with death, are in fact but steps in the system of advance which lead matter from the lower mineral state to the higher condition of organic forms.

The foregoing inadequate sketch as to the general place of soils in nature will serve to show, at least in outline, the importance of the problem which they present, and also to indicate the path which our inquiry should pursue. We shall now undertake to trace the genesis of soils in the different conditions in which they come into existence, beginning with instances in which the observer may verify the statements in almost any part of the world, and then passing to those cases in which the process is not so easily seen but has in a measure to be inferred from geological study.

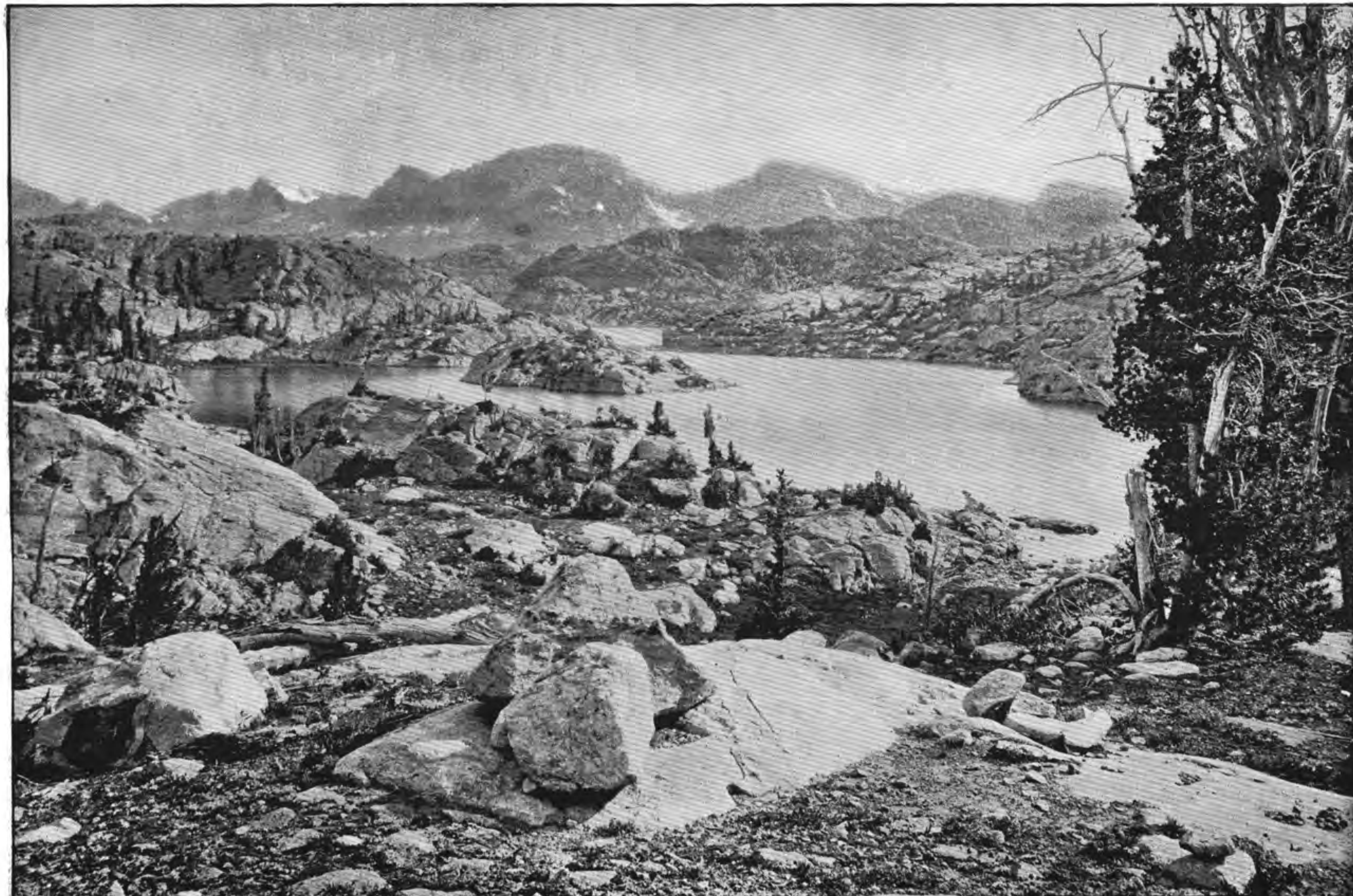
PROCESSES OF SOIL FORMATION.

From what we have already considered it is evident that soils are not original features of the land areas, but have been in some way produced after they were elevated above the sea.

Nearly all the areas of the continents and islands are known by geologists to have been formed beneath the sea and then uplifted above the level of the water. The process of their soil-making necessarily began when the rocks of which they are composed were clad with land vegetation and subjected to the manifold influences of the atmosphere. From time to time, the soils, after they were formed, were swept away by various chances, as when glaciers removing the soft materials left the rock bare, where earthquake-shocks have caused the soil to slip from steep places into the valleys, when lava floods or volcanic ashes have buried portions of the surface beneath layers of rock, or in a far less important but for us significant way, when man for some purpose has stripped away the soil from the surface of a part of the earth. To the observer these instances of the artificial baring and subsequent covering of the bed-rock again with soil are particularly interesting for the reason that they can be more easily understood than the larger work done over cultivated areas; the effects are also more computible in these partly artificial cases than those of the purely natural sort. We shall therefore begin our studies with this small class of soils which we may observe to be forming in old quarries or other places where the detrital coating has been for many years stripped away and the surface left to the processes of nature. (See Pls. III, IV, XVIII, XX, XXI.)

In all the older parts of this and other countries, where the rocks below the soil are of a nature to make it worth while to quarry them, abandoned pits can be found, and the length of time which has elapsed since the area of the bare rock was left untouched may usually be determined with tolerable accuracy.

Visiting any such old excavations where the rocks have not been stripped away for, say, ten years, we observe that on the surface of the stone there is a discoloration which gives it a hue differing clearly from that exhibited in the neighboring quarries where the faces have been recently disclosed in quarrying. Examining the rock closely with a glass the mineralogist can detect the beginnings of the decay arising from the exposure of the materials to the sun's heat and to frost and rain. The feldspar shows signs of the change which reduces it to the state of kaolin, a very soft material, and the hornblende exhibits marks of rusting due to the combination of the iron which it contains with the oxygen of the air. These changes are least on the vertical faces and steep slopes of the quarry; on the level surfaces they are much more advanced; we can indeed find spots where the water stands in shallow pools, where the decay has advanced to a point that a little sand and mud gathers as a film on the stone, the coarse grained fragments being



EFFECT OF GLACIAL ACTION ON A SURFACE WHICH HAS NOT YET BEEN RE-COVERED BY SOIL.

the half-shaped crystals of quartz and the finer matter the decayed feldspar.

All over the surface of a quarry which has been abandoned for as much as ten years we find that tiny lichens have attached themselves to the stone and from it drawn the small amount of mineral matter which they require for their bodies; this they can not do except for the decay which has served to render the material soluble. Even where the unaided eye fails to observe this vegetable growth an ordinary magnifying glass will generally reveal it. At the foot of the slope of rock we may notice a small talus of débris which has washed from the rocks above; examining the mass we find it to be composed in part of stony material, the crystals of which have become detached by decay, and partly of the remains of the lichens which are constantly dying and contributing their waste to the deposit. That the accumulation thus formed is a true bit of soil is clearly shown by the fact that when it is kept moist it affords a foothold for many small flowering plants. The crevices of the rock formed by the joint planes and other fissures are often filled with the débris which has been washed into them by the rains and blown there by the winds and thus affords points of vantage for many flowering plants, which in the moist springtime are sufficiently nourished to flower and ripen their seeds, though in the dry and heated season of summer they wither away.

The share taken by the winds in bringing about the accumulation of dust in ancient quarries is often considerable, but in a verdure clad region like New England the detrital material is usually derived from the artificial cliffs of the quarry.

In the older quarries, the stone of which has been exposed to the elements for 50 years or more, we find the same process of decay much more advanced; the heap of débris begins to creep up the slope and sustain larger and more luxuriant plants; the rifts in the rock are here and there occupied by species of trees which tolerate occasional droughts and their roots are wedging the fractured stones apart so that some fragments have fallen to the base of the slopes. In this work the frost plays also an important part, thrusting the masses asunder as it expands in freezing as effectually as the process is accomplished by the quarryman's wedges and hammers, though more slowly. We note also the fact that the lichens are larger, and evidently better nourished, than in the case of the first quarry examined, and they are therefore yielding more vegetable matter to the increasing talus. In the moist places the mosses are spreading upward from the base of the cliffs; with their spongy mass they hold water even in tolerably dry times, so that the rock is gradually being enveloped in a mantle of their growth. On the surface of this mass the débris worked from the rocks is constantly gathering, so that the coating affords sufficient soil material for the support of many plants, such as our huckleberries and other forms of flowering vegetation. These by their annual contribution of leaves and stems add still more to the increasing coating of commingled rock waste and decayed organisms.

From the aspect of old quarries to that of natural rock surfaces left bare of soil at the end of the last glacial period is an easy transition for the observer to make. On the fields of glacially bared rock, from which the ice has scraped and rubbed away the débris which once covered them, we may find every stage of the healing process which takes place when the solid parts of the earth have been stripped of their soil covering. The variety of conditions depends on the resistance which the rocks present to the agents which tend to break them up and in an important way on the nutritive value which the broken-up stone has for plants. Thus it is when the rocks are composed of quartz or other forms of pure siliceous material which is little affected by the atmosphere, especially where, as in compact quartzites and sandstones, the stone seems at times to bid defiance to the elements. As in the case of the rocks of this nature near Sugar Hill, New Hampshire, known as the "Thrashing floor," and the innumerable other instances in the region of crystalline formations in northern North America, the surface is so little decayed that it still bears the finer marks of the glacial scratchings, though, in the thousands of years which have elapsed since the glacial period, it has had no other protection against the weather than a thin sheet of moss and lichens which was in the course of time formed on the surface, (See Pls. III, IV, and XXXI.) A little decay was required in order to support this thin growth, but the rotting has not been at all sufficient to remove a twentieth of an inch in depth from the stone. There are in the aggregate in the northern part of this continent many thousand square miles of rock of this exceedingly resisting nature, which, though affording very little mineral matter for the formation of soil, still has furnished enough to maintain a scanty vegetation. The fact is that where there is but a small amount of material yielded by the soil to supply the ashy matter for plants the precious store is effectively retained by the vegetation, each plant deriving its supply of ashy matter mainly from the decayed bodies of its predecessors.

CLIFF TALUS SOILS.

From this condition in which the least possible soil making has been effected in the vast time which has elapsed since the glacial period, we may in a region underlaid by rocks of varied hardness, such as the glaciated region of New England affords, find every gradation in the measure in which the rocks have been brought into the condition of soil. Generally the decay of rocks has been great enough to furnish soil sufficient to maintain a tolerably luxuriant vegetation. But it happens in some instances that, while the rock breaks up rapidly, the size of the fragments is on the average too large to permit them to be used in soil making. This condition occurs where the rock is rifted by many joints or other divisional planes so that it breaks into a multitude

PRECIPICES WITH TALUS OF ROCK FRAGMENTS PASSING DOWNWARD INTO RUDE ALLUVIAL TERRACES.

This picture is taken from within a cavern arch.

of fragments of considerable bulk. These bits of stone accumulate at the bottom of the cliffs, forming a steep rocky talus into the interstices of which the finer matter yielded by decay penetrates below the level of daylight, so that the plants can not convert it into soil. We may observe that each of these masses of stone is attacked by lichens which are doing their fit work; but before they have time to accomplish the task the surface is covered with new falls from the overhanging cliffs. Usually we find that near the lower margin of this talus the plants have managed to stretch the mantle of vegetation over its surface, and though from time to time rock avalanches invade a portion of the field thus won to the uses of life, the growth gradually creeps up the slope. With each downfall of material from the precipice the talus rises nearer to the top of the cliff, until in the end the face of the escarpment is buried in its own rubbish. (See Pls. V, VI, VII, IX, XI, XII, and XIII.)

The way in which vegetation manages to create a soil on this rocky talus is interesting and easily traced. It is in effect as follows, viz: into the crevices between the stones fall, not only the fine materials washed and blown from the cliffs, but also quantities of leaves from neighboring forests or other fields of vegetation (see Fig. 1). The whole mass thus formed, but for the fact that it is lodged so far below the surface that

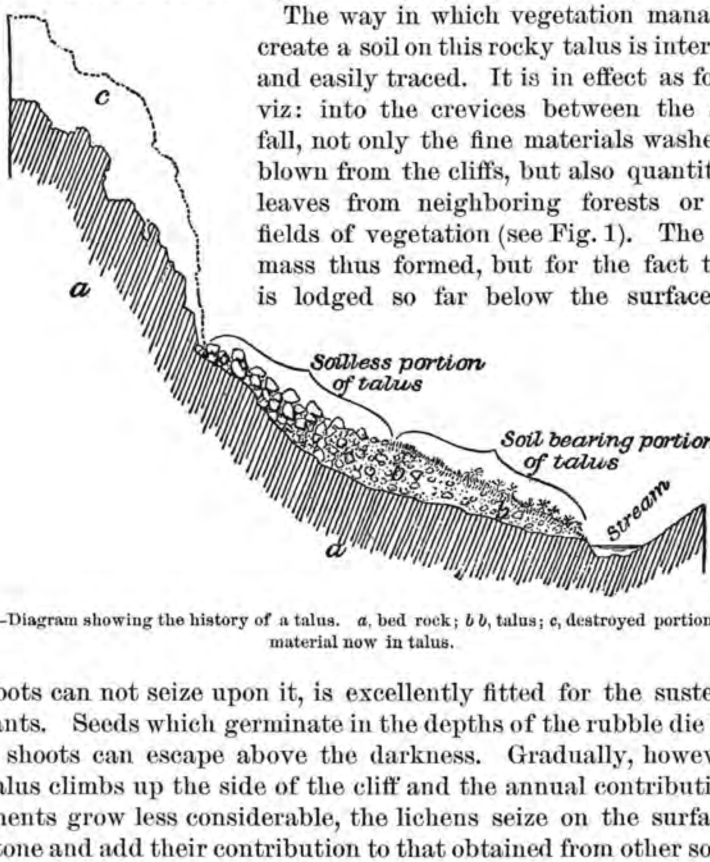


FIG. 1.—Diagram showing the history of a talus. *a*, bed rock; *b b*, talus; *c*, destroyed portion of cliff; material now in talus.

the roots can not seize upon it, is excellently fitted for the sustenance of plants. Seeds which germinate in the depths of the rubble die before their shoots can escape above the darkness. Gradually, however, as the talus climbs up the side of the cliff and the annual contributions of fragments grow less considerable, the lichens seize on the surfaces of the stone and add their contribution to that obtained from other sources, and all the while fragments of rock are decaying and adding to the accumulation. Finally the fine débris rises to the level of the daylight, the seeds of the plants of most vigorous growth take root and flourish in what is really the very rich soil. Not long after the vegetation secures a good foothold, the mass of ruin becomes the seat of a heavy growth of large trees. Such talus slopes, indeed, are often covered by very luxuriant forests.

The soils formed on talus slopes are generally well suited to natural vegetation, though for a time they are not at all adapted to the uses of the plow. The large fragments of rock inclosed in the somewhat dispersed earth gradually decay; whenever a crevice forms, the roots of the stronger growing plants send their fibriles into the opening and these, expanding with great energy as they grow, rupture the mass and so extend the surface exposed to decay. To conceive of the importance of this action we should bear in mind the fact that in such a soil there are usually within the limits of an acre millions of these root processes searching for every cranny in which they may find nourishment for the plants to which they belong; no chance escapes them; no sooner is the slenderest crevice opened than they invade it, and if they find sustenance there they burst the mass as with a wedge. So effective is this process of external decay combined with the riving action of the root that unless the fragments of which they are composed are very unyielding these talus deposits are rapidly converted into deep and fertile soils. They are rarely well suited for ordinary tillage for the reason that as long as they are stony they turn the plow or spade, but they are excellent nurseries of timber and admirably suited for the culture of the grape; some of the best vineyards of the world are situated on slopes of this description.

It often happens that deposits formed of detrital materials are shaken down the slopes on which they rest by violent earthquakes. It is characteristic of regions which are much affected by such shocks that the detritus at the foot of cliffs is reduced much nearer to a horizontal attitude than it ordinarily assumes. It is naturally impossible to give any graphic representation of this action in the case of débris lying on steep slopes, but an adequate idea as to the efficiency of these disturbances in moving débris may judged from the fissured character of the field shown in Pl. VIII where the earth has recently been broken by an earthquake.

The above description as to the method in which cliffs gradually become covered by talus slopes is mainly applicable to the escarpments which are developed in countries which have been subjected to the action of glacial ice, and to those which have been formed along the banks of rivers which after a time have worked away from the bases of the steeps which they carved. There is another class of cliffs, such as are abundantly found in regions south of the glaciated fields, where the precipices are due to the fact that the materials of which their faces are formed are rapidly passing into solution and are borne away to the streams. In such cases the cliff usually exhibits hardly a trace of true talus, for the reason that the fragments in their divided state decay even more rapidly than the firm-set rock whence they are derived. Such cliffs retreat across the country, leaving at most a thin

VIEW SHOWING VARIED RATE OF DECAY OF TALUS FORMATION IN TRIASSIC SANDSTONE SCHIST NEAR FORT WINGATE, NEW MEXICO.

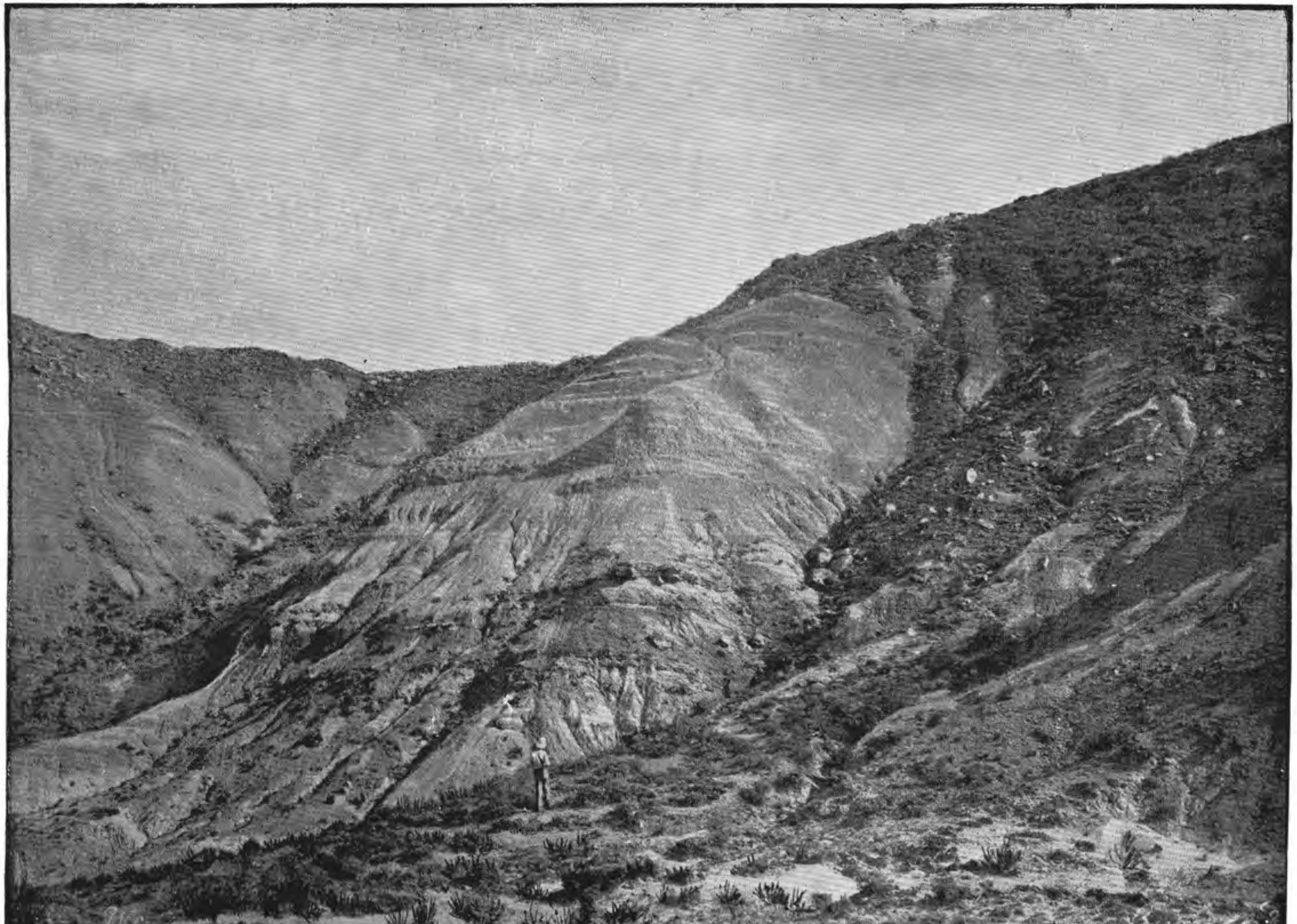
layer of very hard materials as a sheet upon its surface. Very often nothing whatever is left to denote the ancient positions of the escarpment talus (see Pl. XIV).

The study of the formation of soils on rock taluses leads us naturally to another condition in which soils are developed in confused masses of rocky matter, i. e., where they form on the waste left at the close of the glacial period in the regions over which the ice has moved, or in which, though the field may have been in front of the glacier, the débris it produced has been spread. Clearly to understand the work done under the peculiar conditions of the glacial epoch, it will be well for the observer to know something of the living ice streams, as they are exhibited in Greenland, Norway, or Alaska. From the abundant studies of their action in these and other countries, it has been made plain that the first effect arising from the presence of these singular masses of solid water on the surface of any district is to strip away the soil and other incoherent deposits of its surface, the waste being sent forth beyond the limits of the field by the streams of fluid water which flow from beneath the icy sheet, or they are pushed forward as by a scraper, or conveyed in the mass of the glacier to its front and there dropped on the ground as the mass melts away. When one of these glaciers of to-day has maintained its front a considerable time in one position, we find there a heap of stones and coarse sand which has been shoved forward by the movement of the slow-going streams or carried in its mass and dropped at the ice front. The greater part of these stones are smoothed by the ice carriage, and all the matter in the moraine is entirely without vegetable growth and usually deprived of finely divided rock, such as sand of small-sized grain or mud, this much divided material having been washed away by the streams of water which flow from beneath the glacier or over its surface, these streams carrying away all but the coarser fragments of the rock (see Pls. IV, XII).

In Switzerland, and most other countries where glaciers exist, they are now slowly retreating up the valleys they occupy, with occasional interruptions in which they readvance for a short distance, so that these frontal moraines are being constantly left to the action of the soil-making agents. No sooner is the mass of stones deserted by the ice than the great army of plants invade it. First comes the skirmish line of the lichens, which, springing from light spores easily wafted through the air, seize upon the rough places along the stone. When, as is so frequently the case, these fragments have too little fine material between them to fill the interspaces, the process of soil-making is slow; it goes on as in the formation of the rocky talus before described, by the falling in of decayed bits of lichen, the blowing in of leaves, and the slow decay of the bowlders which form the mass. As the bowlders are composed of hard rocks, that by endurance have been able to withstand the violent disrupting action to which they were exposed in their journey in the ice, they break up much more slowly than the fragments formed in an ordinary talus. So gradual, indeed, is the process of decay that in the case of many of these moraines left in New England and other parts of the United States by the ice of the last glacial period, the bowlder heaps have not yet had their interspaces filled by material to the level where the plants can make use of the débris and convert it into soil. It is sometimes possible to creep down into the cavern-like recesses of these moraines and see the accumulation which is gradually filling the crevices and slowly rising to the surface of the mass. We may in such places observe that the fragments are yielding a more or less considerable amount of débris to the soil which is accumulating in the crevices. A large part of the morainal matter left by the glaciers of the ice age has in this way been brought into a state in which trees can find root between the fragments; other portions, where the erratics are large and enduring, still retain the aspect noted in Pl. xv, but in all of these the process of crevice filling is going on, and in time all such bowldery places will be forest clad.

GLACIATED SOILS.

Where, as is usually the case, the ground left bare by the retreat of the ice is occupied by occasional large stones which are extensively mingled with gravel, clay, and sand, all left compactly huddled together as they fell from the melting ice, the rocky material is very quickly converted into soil. At first, owing to the lack of vegetable matter, it will not support flowering plants, as we may see by examining the earth left bare wherever in an artificial way considerable areas of these bowldery clays are exposed, as, for instance, in pits whence materials have been taken for road repairs or in the heaps thrown out from beneath the surface beside railway cuts. Here again the lichens and mosses, because of their tiny, easily wafted seeds or spores and their small need of nutriment drawn from the earth, find foothold and prepare the way for the higher groups of plants, so that in a few years species with strong roots occupy the area and rapidly mingle organic matter with the mineral substances and produce a fertile soil. Such glacial till or bowlder clay soils commonly have a remarkable endurance to cropping, for the reason that, being largely composed of rocky fragments, the process of decay which goes on upon these bits constantly yields to plants the ashy materials they need, the very substances, indeed, which the process of cropping tends to take away from the soil. The main difficulty with soils found on the till or bowlder clay is that the material is generally rather impervious to water, and the roots of the plants are not able to penetrate the dense mass. Moreover, they are commonly filled with large bowlders, which impede the plow and are often so numerous and of such great size that it is not profitable to remove them. Yet the greater part of the tilled land of New England, Canada, northern Britain, and much of that of the northern parts of Europe has been



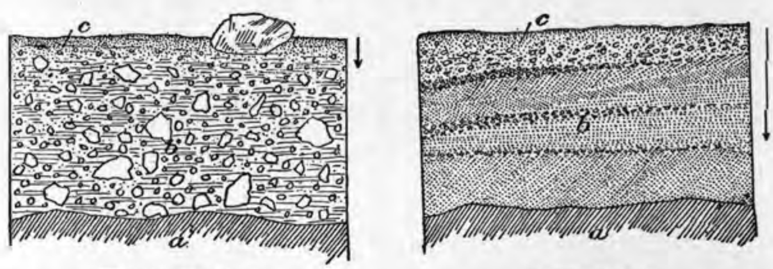
PROCESS OF DECAY OF SOFT ROCKS WHICH ARE EASILY WORN BY FLOWING WATER.

won from these bowlder-covered fields. The farmers heap the stone in great walls or upon the surface of the bare rocks; or where the erratics are too large to be readily moved they excavate a pit beside each one and so provide it with a place of burial so deep that the plow will not touch its top. In New England it is probable that more labor has been expended in this tedious task of clearing the bowlders away from the tilled ground than has been given to the construction of all the roads and farm buildings of the country (see Fig. 2 and Pl. XV).

The way in which the pebbles of a glacial soil afford nutriment to plants through their decomposition may often be clearly seen in the stubborn fields where these large erratics abound. Around the base of these bowlders, which the farmers, on account of their great size, have been compelled to leave untouched, we may often find a narrow strip of very fertile earth on which many plants requiring rich feeding flourish luxuriantly. If the bowlder, as is generally the case, is of some granitic rock, it slowly decays in the air, and every season sends down to its base a certain amount of material derived from the crystals of feldspar and mica, rich in lime, potash, soda, and other important soil ingredients; this share of fertile substances which may be shed from a stone many feet in diameter nourishes the plants which feed in the strip of earth next the stone. Each pebble in the soil is in a smaller way, but in proportion to its size and rate of decay, doing the same useful work for plants. On account of their solidity, due to the fact that only the very enduring stones survived the rough handling of the ice, they are rarely riven by the roots; some of these stones are so dense that they still carry on their surfaces the fine scratchings due to their journey in the glacier, thus showing that they have not decayed to the depth of one-fifteenth of an inch in all the time they have been exposed to the solvent action of the soil. In most districts, however, the greater part of these ice-carved fragments are so far decayed that a portion of their substance has already become food for plants, and in time they will be entirely converted to this service.

Where there is clay enough in the glacial waste to retain a share of the water which comes to the fields, and too much is not retained, the progress of soil-making is rapid. Where, however, the water either passes swiftly through the débris or can not find a passage at all the formation of a fertile layer is much more difficult and in some cases becomes impossible. In the district formerly occupied by glaciers are many fields having one or the other of these hindrances to soil-making. The washed gravels and sands deposited by the flowing waters during or just at the close of the glacial occupation of a country are often so permeable to water that they dry out immediately after a fall of rain. In this case the roots, except those of strong growing trees, can not get the humidity they need. Moreover, in the long periods of drought the vegetable matter which may have become mingled with the earth is so far exposed to atmospheric action that it can not be preserved from complete decay. Furthermore, the finely divided matter, which alone can enter into solution in the water, is constantly being borne down into the depths of the earth beyond the reach of the roots, either dissolved in the rapidly percolating water or carried along in the form of mud in the downward-setting subterranean movement. By these actions the formation of a soil is hindered, and many of these sandy areas within the old glacial region are essentially worthless for tillage. (See Fig. 2.)

Excellent instances of such soils, which are made unprofitable to agri culture by the extreme ease with which the rain water passes through



Till or bowlder clay. *Stratified drift.*

FIG. 2.—Sections showing the two common varieties of glacial detritus; *a*, bed rock; *b*, glacial detritus; *c c*, fine sand and clay brought up by ants and earthworms. The arrows show the relative permeability of the materials to water.

them, exist in many parts of North America and in Europe in the regions which lie to the south of the southern line of the glacial sheet, or which lie within the ice-occupied district in positions where sands were accumulated during the retreat of the great glacier. Thus on the islands of Marthas Vineyard and Nantucket, Massachusetts, south of the most southern line to which the glacial mass appears to have extended, there are great areas of sand plains composed of débris brought out from beneath the ice by the subglacial streams of fluid water. The great plain of Marthas Vineyard occupies an area of about 30,000 acres. The whole of this district lies in a position where it is near the great markets. It is free from bowlders, and is thus easily reduced to tillage, but it has remained since the settlement of the country essentially useless to man, and has so little value that it is not deemed worthy of taxation. The material of which this soil is composed is chemically not unsuited to the nurture of certain valuable crops, but the mass, owing to the partial lack of the finely divided materials essential to soils, is so porous, that all the rain water at once and within a few minutes after the rain has ceased to fall passes below the level occupied by the roots.

Other instances of the same nature occur in Plymouth and Bristol Counties, Massachusetts, and in the southern part of Long Island, New York, in New Jersey, as well as elsewhere, wherever the rocks worn by the glaciers have afforded large quantities of siliceous débris. Where the material yielded to the wearing action is of a limy or clayey nature these plains formed in front of the ice are often of a more compact structure, and therefore better suited to the needs of vegetation.

EARTHQUAKE FISSURE IN ARIZONA, SHOWING THE MANNER IN WHICH THESE SHOCKS MAY RUPTURE THE SURFACE.

Quite opposite conditions, those in which the water cannot penetrate the soil because of the amount of clay it contains and its exceeding compactness, lead also to an arrest in the process of soil-making. In this class of cases the roots of the plants find difficulty in penetrating the tough foundation, and so the area is generally given over to the mosses, which, owing to the spongy nature of their growth, retain yet more water, and so the area, unless steeply inclined, is reduced to the state of a swamp. Now and then some water-loving plant of the higher orders of vegetation may be able to strike its strong roots through the peaty swamp material and derive some nutriment from the surface of the clay beneath. Generally, however, they content themselves with the little mineral matter which the bog earth contains and which has been brought to it by streams which flow into the morass from the neighboring dry land.

Although the conditions of soil-making in glaciated countries are difficult, the great invading armies of plants which hurried into those regions as the ice went away have in a wonderful manner subdued the stubborn fields and covered them with a coating of vegetation which is on the whole very well fitted for the uses of man. The soils of these regions have been the nurseries of our race. The Aryan folk, according to the opinion of those who have most attentively studied their unwritten history, appear to have attained their character in the glaciated districts in and about the peninsula of Norway and Sweden. Their name signifies plowman, and they were probably the first people who used this instrument on the stubborn bowlder-set fields of that part of Europe; perhaps, indeed, the first to nurture the earth with the aid of the plow. Their descendants in Scotland, northern and central England, and by far the larger part of North America which lies north of the Potomac, the Ohio, and the Missouri, have dwelt on débris of glacial origin. The soils of these once ice-ridden fields are rarely of great natural fertility, but with labor and care they generally afford a tolerably certain return to the husbandman and endure very well the tax he puts upon them.

VOLCANIC SOILS.

We now turn to the conditions which control the production of soils on rocks which have been formed on the surface of the land by volcanic action. These fields, though occupying a smaller area than those which have been deprived of their vegetable coating by glaciers, are much more widely disseminated over the earth. While the glaciated districts are confined to high latitudes and to certain elevated regions near the equator, volcanic outflows may occur in all parts of the continents, though they are usually limited to the districts which are or were at the time of the igneous activity near the sea. Although these fields covered with rock which was once molten are widely scattered and are usually of small area, some of them occupy regions of thousands of square miles in extent. In the aggregate they probably amount to near the thirtieth part of all the dry lands and include some of the most sterile as well as some of the most fruitful parts of the earth. The region about Naples and that of the volcanic district of central France and parts of the Sandwich Islands afford types of excellent soils formed on these volcanic materials; while in each of these districts, as well as in the extensive lava fields of the cordilleras of North America, other plains overlaid by lava beds are examples of the infertility which may come from volcanic action (see Pl. XXI).

The solid matter which a volcano throws out upon the surface of the earth may be in either of two states. It may assume the form of fluid lava, which flows over the surface in the manner of streams, filling and clogging the original river or torrent valleys, or, in rarer cases, covering the whole surface of the area in which the outbreak occurs with a vast sheet of molten rock; or the molten matter may be blown to fragments termed ashes by the energy of the dilating steam escaping during the eruption; these comminuted bits of lava, which solidify as they fall through the air, often cover the earth with a deep coating like fine gravel or sand. In most cases the flow of lava from a volcano is limited to a few streams which rarely in any one eruption exceed half a dozen square miles in extent; but it sometimes happens that the escape of lava is not from the tube-like orifice of an ordinary crater, but the mass of fluid will pour forth from a long rent in the earth. In this case the volume of the ejection may be vastly greater and the tide of molten matter may spread over an area of many thousand square miles. Thus in Oregon and Washington there is a district containing not less than 100,000 square miles of territory mainly covered by vast sheets of lava, the product of successive eruptions which appear to have broken forth from extended fissures. In eastern Europe, in southern India, and elsewhere there are similar districts of vast extent. In the region of the Deccan, in southern Hindostan, these sheets of lava have an aggregate depth of many thousand feet and form the elevated table land of that name (see Fig. 3 and Pl. XVII).

The comminuted lava which is blown to fragments by the explosion of the steam it contains is scattered farther than the lava flows and often covers the surface of the earth to a depth sufficient to place the original soil beyond the reach of plant roots. So widely is this ashy matter distributed and so vast is it in amount that as a means of destroying the vegetation of the earth it must be regarded as more devastating than lava flows. In the great eruptions of the volcanoes of the Malayan Archipelago which have occurred within the last 120 years the total amount of this pulverized lava which has been hurled into the air and fallen upon the land or sea may safely be estimated at not less than 100 cubic miles, or enough to cover the area of a district the size of the State of Massachusetts with a layer over 6 feet deep. It is not improbable that the total amount of this earthy matter poured forth from the

PROCESS OF DECAY IN TALUS FORMATION IN MUCH-JOINTED GRANITIC ROCK, MOUNT LYELL, SIERRA NEVADA, CALIFORNIA.

Javanese volcanoes during that time has been as much as 200 cubic miles. On the surface of the earth it is perhaps safe to say that in the average each year sees the soil destroyed or deeply buried over a region of some thousands of square miles in area by the action of these volcanic products.

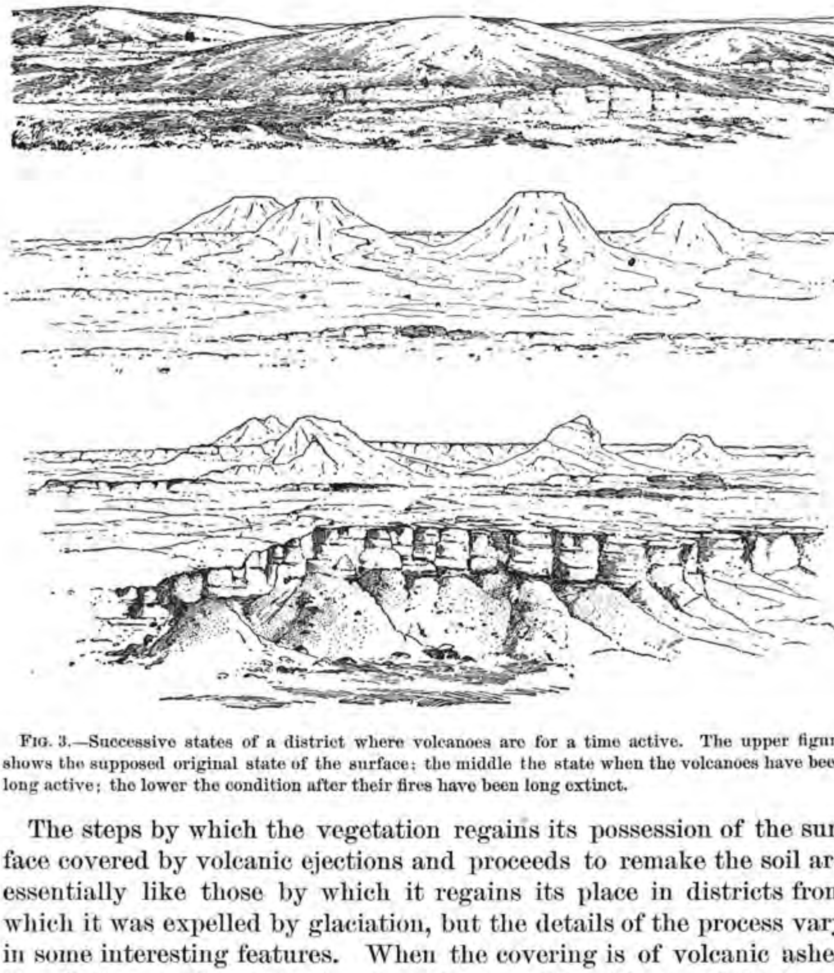
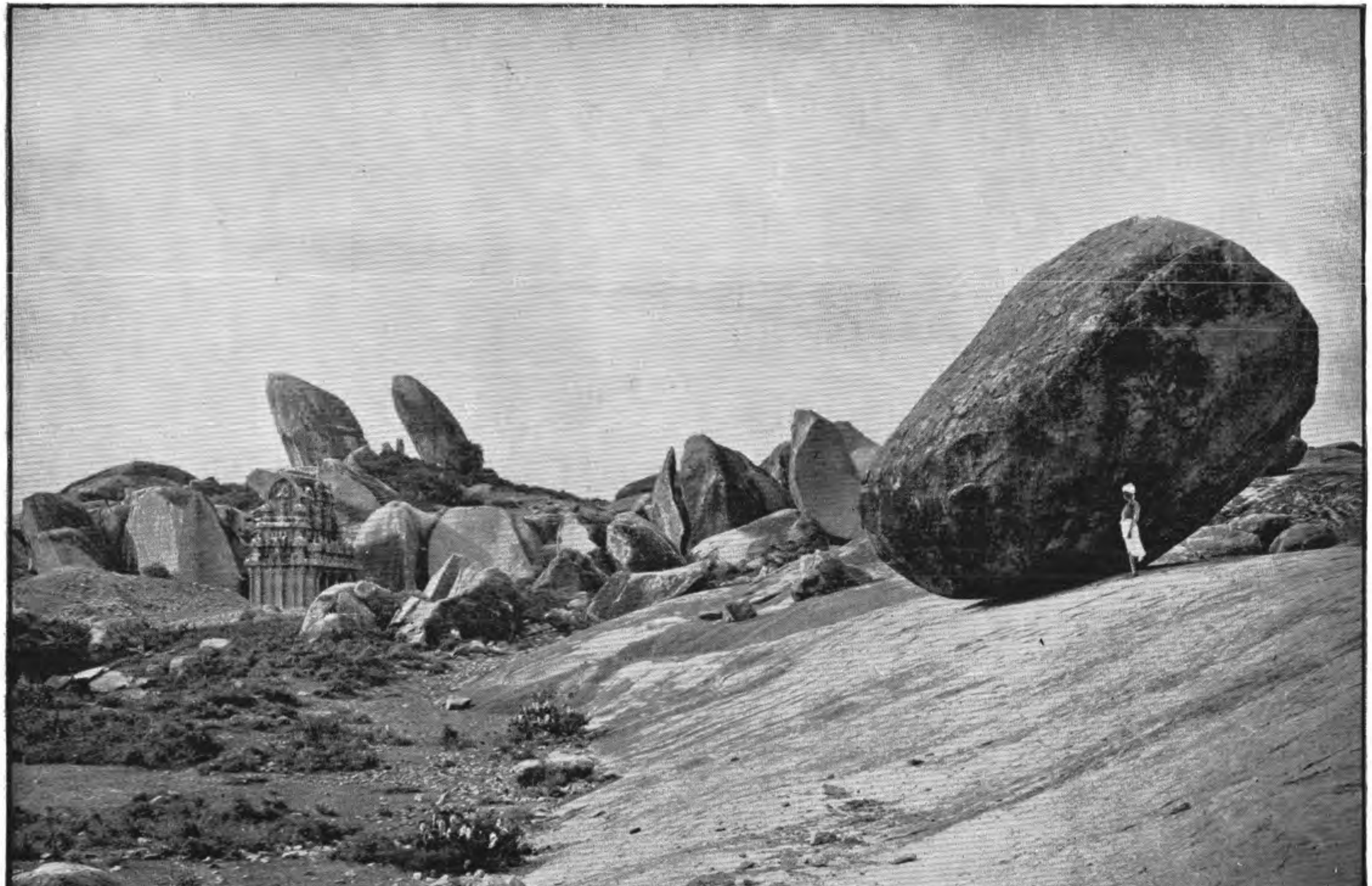


FIG. 3.—Successive states of a district where volcanoes are for a time active. The upper figure shows the supposed original state of the surface; the middle the state when the volcanoes have been long active; the lower the condition after their fires have been long extinct.

The steps by which the vegetation regains its possession of the surface covered by volcanic ejections and proceeds to remake the soil are essentially like those by which it regains its place in districts from which it was expelled by glaciation, but the details of the process vary in some interesting features. When the covering is of volcanic ashes the effect upon the vegetation depends upon the thickness of the sheet. In all parts of the field, except upon the flanks of the volcanic cone itself, this comminuted rock comes to the earth in a cooled state, having dispersed its heat in the lengthened journey through the atmosphere. In many cases the fragments are driven upward to the height of from 7 to 10 miles, and it is some hours before they find their way to the earth. Near the cone and upon its sides there are often heavy rains of heated water which effectually destroy the plants and seeds of vegetation, so that the country is completely sterilized. A little farther away these torrential rains are not so hot as to destroy life, and there we often find the old soil buried beneath the ash shower, but in other features essentially unchanged (see Pl. XIX).

It is characteristic of volcanic ash that it is generally a very light substance and the particles do not cohere with one another, at least until they are considerably changed by the agents of decay. They are like the sands which lie on seashores or in dunes. Their lightness is due to the fact that the bits enclose blebs of air, which are often so numerous that the fragments will float in water. Under the influence of rain water the ash easily slips down the steeper slopes on which it lies and much of it goes away through the rivers to the sea. That which remains, provided the average thickness be not more than 3 feet, washes down into the valleys, leaving here and there exposed patches of the original soil, with the plants, or at least their seeds, essentially unharmed. These remnants of vegetation serve as colonies, whence the organic life spreads over the sterilized fields. The process of this extension takes place at rates varying with the nature of the ash bed. Where the material is of a coarse nature, the fragments of the average size of a pea, the deposit may long resist the advance of vegetation, for rain goes through it as through a sieve and plants which depend upon their roots for sustenance find it too dry for their needs; the result is that for a time the lichens alone can maintain a place upon the ground. In most cases, however, the fragments of which these ash beds are formed are easily decomposed. Cooling rapidly from the state of fluid rock, they are often as frail as Prince Rupert drops and are broken to bits by the weight of the superincumbent materials or by the changes of temperature in the seasonal variations of heat. Moreover, their chemical nature favors decay. At first sight the material of which they are composed appears to be a dark-colored glass, but though glassy in its general character it usually contains a good deal of lime, potash, soda, and iron, substances which greatly promote the action of the agents of decay. The result is that within a score of years this ashy matter has become compact enough to retain a share of the rain water, and its materials are sufficiently decayed to fit the field it covers for the growth of a tolerably luxuriant vegetation. When the ash is more finely divided, with its particles of the size of ordinary sand, the water is sufficiently retained and in a few years the plants may do their usual work of renewing the soil-coating.

So speedy is the decay of this volcanic ash in all countries where there is a fairly abundant rainfall that the material usually cements together by the partial decay of its fragments, forming the variety of soft rock known as tuff. This consolidation goes on most rapidly where the divided matter falls into a basin containing water, as a lake or the sea, but it occurs in these cases when the material becomes sufficiently close of texture to hold rain water in a permanent manner. In any case, when the mineral matter next to the surface has been mingled with



VIEW SHOWING PROCESS OF ROCK DECAY WHERE THE MATERIAL CONTAINS SOLID PORTIONS WHICH ARE NOT READILY CORRODED.

plant mold, as always happens in rainy districts, these ash beds make good soils and some of them are of admirable fertility. The variation in their fitness for the use of plants depends on the proportion of the various substances which the lava contains. The range in this regard is very great. Some lavas are mainly composed of mineral species like silica and iron, which are relatively of little use to plants; others abound in the elements which most promote the growth of vegetation. Even from the same volcano there may be ejections which at one time afford lavas and ashes well suited for soil-making and at others produce ejections which are not well adapted for this end. In general, however, the most fertile soils of volcanic districts, and indeed some of the most productive in the world, are in these ash-covered fields. In the region about Naples, where the ashes of Vesuvius and other volcanoes of the district which at various times in the last 2,000 years have been in eruption have covered the surface to a great depth, the earth richly repays the husbandman for his labor.

In the great outbreak of Vesuvius in the year 79 of our era, a sheet of ashes covered the country over a radius of 20 miles from the crater to an average depth of probably from nine to ten feet, yet the tillage of the country seems not to have been seriously interrupted. In fact, when the ash is of a tolerably fine grain and composed of easily decomposed rock rich in mineral materials, such as are required by plants, the effect of the downfall during an eruption may be to fertilize the field upon which it comes. Looking upon the surface of a cultivated district which has just received such a shower from a neighboring volcano the appearance is that of utter ruin and desolation. The earth is smothered beneath the blackish mass of powdered rock which often levels over the walls and fences and mantles the roofs like the snow after a great winter's storm. The material seems the very image of sterility, and if it were an unprecedented visitation the people might abandon their fields in despair, but experience has taught them that a little time will return them a fruitful earth. The ashes, at first very open textured, settle down into a compact mass or are swept away by the rain, and when the sheet has settled so that it is not over a foot or so deep the farmer can by plowing or spading often begin to crop it again in the very year in which it falls. In a short time the mass may be better soil than that which was buried, for the older layer has ordinarily been somewhat exhausted by tillage. Owing to the frequent and usually thin falls of volcanic ash the region about Naples has had the fertility of its soils maintained better and at less cost to the tillers than those of most regions which are exempt from such visitations. The same is the case with the volcanic districts of the Javanese Archipelego, where these ash falls have been greater in amount than in any other known district of the world. Very few areas are thought to have been permanently made desolate by these showers of comminuted lava; even where the immediate result has been calamitous, the final result is usually not evil.

The process of soil restoration on the lava which flows from the volcanic vent over the surface of the earth is usually much slower and more ineffective than in the case of the areas covered by the layer of ashes. When the lava stream or sheet has any considerable thickness it retains a share of its heat for many years after the mass has ceased to flow; while it is cooling the plants have no chance to obtain a foothold on its surface. Long after the outer part has acquired the temperature of the air, the inner portions of the lava retain a great deal of heat; this causes every deep fissure to send forth an acid steam which is very deadly to vegetation. If the lava flow is a hundred feet in depth, as is not infrequently the case, it may be centuries before the temperature permits the sprouting of seeds upon it. The conditions of the lava surface when the mass has cooled to the point where plants can begin their work of soil-making differs greatly according to the mineralogical and chemical nature of the rock of which it is composed. In many cases, notably in the Vesuvian district, the rock is easily broken up by atmospheric action and soon becomes covered by a layer of débris. Generally the contraction of the rock, which shrinks much on cooling, leads to the formation of very numerous crevices, extending downward some distance from the surface; into these crevices and also into the irregularities of the lava plain produced by the "roping" of the lava while it flowed, the rock detritus gathers (see Pls. XX and XXI). The first plants to take a hold upon the rock are usually the lichens. Their waste, mingled with the decaying lava, soon affords the beginning of a soil in the crevices and depressions. In these vantage places the higher flowering plants find root and extend the field fitted for their needs in substantially the same manner that we have noted when they operate on a country from which the ice of a glacial period has just passed away.

The rate at which soils are formed on the surface of lava is, as above remarked, dependent on the mineral nature of the deposit, and this varies greatly in different volcanic regions, and even in the case of the same volcano in flows which occur at different times. Thus on the island of Ischia the vast flow of lava from one of the several craters which spread such wide destruction that the Syracusan colony was abandoned in the fourth century B. C., the rock has remained for more than 2,000 years but little affected by decay. Only here and there have the laborious islanders succeeded in gathering enough soil together to maintain their plantations of vines. This soil, though very scanty in amount, is of surprising fertility. Many native plants attain to such a luxuriance of growth that at first sight they often defy recognition. While these Ischian volcanoes have produced very enduring lavas which have been little changed in twenty centuries, several of the effusions from Vesuvius of comparatively recent date have decomposed with relative rapidity,

VIEW OF A MOUNTAIN VALLEY SHOWING COALESCED TALUS SLOPES THROUGH WHICH THE RIVER FINDS ITS WAY BELOW THE SURFACE.
Showing also patches of vegetation beginning to form on the face of the detritus.

forming tolerably deep soils. The rate of decay which permits the formation of soils on lavas is to a great extent determined by the rainfall of the country in which they lie. Thus, in the arid lands of the Cordilleras, the lavas of volcanoes long extinct are generally soilless, while those of the relatively well watered country of the upper Missouri, though not more ancient, have in many places produced an abundant soil.

SOILS OF NEWLY ELEVATED OCEAN BOTTOMS.

The foregoing account of the processes of soil formation on the land areas, where the accidents of frost and fire or those arising from land slides or avalanches have deprived the surface of its natural covering, shows us how swift and effective are the means whereby organic life wins its way back to the regions from which it has been rudely dispossessed. We have next to consider the rather different conditions attending the formation of soils on lands which have newly emerged from beneath the sea. The instances in which this process can be observed are rare and have never been adequately recorded. So gradual in most instances is the speed of uprising that the land gains on the sea at the rate of only a foot or two in a century and the soil gradually extends so as to cover the emerged surface. It is, however, tolerably certain that in many of these changes of level the upward movement takes place rather swiftly, so that in a few years a large area of land is left dry and thus subjected to the actions which make soils. Thus, at the close of the last glacial period a large part of the northern and eastern region of this continent, and probably the neighboring portions of Europe, were below the level of the sea, from which they emerged in an upward movement, evidently of a rapid nature. There is reason to believe that the uprising in the region along the New England coast was at the rate of as much as a hundred feet of altitude in a year,[1] the result necessarily being that a large extent of country newly won from the sea was open to the incursions of plants. To conceive the way in which they won a foothold on this surface and reduced it to the state of soil it is necessary to consider the conditions of the sea floor in the shallows next the shores of the continents, for it is mainly from such ocean bottoms that the new lands are won by the process of continental upgrowth.

The bottom of the sea next the continental shores is usually, to a great extent and to a great depth, composed of matter which has been removed from the land by rivers and waves and distributed over the bottom by the action of the tides. Along the Atlantic coast of Europe and North America this deposit forms a broad fringe of shallows the surface of which slopes gradually from the shores, generally at the rate of 5 or 10 feet of descent to the mile, until it attains a depth of about 500 feet. Then it descends rather suddenly into deep water. Along with the material swept from the land, sand and mud derived from ancient

[1] See Eighth Ann. Rep. of Director of U. S. Geol. Survey, 1886-'87, p. 987 et seq.

soil which the streams have carried out from the interior of lands or waves have removed from the coast line, there is mingled a large amount of organic matter derived from the decay of animals and plants which dwell on the sea and, dying there, give their remains to the bottom. Wherever this detritus is very rich in lime, as is the case in the portions of the sea floor on which shell-fish or corals abound, the deposits are apt to consolidate as they are formed, making loose-textured limestones, generally with more or less admixture of sandy matter. Where mud prevails the resulting beds are of a clayey nature and do not commonly become more compact than ordinary brick clays. Where, as is commonly the case, the materials on the floor are mainly sandy, the strata which they build remain in an incoherent state, for it is not until they have undergone considerable changes that pure sands will firmly cohere.

In most cases all materials laid down on the sea floor have in them a mixture of ingredients well suited to the formation of tolerably fertile soils. These they derive in the main, or in most instances, altogether from the organic materials which they contain. Wherever by some chance we have had lifted into the air a portion of the ocean floor which was covered with siliceous sand, it remains for a long time sterile. Such instances of arenaceous sea bottoms are fortunately rare, and when the continental fringe or shelf rises into the atmosphere there usually is enough fertile material in the mass to support plant life, and generally the mineral matter is suited for the maintenance of a good soil. Moreover, the substances not being much consolidated, there are no such hindrances to their appropriation by plants as exists in the older and more consolidated rocks that underlie the whole earth and appear at or near the surface over the greater part of its area. Except when composed of limestone the newly emerged sea floors generally have a composition which offers no resistance to the penetration of plant roots.

We may obtain some imperfect idea of the process by which land newly risen from the sea becomes occupied by vegetation by examining the areas where the tides have been diked out from a territory which they have been accustomed to overflow, and the area of sand or mud flats thus opened to land vegetation. We note that the surface is at once seized upon by the various spore-bearing cryptogamous plants, such as the lichens and mosses, which make a whitish or yellowish crust on the surface. After a short time, when these lowly forms have made a layer of intermingled mineral and organic matter perhaps a third of an inch thick, higher species of slender and lowly habit find a lodgment, and by sending their roots a little further into the earth deepen the nascent soil. In their turn come the sturdier plants which demand more nutriment, and in the course of a few years the earth is fit for the occupancy of forest trees.

In the great plain land of the Southern States of this Union, includ-

TALUS DEPOSITS IN A MOUNTAIN GORGE WHERE THE STREAM HAS SLIGHT CUTTING POWER; LAKE CANYON, CALIFORNIA.

ing the eastern parts of Virginia, the Carolinas, Georgia, the whole of Florida, and the fringe of lowlands bordering the Gulf of Mexico and the Lower Mississippi, in general all the surface of the region below the level of 500 feet in altitude, we have a district in which the land has recently arisen from the waters of the ocean and become soil covered. In all the lower lying parts of this vast area, say the ground within 300 feet of the sea level, the emergence is so recent that we can still perceive that the surface usually has the peculiar gently undulating shape which is characteristic of the sea-floor. In this part of the country it is interesting to observe the process of soil-making on the different classes of materials—clays, sands, limestones, or various admixtures of these substances. We note in the first place that the soil on this district is generally thin, a fact which goes to show that unlike the deep rich earths of other and higher lying regions, it has not been a long time in the process of construction. Then we may trace the varying degree of retardation which the soil-making process has met and from the inquiry learn among other things how slight differences in the conditions of the rock may produce very important variations in the results.

One of the best places to study these southern soils is in Florida, for in that State the surface varies but little in height or in climate, and the condition of the rainfall to which it is exposed and the profound differences in soil are due mainly to variations in the nature of the underlying rock. In the region of the Keys we have that rare form of coast deposits consisting of coralline limestone; the islands being in fact ancient reefs which have been elevated to the height of 20 to 40 feet above their original position. The material of which they are made is nearly pure limestone, derived from the remains of corals and mollusks and other lime-secreting organisms which lived on the reef while it was below the level of the sea. There is in the mass a little volcanic ash brought to the region by ocean currents from remote volcanoes and a small admixture of various other substances, such as phosphorus from skeletons of fishes and crustaceans, a little potash, soda, iron, and other mineral matters taken from the sea by marine animals and plants and built as fossils into the deposits of the sea floor. The material is a very good source for a supply of the mineral elements necessary to insure fertility in a soil. The rainfall is great and the temperature is tropical, so that the vegetation, when it finds a foothold, is very luxuriant. But a large part of the surface of these reefs remains singularly destitute of soil; here and there only do we find a patch of detritus which is deep enough for ordinary tillage, and this only where the slope of the ground has preserved in a small area the accumulation of débris which has been produced over a much larger neighboring surface.

The cause of this paucity of soil in a region where we should expect to find an abundant deposit is interesting, and it leads us to discern a certain feature of the earth's history which has generally escaped attention. There can be no doubt that soil-making material of fertile quality is produced on these reefs with great rapidity. The little there is of it in the crannies and low places of the rocks bears a luxuriant foliage. What, then, is the reason for the small amount of the accumulation? The explanation is to be found in the remarkable purity and solubility of the lime rock which forms the Keys. It is evident that this rock is rapidly wearing away; it is everywhere channeled by sink-holes and caverns, and the water which flows from them is heavily charged with limy matter. The fact is, that as fast as the rock decomposes and the bits are appropriated to the soil they dissolve in the water and are returned to the sea in a state of solution. The result is, that it is impossible to keep the mineral elements in sufficient proportion in the mixture with decayed vegetable matter to form a continuous soil coating. It is only where the decomposed rock is washed from a considerable area of the surface into some cavity that a soil of ordinary thickness can be formed. If there were 10 or 20 per cent of ordinary sand in the limestone there would be a solid basis for the soil which would serve to inclose the vegetable matter, or if the region were in a moist, cool climate the slower decay of the limestone bits would still enable them to remain to nourish the plants. In such a climate in the winter season there would be no process of solution going on, and the rain water being less heated the solvent action would be much less considerable than in the summer season, but in this frostless land, where the rainfall amounts to as much as 90 inches per annum, all the bits of stone which should go to form a soil are taken into the water and borne away. We shall hereafter have occasion to note that in other limestone districts the excessive solubility of the mineral matter, as well as its occasional insolubility, may alike interfere with the formation of soils.

In the everglade country of Florida we have another type of soils which, though in part coming under the head of swamp deposits, deserve mention here, though they must be again referred to in a later section of this report. In the everglades the water on the eastern side and in the central portions of that remarkable region rises in the late summer and autumn until it forms a vast lake covering almost the whole area. When in this extended form this water absorbs a great deal of lime from the rocks which it covers. When these waters dry away in the winter and spring they leave a thin coating of limy mud intermingled with leaves on the surface of the bared earth. This, accumulating from year to year, forms a peculiarly black dense soil, rich in lime and other elements needed by plants, and therefore of remarkable fertility. Unfortunately, only a small part of this excellent soil-making material is retained on the land; the greater part escapes to the sea through the streams which drain the everglade country.

In the central and northern parts of Florida, there are extensive areas occupied by sands which have evidently been subjected to the action of strong marine currents, and in this manner have had the finer

PROCESS OF EROSION OF RATHER SOFT ROCK, THE TALUS FROM WHICH IS INVADING FOREST.

materials, such as clay, removed from them. Here the soils are very thin because the plants find little mineral nutriment. The siliceous element is, it is true, essential to plants, but they can not support themselves on that alone. In such places we find scrubby pine trees rising from an earth which bears little other vegetation. The roots of these trees strike deep into the earth and thus, occupying a large space, gather the little they need for their scanty growth; but the ordinary annual and herbaceous plants can not endure the sterile conditions. Moreover, the soil is not only lean, but the rain which falls upon it quickly percolates, carrying with it to a considerable depth nearly all the soluble material which might be useful to plants and leaving in the rainless season no water near the surface. The conditions of this region as far as its soil is concerned remind us of those which we have noted as occurring in the washed sands of the glaciated part of the world. In both we have the surface covered by porous sands which, by permitting the speedy and complete passage of the water, hinder the work of making the earth a fit place for plants.

In a large part of the southern lowlands the evils arising from the sandy nature and excessive poverty of the soil are considerable. In most districts, however, there is a sufficient admixture of clay to make it possible for the forests and lower growths to convert the mineral matter into fairly good soils. It is probable that the whole region was covered by a growth of flowering plants almost at once after its last uplifting above the sea; as yet, however, the work of soil-making is much less advanced than it is in the higher country, where the surface of the earth has been above the ocean many times as long as the southern coastal plain.

We have now considered the processes of soil formation where the surface of the earth is newly exposed to the conditions which create this covering. We shall now have to undertake a more detailed study of a typical soil with a view to acquiring a general idea of what we may term its physiology; that is, the way in which it is maintained in its essential functions and the manner in which the various processes of a geologic nature which go on within it are accomplished. In this task we shall consider little of the chemical work which is done in this stratum, for the reason that such problems for their understanding demand a good deal of technical knowledge and come rather more in the special domain of chemical than within the limits of geological science.

For the purpose of our further inquiry the reader should keep in mind the general aspect of at least two classes of soils which are familiar to most persons or may readily be seen in all parts of this country save those which have been extremely affected by glaciation, viz, those derived from the decay of the rocks which are immediately below the soil and those which have been brought into the region by rivers and deposited in alluvial plains. It is well also to know something of the aspect of the glacial and volcanic ash soils, but a sufficient idea of these may, perhaps, be gained from the figures which accompany this text.

PHYSIOLOGY OF SOILS.

So far we have been considering those very general features concerning the origin and distribution of soils which we may term their physiography. We shall now proceed to examine into the details of certain processes by which soils come to serve the needs of plants, the ways in which their fertility is maintained, and in general their relations to geological actions. These inquiries should be begun upon that type of soils which occurs on the older part of the land surfaces, on those portions of the continents which for many geological periods have been above the level of the sea, for there alone can we trace in a satisfactory way the successive steps in the history of a soil. After learning the history of such a typical area we may then compare the deposit with the less normal forms, some of which we have sketched in the preceding pages.

This detailed study of the physiology of soils may best be approached through a consideration of the forces which operate in the production of such deposits. It is easily seen that all soils represent the application of a certain amount of energy, which diversely applied constitutes in the aggregate a vast sum. Soils are composed in part of rocky matter which has been broken into bits and mingled with organic matter. The stony material has been much affected by chemical agents which have produced an evident decay, and this also indicates the application of energy. The vegetable and animal waste, which is as necessary in a soil as is the mineral matter it contains, owes its existence to the special application of energy which brought the elements of the plants from the soil and the air into the combinations of life which contribute so much to the soil. We shall now inquire as to the source and methods of application of these diverse modes of action.

It does not require much observation to show us that the greater part of the forces which operate on the soil are derived from the sun. It is clearly solar heat which causes all the movements of animal and vegetable life; and all the growth of roots, stems, and leaves is evidently due to the warmth of the growing season. In our latitudes, when the sun moves away to the south, the share of its radiation to our land is so far diminished that the growth of plants is arrested and the ground is commonly frozen, so that all the operations which lead to soil-making are for the time suspended. When the great source of power rises higher in the springtime, all the machinery of organic life and chemical change in the superficial parts of the earth renews its activity. Thus the dependence of the soil upon the solar heat for all the actions connected with seasonal temperature is absolute.

Slightly more extended considerations show us that the rainfall which comes to any country is also due to the heat of the sun. The waters of

CLIFFS OF SOFT ROCK WITHOUT DISTINCT TALUS.

the sea, warmed by the rays from the solar center, ascend as vapor. Their upward movement is due to the energy which is thus applied. When these vapors attain the higher regions of the atmosphere, they are drifted by the winds, which owe their motion also to the same source of heat, and pass from the oceanic areas to the land, where, if not before precipitated, the store of moisture descends in the form of rain or snow. Falling upon the earth, this water imported from the sea becomes a part of the chain of causation which is in various ways related to the formation or destruction of soils. The rôle of actions is extended and varied, but it is easily to be understood, and it constitutes one of the most charming series of phenomena which the earth exhibits to the inquirer.

When the water which falls from the clouds comes down in the form of snow it descends gently upon the earth and accumulates in the familiar covering which winter lays upon lands outside of the torrid zone. At first and for the duration of a single season the effect of the snowfall is advantageous to the soil, for it prevents the deeper freezing which is likely to take place when the earth lacks this snow blanket. The frost which has seized upon the ground before the snow falls is melted by the heat ascending from the deeper earth. Often the warmth thus induced in the soil is sufficient to start the lesser plants into life and even to stimulate into a certain activity the roots of trees whose trunks and branches are in the cold upper air. It has often been observed that in frigid countries, where the snowfall is so deep that it does not melt away until the summer warmth is well affirmed, the small flowering plants will blossom beneath the frozen sheet. Released by the action of the snow covering from the bondage of frost, the soil is free to undergo the manifold chemical changes which are necessary to bring the mineral part of its constituents into the state in which they can serve for plant food. Thus the season of preparation of the soil for the demand which the roots make upon it is, through the action of the snow covering, very much prolonged, and the preparation of nutritious matter takes place at a time when there is little or no drain made upon it. The advantage of this condition, brought about by the snow blanket, is recognized in the adage, "Snow is the poor man's manure." In this phrase farmers have embodied their sound observation as to the effect on the open soil which the winter's mantle insures.

If the snow vanishes, as it usually does during the summer season, the effect of the accumulation is altogether beneficial. If, however, the covering is so thick that it outlasts the time of warmth, so that the layer thickens from year to year, the mass soon begins to move downward toward the sea. Even in a single winter snow which is deposited on a steep slope takes on a glacial movement and creeps toward the base of the inclination, carrying with it the loose materials which lie upon the surface. Where this action is continued and intensified the effect is, as we have already noted, the inevitable destruction of the soil. This glacial movement acts upon the earth's surface as a rasp, gradually wearing away at first the incoherent materials which lie upon the more solid ground and afterwards the firmer rocks, which it may erode to a great depth. When the ice sheet disappears it leaves the land bestrewn with débris of various kinds. The old valleys by which the rain waters were discharged are greatly changed in form, so that, as in the boreal parts of North America, the originally well drained surface is to a great extent occupied by lakes and swamps or by sandy and rocky fields, on which the soil-making processes find it difficult to accomplish their work in a way to serve the interests of higher life. The sharp contrasts between the conditions which are brought about, on the one hand by a temporary covering of snow and ice and on the other hand by the more continuous coating of a glacial sheet, affords us one of the many instances in which slight differences in the mode of natural action produce on the soil as elsewhere the widest variation in effect (see Pls. IV and XVI).

There are only a few places within the limits of the United States where glacial work on a considerable scale can now be observed, and these are all situated in the western portion of the Cordilleran region. It may therefore be worth while to note certain familiar examples of the rubbing action which even an ordinary winter's snow sheet has upon steeply inclined portions of the earth, where it lies as a thick covering. If we visit a hillside of moderate steepness at a time when a thick coating of winter's snow has just been cleared away we may note in the attitude of sticks and other dead bits of wood that the surface has been subjected to a certain amount of rubbing which has urged the fragments down the hill. Thus we not uncommonly find where a branch, fallen from a tree, has in its downward movement encountered some obstacle, such as the trunk of a tree, around which the bough has bent in the manner of a bow, the two ends being dragged some distance down the hill. Occasionally we can note where stones, sometimes as large as a man's head, have been pushed down the hill, leaving a slight groove to mark the energy with which they have been urged forward in their movement. Sometimes, though rarely, this downward movement of the winter's snow is sufficient to disrupt small stone columns which have been constructed upon steep hillsides. Thus, in the cemetery in Augusta, Maine, where the monuments have been placed on a steep hillside where the snow deeply accumulates, it has more than once happened that the slow, creeping glacial movement has broken off stout tombstones and iron fences which surround graves. This action has taken place, not in the manner of an avalanche, but with a slow motion which carried the disrupted objects only a few feet from their original position. In this way we see how, even in regions where true permanent glaciers are unknown, the snows of winter give us a very clear semblance of their action.

On the greater part of the earth the rainfall comes in the form of flood water or ordinary rain, and as such journeys downward to the sea. To understand the function of this fluid the observer should trace

MORAINAL FRONT IN EASTERN MASSACHUSETTS, SHOWING THE WAY IN WHICH VEGETATION OCCUPIES A BOWLDER-STREWN SURFACE.

its action from the place where it fell upon the earth to that where it reentered the ocean. This, at least in a general way, I shall now endeavor to do. When the drops of water strike the surface we observe that they fall with a certain amount of force; this energy is immediately due to gravitation, but it is remotely owing to the sun's heat, which uplifted the water to the clouds whence it falls. This blow of the raindrop may seem of slight importance, but it is really of great moment. If we watch any newly plowed field where it is exposed to a heavy rain we notice that the drops cut the clods to pieces in a rapid manner. After a single shower following the work of the plow we may here and there find where a flat pebble or a potsherd has protected the earth from the assault of the descending water. Each of these sheltering bits rests upon the top of a little column of soil, which may be an inch in height. In many countries, as for instance in Colorado, where there are extensive areas of soft rock, with occasional hard patches of material contained in their beds, we find that this phenomenon is shown on a large scale, the columns often being 20 feet or more in height, each capped by the protecting stone which has preserved its pedestal from the stroke of the raindrop.

It is to the disrupting effect of this reiterated dropping of the rain that we must in the main attribute the rapid washing away of soils which are by tillage much exposed to the direct attack of storm water. If there were no natural protection against this the soils would be in a geologically brief time entirely swept away; they would indeed not now exist as a general coating, but would be limited to certain places of a swamp-like character into which the detritus from higher lying rocks would be swept by the floods. From all surfaces of evident slope the materials would be worn away. Fortunately for the economy of the earth, a nearly perfect natural protection is afforded by the coating formed by the stems, branches, and leaves of plants, which along with the débris from their bodies lying confusedly heaped upon the ground, serves to protect the earth from the direct action of the falling rain and yields the water gradually to the under earth.

As soon as the rain drops strike the surface they flow together and form a thin sheet of water; where the earth is bare of vegetation a part of the fluid quickly gathers into rills and flows away, rill joining to rill until considerable streams are formed. On plowed ground this surface water bears with it a heavy burden of the soil which it conveys away to the lower lying district and often transports to the greater rivers and thence to the sea. A large part of this loss of the soil is due to the admixture of its substance with the water under the action of the falling raindrop. In a time of heavy rain a field, if it be much inclined in its surface, will often lose on the average half an inch in depth of its soil covering by this action. On the other hand, in a forest-clad country the rain even where it descends in heavy showers forms no sheet of water upon the surface; it is all absorbed in the forest bed and thus no small rivulets result. The water sinks into the spongy coating, and in that tangle of decaying vegetation it slowly creeps down the declivities until it is gradually yielded to larger streams, trickling out along their margins from the mantle of leaves, twigs, and roots which covers the earth perhaps to the depth of 2 or 3 feet. While on a bared field there may be two or three rivulets formed in a time of heavy rain on each square yard of the surface, so that the area is quickly seamed by a labyrinth of little valleys, in a neighboring district having the same character of soil and a like inclination of surface, but covered by a virgin forest growth, we may not find an average of one stream to the square mile. This feature is illustrated in the accompanying diagrams, which are intended to indicate the contrast. While each of these water ways in the forest is occupied by a perennial brook fed from the spongy soil, stream beds on the tilled land are all dry save when the rain is actually falling (see Fig. 4).

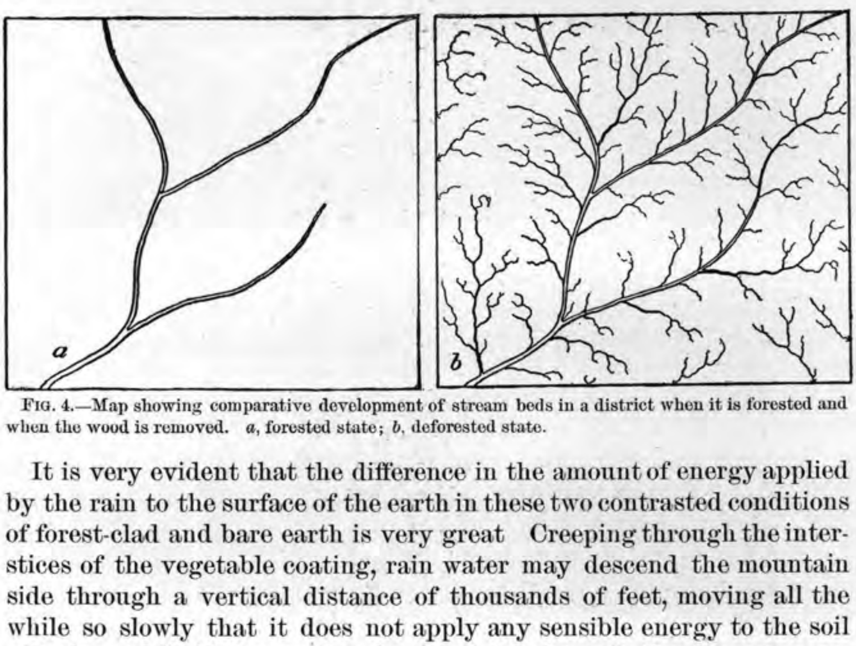
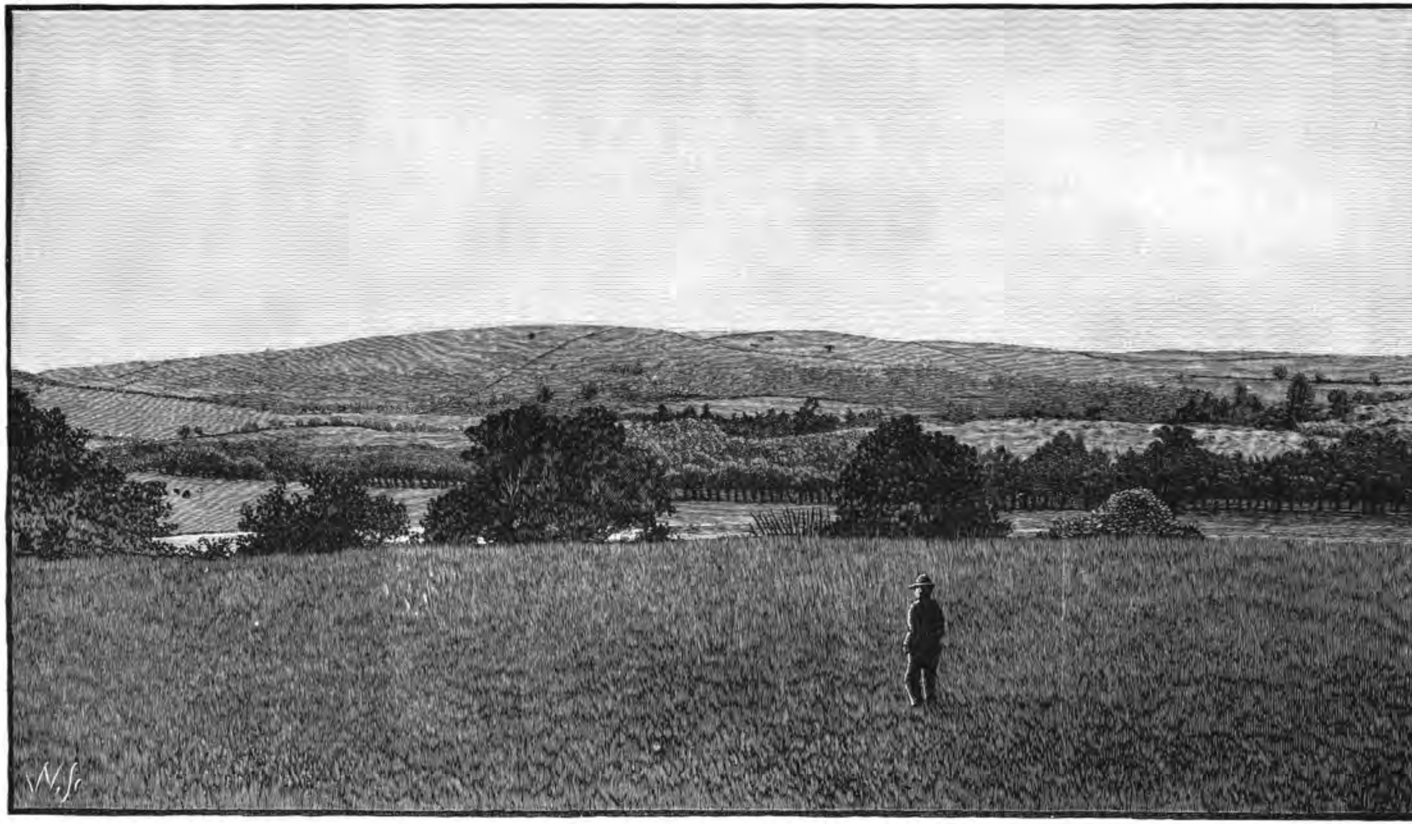


FIG. 4.—Map showing comparative development of stream beds in a district when it is forested and when the wood is removed. *a*, forested state; *b*, deforested state.

It is very evident that the difference in the amount of energy applied by the rain to the surface of the earth in these two contrasted conditions of forest-clad and bare earth is very great Creeping through the interstices of the vegetable coating, rain water may descend the mountain side through a vertical distance of thousands of feet, moving all the while so slowly that it does not apply any sensible energy to the soil covering, while if that surface be deprived of vegetation it may on account of its swift motion apply an intense erosive force to the incoherent soil.

All that part of the rainfall which flows away over the surface tends to destroy the soil coating, and, as we have seen, it effectively accomplishes this end wherever the earth is not protected by its action. This surface water, however, represents only a portion of the rainfall; the remainder enters the earth near where it falls and is thenceforth, until it is again gathered into the surface waters through the springs, mainly an agent of soil construction. The proportion of the under and surface water, or that which sinks into the ground and that which flows



DRUMLINS OR LENTICULAR HILLS IN EASTERN MASSACHUSETTS, SHOWING THE ARCHED OUTLINES OF THESE DEPOSITS.

away upon it, differs very much according to the physical characteristics of the district in which it falls. In general, the ground water is proportionately much greater in amount in those cases where the surface is forest clad than where it is tilled, for in the woods the earth never becomes baked or compact, and, held in the forest sponge, the water has ample time to penetrate the soil before it escapes to the streams, while on the bare ground it slips away rapidly toward the sea. It is a familiar observation that the soil of a tilled field, especially if it be of a clayey nature, remains quite dry in its under parts even when its surface has been seamed by a torrential rain. Where the earth is very open textured, as is the case with the washed sands of the glacial districts or of the similarly sandy and nearly soilless areas of Florida, the water, however heavy the rainfall, may all immediately penetrate the ground without flowing over its surface. Thus in the glacial sand plains of southeastern Massachusetts there are often no traces of stream beds over districts of many square miles in area. It is evident that no water has flowed over them since they were formed in the closing stages of the last ice-time, save perhaps during winter when the soil was firmly frozen. Where the soil is a dense clay, even though it be covered by primitive forests, the proportion of the water which enters the earth may not exceed one-third of the rainfall. On tilled ground the relative amounts of the under and over water varies exceedingly, in a measure determined by the character of the rainfall, whether rapid and brief or long continued and slight. When the surface is of bare rock the amount of penetrating water is always relatively small in quantity (see Fig. 2).

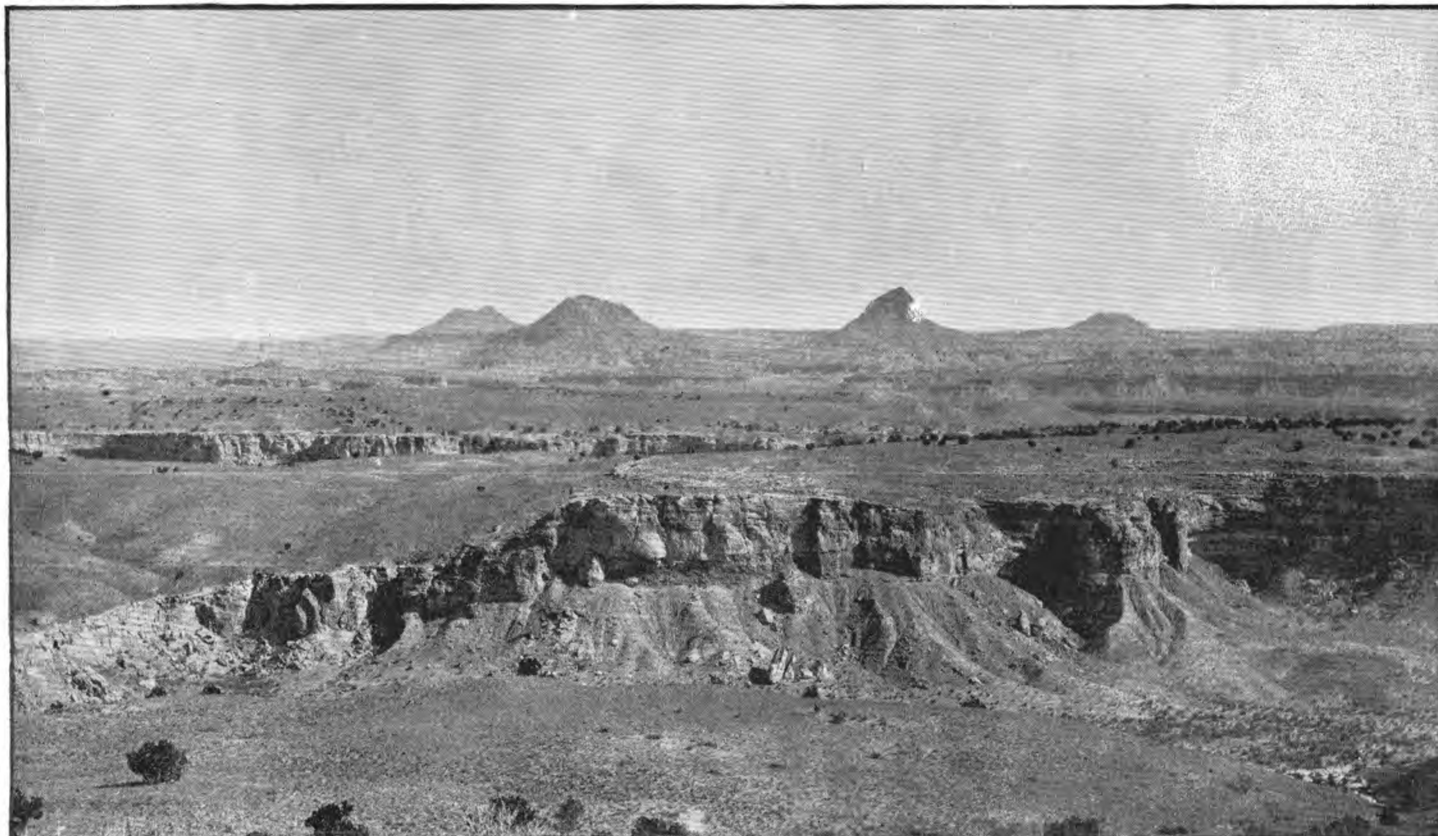
When the winter's snow remains on the ground throughout the frigid season and the under earth consequently passes from the frozen state which it acquired before the snow came down, the melting snows commonly yield their water to the under soil in a larger measure than is the case with other forms of rainfall. The snow when it gradually disappears commonly melts most rapidly upon its contact with the earth, so that the water retained beneath the remainder of the coating has abundant time to filter into the soil. The reader may have noticed that in the time of snow-melting the layer generally lies upon extremely wet earth, and if the soil be of a clayey nature there may be an almost continuous sheet of water upon its surface. Thus regions where the snowfall is abundant and persists into the spring-time are apt to get a thorough soaking of the earth at the time of year when abundant watering is extremely advantageous to natural as well as to tilled vegetation.

That part of the water which has entered the ground is the efficient instrument of soil-making. All other processes contributing to this end depend upon its action in an immediate and complete manner. We shall therefore have to scan the history of ground water in a somewhat careful way. When the heat of the sun takes the water of the sea into clouds in the form of vapor the fluid rises in the distilled form; it has left behind all the mineral substances which were dissolved in it and is in a nearly chemically pure state. There probably remains some trace of certain dissolved substances, but the quantity of admixture is so small as to have a scientific interest only and no economic consequence whatsoever. When the vapor is converted into rain, and possibly while it is still in the diffused form of clouds, the water is in a condition to absorb into its mass various gases for which it has a physical affinity. The measure of this capacity for taking in gases varies greatly and does not immediately concern our inquiry. It is, however, as we shall see hereafter, of the utmost consequence that among the gases which this liquid readily and in large quantities absorbs, is that combination of oxygen and carbon commonly known as carbonic acid gas (CO_2) now termed by chemists carbonic dioxide. This substance exists in all parts of the air in proportion to its weight in nearly equal parts. Thus in the atmosphere through which it passes, the rain has a chance to absorb a considerable amount of CO_2 before it touches the earth. Snowwater, because of its frozen state, probably takes in less of this gas and may enter the earth with comparatively little of the material dissolved in its mass.

When the water from the clouds, coming either in rain or snow, enters the earth, it commonly passes through a more or less extensive layer of organic material in the state of decomposition. From this layer it takes up a yet larger charge of this gas as well as of other materials which are of importance in its subsequent work. It probably gains from this layer an additional amount of ammonia and other nitrogenous substances which it had begun to acquire in its journey through the air, but it notably increases its store of carbonic dioxide. The quantity of this gas which water may contain when it finally enters the true soil is indeed surprising; it may amount to several times the bulk of the fluid.

Now on the presence of this dissolved carbonic acid gas depend some remarkable effects which water produces on the soil. The most notable influence of the CO_2 contained in the soil-water arises from the singular increase in the capacity of the fluid for taking substances into solution, which is afforded by the presence of this gas. Ordinary distilled or rainwater at the temperatures which prevail on the earth's surface has very little capacity for taking such mineral matters as abound in ordinary soils into solution; it will take up only a trace of lime carbonate or lime phosphate or of the ordinary salts of magnesia, iron and a number of other substances which must be brought into solution before they can be of use to plants. The charge of CO_2 which water may absorb before it enters the deeper part of the soil increases by some fifty-fold its capacity for dissolving lime carbonate and manifolds its absorbing power in the case of many other substances.

In passing through the layer of vegetable mold and the upper part of the true soil, in which there is much decaying organic matter as well as many living roots, the water encounters a set of conditions which are exactly fitted to provide it with this charge of carbonic dioxide. In the decay of carbonaceous matter CO_2 is generally formed in larger



ASPECT OF A SURFACE ON WHICH LIE EXTINCT VOLCANOES; ALSO SHOWING DETAILS OF TALUS STRUCTURE.

amounts than any other gas. The reader is probably familiar with the fact that wells and other pits which have been sunk through rich soil are likely to become filled with this gas, or what is commonly called fixed or irrespirable air. The presence of this gas frequently leads to the death of those who venture into such excavations without the simple precaution of testing the nature of the air by means of a lighted candle lowered into the pit. Among the many nice adjustments of the conditions of the earth to the needs of life we must reckon this arrangement by which the soil water absorbs a large part of its charge to the gas which renders it most efficient in its work through the decay of kindred forms.

It is a characteristic feature of water that its capacity for absorbing and retaining gases rapidly increases with an augmentation of the pressure upon it. This may be seen by observing the action of CO_2 in a common glass siphon charged with what is commonly called soda water. This fluid consists of ordinary water into which the above-named gas has been introduced by pressure. We note that while the fluid remains tightly inclosed, the gas is not visible; but on opening the stop-cock the gas may be seen rapidly to separate from the mass of fluid and form bubbles which rise at once to the surface. If the

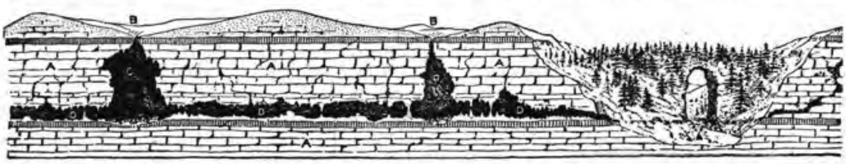


FIG. 5.—Diagram showing action of soil water in excavating caverns. *a a*, layers of limestone, easily dissolved in soil water; *b b*, sink holes by which the soil water enters the cave; *c c*, vertical shafts or domes; *d d*, horizontal galleries. The arch in the middle entrance is a natural bridge or remnant of a large cave.

passage is widened the uprush of the gas will be so rapid and plentiful that a portion of water will be driven out with it. If the escape is made gradual the gas will be seen to separate bubble after bubble until the eye readily recognizes the fact that a quantity of the CO_2, amounting in bulk to several times that of the water, has escaped from the vesse without sensibly diminishing the quantity of the fluid. By this experiment it is easy to perceive how great an amount of carbonic dioxide water, under slight pressure, may contain.

When it enters the under earth and passes thence into the subjacent rock the soil water, provided it courses through limestone, excavates caverns which are so well known in many parts of this country. The soil water gathering on the surface finds its way downward through the joints of the rocks which it gradually enlarges, forming a vertical shaft or dome; thence it creeps through galleries to its place of discharge into the open-air rivers of the region in which the cave lies. At the upper entrance of the cave a funnel-like depression is formed, at the bottom of which there is a shaft which permits the downflow of the water into the chambers below. (See Fig. 5.) These pits are often very numerous and sometimes seriously interfere with the work of the farmer. If he leaves them open the beasts of his fields are often killed by falling into the caverns. If he artifically closes the shafts, water gathers in the basin, frequently overflowing considerable areas of tilled land. The general aspect of these sink holes is shown in Plate XXII.

When the ground water enters the depths of the earth it passes into a realm where, with each step of its descent below the surface, it becomes liable, especially where the soil is wet, to be more and more subjected to heat and pressure; owing to this action it is constantly enabled to increase its charge of the gases, which aid it in dissolving substances of a mineral nature. Thus when it penetrates the underlying rock, as it often does to a considerable depth, the pressure to which it is subjected, due to the column of water above it, materially increases its capacity for dissolving limestone and other rocky matter. When it flows back toward the surface the pressure is reduced—it loses a portion of the CO_2; and as it held the mineral matter by virtue of this gas and in proportion to the quantity which it contained, the dissolved substances are in part laid down near the surface of the soil. The importance of this action in bringing upward to the true soil materials of value, which plants could not obtain by means of their roots, is doubtless very great (See Fig. 6.)

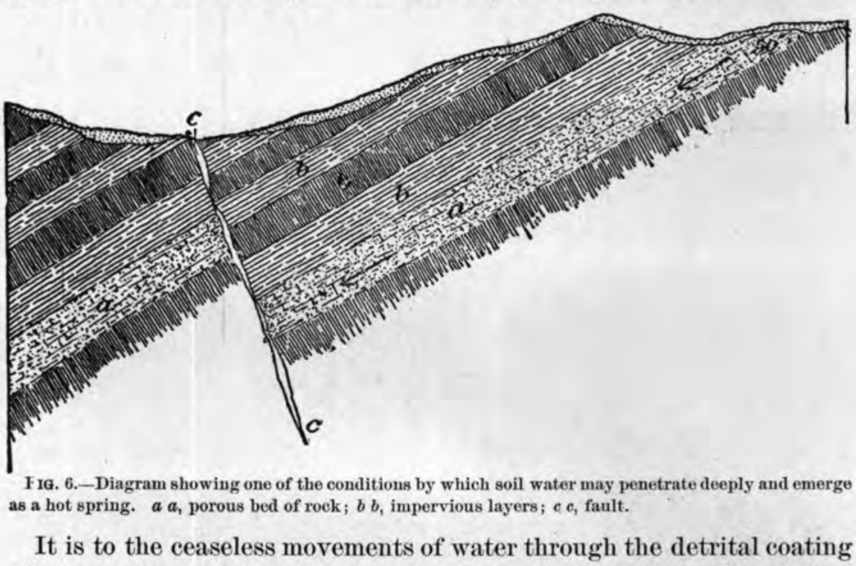


FIG. 6.—Diagram showing one of the conditions by which soil water may penetrate deeply and emerge as a hot spring. *a a*, porous bed of rock; *b b*, impervious layers; *c c*, fault.

It is to the ceaseless movements of water through the detrital coating of the earth, and the consequent solution and carriage of materials which are brought for the needs of plants into positions where the roots can feed upon them, that we owe much of the fertility of the earth. It is therefore desirable to consider another action which, combined with that just described, still further favors the process of uplifting the nutrient matter of the earth into the levels where the roots do their appropriate tasks. This uplifting effect on the ground water is brought about by the process of evaporation. When a soil is filled with water as it is after a time of heavy rain or melting snow, all the crevices of the mass

VIEW SHOWING RAPID DECAY OF LAVA.

The dead trunks in the foreground were overturned by the stream. The smooth surfaces are occupied by volcanic dust.

and the spaces between the bits of organic and mineral detritus are occupied by the solvent fluid which takes into itself a large share of the soluble matter which the neighboring earth affords. Such a time of thorough watering is apt to be followed by a season of drought in which evaporation goes on in a rapid and effective manner; the superficial portion of the soil water then passes into the state of vapor and disappears in the atmosphere. As the evaporation takes place altogether at the surface of the earth, the upper layer of soil becoming partly dry, the spaces between the grains of the material suck up the water from lower levels of the earth; this in turn evaporates and as it goes off as vapor it leaves all the mineral matter held in solution as a deposit in that part of the earth, sometimes sufficient in amount to form a crust.

It may not at first seem clear that the process of vaporizing the surface water should cause the lower lying fluid to rise to the upper level of the soil, but the action may be made perfectly clear by remembering the kindred phenomena exhibited by the wick of a lamp, which draws up the oil as rapidly as the flame consumes that part of the fluid in the upper portion of the capillary tubes formed by fibers of which the wick itself is composed. Or we may in any tree find a partial illustration of the same principle; the sap rises because the evaporation from the surface of the buds and leaves calls upon the fluid which is lower in the plant to supply the place of that which goes away as vapor, so that the whole structure becomes like a great wick in which the water is gradually drawn upward perhaps hundreds of feet above the reservoir of the soil. This analogy is satisfactory only in part, for the reason that at the extremities of the branches where growth is going on a certain movement of the sap is due to a peculiar action of cells which can not be here described, but in the body of the trunk the motion is probably caused by capillary attraction.

The energy of the attraction which the adjacent surfaces of the soil exercise upon the water may perhaps be more clearly conceived if we note the fact that if wedges of dry wood be driven into a crevice of a rock and then be wet, the water will be drawn into the interstices of the wedge with such energy that a disruptive effect will be produced so powerful that it may rive the tough stone asunder. It is in good part to this capillary process set in action by the demand which the roots make upon the soil as well as by the evaporation from its surface, that we owe the ceaseless to and fro wandering of the earth waters. These movements enable the fluid to gather into itself a great variety of substances. In its journeyings it offers the matters it has dissolved to the rootlets of plants so that they may select the materials necessary for the sustenance of the individuals to which they belong.

To this capillarity we also owe, in large part at least, the efficiency with which the soil water attacks rocks, whether those which form the massive substructure of the soil or bits which are mingled with the detrital layer. By this attraction of fine interstices of the stone water is sucked into its inner parts, taking with it the charge of CO_2 which promotes the process of decay. In this manner the soil water operates continually to break up solid parts of the earth and by the process of rotting brings them into the dissolved state from which they may pass into the realm of plant life. Thus the ground water not only acts as the intermediary between the mineral and the vegetable kingdom, but it is continually winning new materials to the state where they will serve the needs of vital processes.

It may well be noted that recent researches on the mode by which plants take in mineral matters through their roots point to the conclusion that the process of appropriation is assisted by the excretion from the underground parts of the plant of some chemical substance, the exact nature of which has not yet been determined. The true value of this assistance which the plants give in the process of taking mineral materials into solution has not yet been ascertained in a definite manner. It seems, however, safe to say that whatever be the result of further inquiry in this direction we shall still, in the main, have to attribute the fitness of the mineral material for the uses of plants to the solvent action of the carbonic dioxide contained in the water.

There is yet another physical property of water which has a great influence on its action within the realm of the under earth. This is the quality by which the materials dissolved in water are evenly distributed through the fluid. It is easy to observe that when we place any portion of a soluble substance in a vessel containing water the material distributes itself uniformly through the mass; thus, if we drop a little carmine ink into a glass of the fluid, we note that without any stirring it rapidly mingles with the mass until every part is alike colored with the dye. This diffusive action operates in the case of all substances which are really dissolved, be they fluids or gases; it acts, as we may note, through the rapid diffusion of odors more quickly in the air than it does in fluids, and more rapidly in water than in the case of other liquids.

The result of this process is that whenever ground water obtains in one part of its mass a particular material, this substance in the state of solution is gradually diffused through the adjacent earth. The process of diffusion goes on more slowly in the confined interspaces of the soil than in a mass of unobstructed water, but it nevertheless proceeds in an effective manner. In this way a small portion of the ground water which may be adjacent to mineral matter that affords the solution a substance of a nature to be useful to plants does not retain this matter in a small compass, but yields it to the neighboring fluid, and so greatly extends the chance of its coming to the roots of plants. The effect of this action is also in another way beneficial. When in contact with a particular mineral substance the ground water, but for this principle of diffusion, would take up a relatively large amount of certain chemical materials and so become poisonous to the sensitive root. If there were no influences of an equalizing kind at work the soil water would be

PROCESS OF DECAY OF OBSIDIAN OR GLASSY LAVAS NEAR MONO LAKE, CALIFORNIA.

locally so diverse in its mineral contents that the plants would not be able to obtain uniform nutrition. By the operation of the diffusive process the roots have a much better chance of doing their peculiar duty than would otherwise be afforded them.

The variations in the level of ground water have another important influence on the soil, for the reason that they bring about a constant movement of the air through the interstices of the earth. When, during a heavy rain, the openings of the débris are filled with water, the greater part of the air they contain when dry is expelled; as the fluid drains away and the water level is lowered the atmosphere is urged again into the spaces by the considerable pressure (about 14 pounds to the square inch) which it applies to the surface. Thus when the earth becomes dry the soil generally contains air to the amount of from one-tenth to one-twentieth of its mass. The next heavy rain which falls repeats the process of expelling the air, and so in succession in moist climates, many times each year, the wetting and drying of the earth pumps the atmosphere in and out of the soil coating. In this way more than the entire bulk of the earthy detritus is each season drawn into and driven out of the soil.

The effects of this action are manifold. Some of them we may profitably note. The air drawn into the soil serves to aid the roots in their process of assimilating plant food. Most vegetables can not tolerate conditions in which their roots are permanently bathed in water during the growing season. This is the case with nearly all our forest trees. A few species, like the bald cypress (*Taxodium distichum* Rich.) and the tupelo (*Nyssa uniflora*), have managed to accommodate themselves to a permanently wet earth by means of processes from their roots which give sap in those parts of their bodies a chance to obtain contact with air. These singular devices serve to show how important it is for the soil to secure the repeated visitation of the atmosphere.

Another effect of the air on the soil is to promote the process of decay in the mineral and organic matter of which it is composed. A certain amount of this change will, it is true, take place beneath the water, but in general these alterations are far less effective than when carried on in the air. Thus while vegetable matter, after life is extinguished, undergoes on the surface of the ordinary humid ground a complete decay which returns all of its matter to the state of dust or gas, the same material when buried under water only in part rots, the remainder continuing for an undetermined time in the condition of peat, lignite, or coal. The complete decay of this vegetable matter is necessary in order that the ashy material may return to the soluble state from which it can again be taken into the plants, and also in order that the carbon may combine with oxygen and form CO_2, which, dissolved in water, gives to that fluid the peculiar power of taking up mineral substances on which the utility of the soil for plants immediately depends. Moreover, were it not for this return of the carbon to the state of gas the atmosphere would soon be deprived of the material and the leaves would be unable to obtain the carbon with which they build the woody matter. Whenever the entrance or exit of the rain is so hindered that the earth does not undergo those successive wettings and dryings which characterize ordinary soils, the effect is to diminish the measure of fertility which would otherwise characterize the deposit. If the limit put upon the successive uprisings and downsinkings of the ground water be such as to keep the soil either excessively wet or dry, sterility will characterize the district thus affected, though it might be otherwise well suited for the nurture of plants.

There is possibly a third way in which the penetration of the air brought about by the alternate wetting and drying of the soil is helpful to vegetation; that is, the action of certain microscopic forms of vegetation akin to yeast plants. It is now deemed probable that some of these lowly forms separate the nitrogen from the air and combine it with potash or soda, thus forming the nitrates of those substances, of which saltpeter is a familiar example. These materials are of great value to plants as affording them nitrogen required in certain of their functions. Although this element abounds in the atmosphere, vegetation can not directly appropriate it, but can do so only through means of ammonia or combinations into which nitrogen has entered. Unless the air freely enters into the soil and is frequently changed by an enforced movement such as the variations in wetness, it seems doubtful if this process of nitrification can go on. There are possibly other ways in which these underground movements of the air affect the processes of plant life, but these which have been given are sufficient examples of its action. They may serve, moreover, to show how the methods of tillage, all of which rest upon the plan of stirring the soil, effect certain of their beneficial results. Plowing, spading, and other modes of overturning the soil are, as unlimited experience shows, essential to the growth of crops. Although these processes doubtless serve a diversity of purposes, such as destroying wild vegetation and burying organic matter which lies upon the surface, the most important effect probably consists in opening the ground in such a manner that it is penetrable by the air. The same influence is exerted in the successive tilling with plows or other tools commonly given to ground occupied by crops whose habit of growth makes such care possible.

Besides the extensive and varied work which water, in its free state, accomplishes in the soil there is a large class of effects of other sorts due to frost action, that is, to expansion by the freezing of the moisture in the soil. In all the regions where cold is great enough to congeal the ground the effects of freezing are important. At least half of the land area of the earth is more or less exposed to this action in the winter. The measure of the effect is, according to the intensity of the cold, extremely various. We find that in certain cases the earth is submitted to a freezing which may, as in the border land of the tropics,

MARGIN OF A LAVA STREAM OVERFLOWING A SOIL OCCUPIED BY VEGETATION.

amount to no more than the occasional and brief congelation of the soil to the depth of a few inches. Again it may in the frigid district about the poles cause the earth to remain permanently locked in frost to the depth of hundreds of feet below the surface, only the superficial soil thawing during the summer season. As an instance of this permanent and profound descent of the frost into the earth we may note the case of the soil at the town of Irkutsk, near lake Baikal, in northern Asia, where the freezing process has extended to the depth of over 700 feet. Not only is the depth to which the frost penetrates exceedingly diverse, but the nature of its action on soils of varied quality is likewise extremely different. It will therefore be necessary in a somewhat careful way to inspect the range of these actions which depend upon the congelation of the ground water.

When the soil water is at any temperature above the freezing point it is ceaselessly moving at rates of speed dependent mainly on the size of the interspaces in which it is contained, the successions of rains and droughts, and the steepness of the declivity on which it lies. Everywhere it is dissolving and distributing materials and yielding them to the demand of the roots. As soon as it is seized with frost all of these numerous functions at once cease to be active, the water changes all its qualities and becomes a mass as rigid as stone, perfectly inert, not only itself dead, but locking all the life of the plants in a deathlike embrace. Thus the frozen conditions mean to the soil the complete suspension of all that vast range of mechanical, chemical, and vital operations which constitute its physiology. A few of these actions we have already endeavored to trace, but the number of the operations which depend on the fluid condition of water, and which cease when it becomes solid, is vastly greater than it is possible to indicate in this sketch.

Although the effect of the soil water while frozen is to reduce the whole of the detritus to the depth to which it penetrates to an altogether inert state, the process of freezing and thawing when often repeated has a noteworthy influence on the conditions of the ground. The ways in which these effects are brought about are somewhat complicated. The process of solidification in the case of water, as in that of many other substances, is attended by the formation of crystals. Save in snowflakes these crystalline forms are not ordinarily visible in ice, but often they may be detected by pouring a thin, colored fluid upon the surface of a block of ice when it is near the melting point. The liquid will then be seen to penetrate along the planes of the crystals, thus indicating their presence, which, because of the transparency of the mass, might not otherwise be evident. The old ice of our northern rivers may in the springtime often be seen in a shattered form where it has been swept against a bank at the time when the streams break up. In such masses we may often observe the massive separate fragments, each constituting a dagger-like bit some inches in length.

Instructive examples of another effect of frost on the ground water may be seen where a sharp frost in spring or autumn comes upon wet clayey ground. The ice is often at that time developed as a thick-set mass of slender columns, which constitute a bristling coating in and on the upper part of the soil. Each of the slender bits may have a length of several inches and a diameter of a quarter of an inch or more. It often happens that we find a layer of earth and small stones which originally lay on the surface of the soil uplifted by these crowded columns to a height of several inches above their original level. With a little care the process of growth can be tolerably well observed; we perceive that separate pieces of ice begin to form between the bits of débris which cover the ground; they grow by additions to their bases due to the successive freezing of the water which the soaked earth affords as they form; they shear the earthy matter apart and rise perhaps to the height of half a foot before the morning sun arrests the process of augmentation. Owing to the open spaces between the slender shafts the ice does not hinder the cooling of the water from which they are formed as it would if the frozen mass were united in the form of a sheet.

It is a noticeable fact that the peculiar species of ice forms above described is commonly produced only in the autumn, when the ground is warm and the air cold; it occasionally though more rarely occurs in the spring, when a cold period follows one of sufficient warmth to bring up the temperature to the thawing point. The reason for this probably is that unless the soil water is moderately warm the frost penetrates the ground with such rapidity as to form a continuous ice sheet, thus arresting the growth of the uprising columns. It is interesting to note the sharp contrast between the condition of growth of this columnar soil ice and what is known as hoar frost. Hoar frost branches grow by accretions to their upper extremities from water congealed from the atmosphere; soil-column ice by additions to the lower end derived from the earth water. It is also interesting to note that this last form of ice exercises a considerable overturning effect on the superficial portions of the soil; although the action is most visible on tilled ground, it often occurs below the leaf-clad surfaces of woodlands.

The formation of ice similar to that above described but occurring in a less perfect way takes place in the interspaces of the soil as far down as frost penetrates. By this action particles of soil are slowly but violently thrust apart and ground against each other so that they are affected somewhat like grain in a mill. This process extends the commingling of mineral and organic matter and serves to make the soil material more soluble. The effect of these frost movements on the soil are not readily discernible for the reason that they go on in an invisible realm, but we can easily note a number of facts which show us something of their nature and effects. All persons who dwell in regions where the earth freezes deeply have noticed the "heaving" effect of frost upon various objects which are planted in the soil. Fence posts if their bases are not placed so deep as to be some distance below the

SUMMIT OF MOUNT VESUVIUS, SHOWING CONE OF COARSE VOLCANIC ASH LYING UPON LAVA WHICH OCCUPIES THE FOREGROUND.

zone of freezing will gradually be uplifted by the successive movements of the soil until they fall over upon the ground. They are dragged upward by adhering earth each time freezing occurs and the soil is forced to expand; when the melting time comes the thawing process, beginning at the base of the frozen section as well as at the top of the ground, releases a certain amount of débris from the frozen state and allows it to slip under the base of the post, so that when the ice is entirely melted away the timber can not return to its original position. The same action takes place in the case of stones which by natural processes may have come into the soil. The tendency of freezing is to lift them above their beds and finally to leave them on the surface of the ground. As we shall see hereafter this action of the frost is directly the reverse of that brought about by the work of plant roots and burrowing animals, which tend to remove the soil from beneath stones and to accumulate material on the surface in such fashion as to bury the masses. Where plants possess long and tapering tap-roots, such as those of red clover and many cultivated vegetables, the effect of this heaving action is often such as to throw the plant quite out of the ground. This rarely occurs to the wild species for the reason that they have adapted the shape of their roots to meet the dangers which the heaving of the soil imposes.

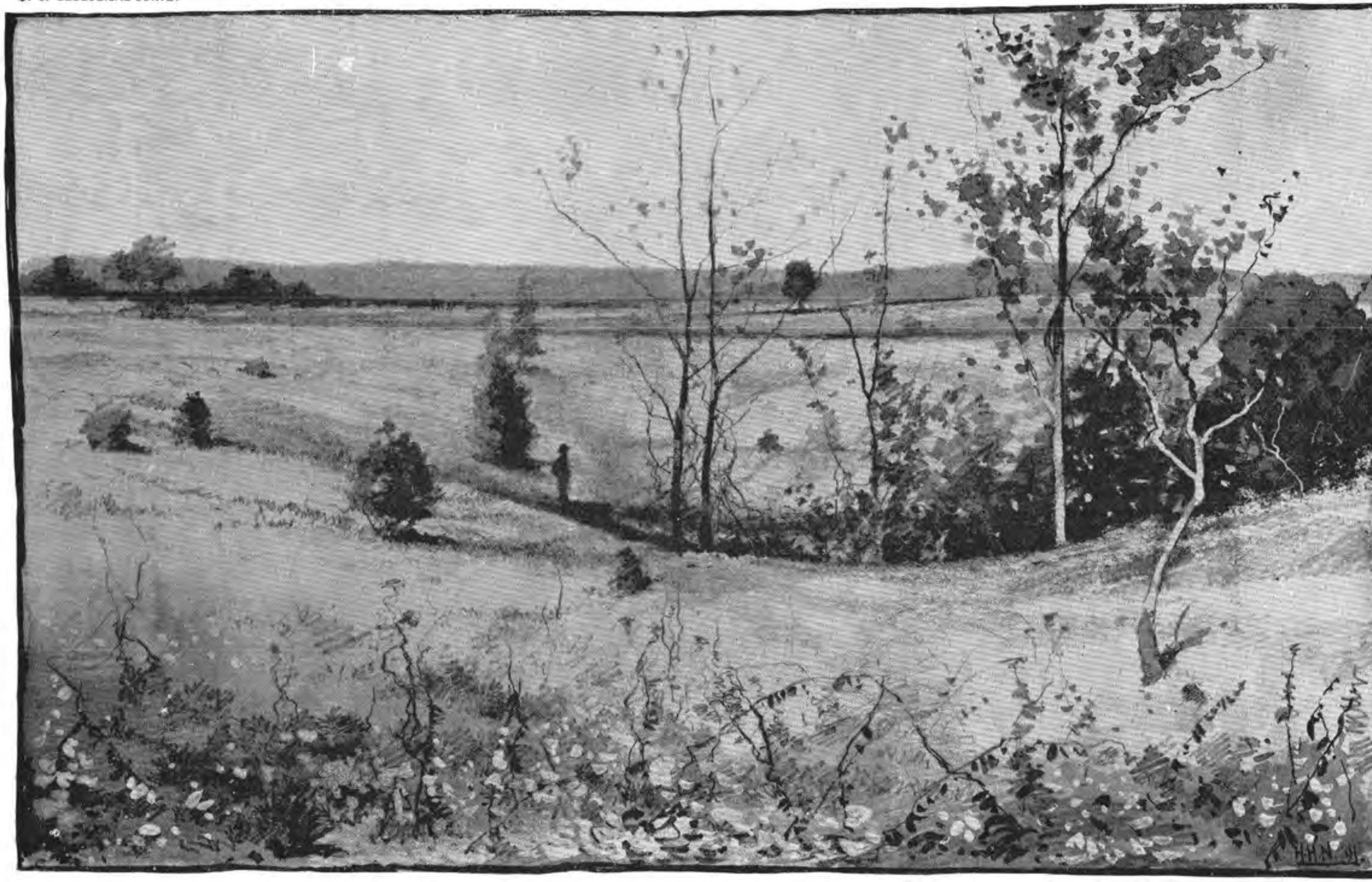
The expansive movement of the soil under the action of frost is in good part due to the fact that water, unlike almost all other substances, has the eminent peculiarity of expanding on becoming solid, the increase in bulk amounting to about one-tenth of the mass. On level soil the thrust which this expansion brings about causes an upward movement in the frozen mass; if the soil is frozen to the depth of 2 feet the rise of the surface may amount to half an inch or more. When the ice melts the particles of earth fall back into the place whence they had been driven. When, however, the surface has a distinct slope, as is the case with the greater part of land areas, the influence of gravity may lead to a slight movement of the expanded coating of detritus at the time of melting in the direction in which the surface inclines. When the frost passes away the fragments of which the soil is composed have been pushed apart by the ice crystals so that they are not in perfect contact with each other.

The reader has doubtless observed the peculiar softness of the ground after the frost leaves it. This open nature of the detritus is due to the fact that bits of earth after freezing do not cling to each other as they did before they were separated by the freezing action. Now, when on a slope even of moderate steepness, a soil thus made incoherent again settles into a firm mass, there results a slight movement of the débris down the slope, which, repeated often during the winter and year after year, causes the soil in frosted countries where the declivities are tolerably steep gradually to move downward toward the stream. From observations made in northern Kentucky I have determined that on a slope of 6 degrees inclination a deep clay-loam soil moved downward at the rate of about 1 foot in from 10 to 20 years. In some cases the creeping movement is probably yet more rapid, but in general it is doubtless, save on slopes of great declivity, considerably slower.

An important effect arising from this downward movement of soil is due to frost action. The amount of freezing is greatest in the upper part of the soil and diminishes as we descend. The result is that particles of detrital matter are shoved over each other in such a manner as to disrupt them. Something of the same action is brought about by the growth of roots. These processes of plants are largest and most numerous in the upper part of the soil. By their action the débris is pushed apart; when they die and decay, openings are left into which the soil again falls. Naturally this movement is most considerable in the direction of the declivity. At the foot of soil-covered hillsides we often find a brook the banks of which are formed of soil presenting newly cut faces. The freshness of these little escarpments makes it evident that the débris must be constantly pushing against the stream; were this not so, the steep faces would speedily break down and become covered with vegetation. Wherever frost operates it is a most effective agent in supplying to the streams the detritus which they convey to the alluvial plains and to the sea. To this action we may in part, at least, attribute the fact that in high latitudes the débris arising from the decay of the under rocks generally forms a thinner coating than in the regions nearer the equator.

Although the effect of frost in hastening the movement of detritus down the slope toward the streams doubtless in part accounts for the relative thinness of the soils in high latitudes, something of this feature must be attributed to the comparative slowness with which rocks decay in cold climates. In such regions the effect of vegetation on the mineral materials is limited to a relatively brief season, and for a considerably part of the year all rock decay is arrested by the frozen condition of the earth.

Not only does the action of freezing water profoundly affect the conditions of the soil in the ways above mentioned, it is also of consequence in the economy of the earth in several more remote ways of action, only one of which is of sufficient importance to demand our attention. This particular influence is brought about by the disrupting effect which freezing water exercises on the rocks into which it penetrates. An excellent example of this action may be seen in any slate quarry where the workmen set the seemingly solid blocks of stone in a position where the edges of the cleavage planes face the sky; water entering into the invisible crevices between the sheets of slate and there expanding, in the process of freezing, will usually in a single winter open the cleavage planes so that the flakes may be readily separated. On any cliff, or even on the rocky summits of mountains, the effect of this frost action may be seen in the great number of blocks of stone which the winter's frost has riven from the firm-set mass. In the upper portion of Mount



VIEW NEAR CAVES OF LURAY, VIRGINIA, SHOWING THE CHARACTER OF SURFACE IN A COUNTRY UNDERLAID BY CAVERNS.

The depression delineated in the foreground is a sink-hole or place of entrance of the cavern-making waters.

Washington, New Hampshire, where the rocks are scantily soil-covered and are thus exposed to freezing, the surface is so thickly strewn with these frost-detached masses that it is hardly possible on certain fields to obtain a sight of the unshaken bed rock.

The work of frost on masses of stone is by no means limited to that first stage of their disintegration which consists in riving them from their matrix. As fast as decay of any kind opens the structures of the masses the water penetrates into the pieces and in freezing them serves to break them into small bits. This process is not arrested until the fragments become so small that they are less in size than the finest grains of sand. Even where the rock has no distinct joints or cleavage planes into which the water can penetrate the fluid is likely to soak into the substance of the stone, and if its elements be not very firmly bound together the freezing will scale a layer of the material from the outer part and this thin sheet will readily fall to powder in subsequent processes of decay. This scaling process takes place most commonly in the case of rocks which have a rather open texture, such as is found in some forms of granite and in most sandstones; it is so powerful an agent of decay that many stones which in the tropics endure very well crumble to pieces in high latitudes. An instance of this frost effect is afforded by the so-called Cleopatra's needle, an obelisk which of recent years has been brought from the frostless land of Egypt to the climate of New York. Exposed to the open air in its new position the process of decay is going on so rapidly that before the end of the century the stone will probably be more effectively disintegrated than it had been in 2,000 years in its original location.

In several ways the disruption of rocks greatly aids the action of chemical agents of decay, which serve to bring rocky matter into the soluble state in which plants may make use of it. In general chemical forces act only upon the outside of rocky matter. As the particles of rock grow smaller the proportion of superficial area to the mass is increased, and this in a rapid ratio. Thus a cube a yard in size exposes 54 square square feet of surface; if divided into cubes of 1 foot each, the aggregate surface exposed to corrosive action is increased to 162 square feet. If it is broken into cubes of 1-inch mass, the material then presents a total surface of nearly 2,000 square feet; still further reduced to bits of one-twelfth of an inch in diameter, the exposed faces of the rock are increased until their surface is equivalent to about 20,000 square feet, or nearly half an acre in area. In the finer bits of earth, such as compose the principal part of the mineral matter contained in the more fertile soils, the total area of a cubic yard of rock which in the original massive form exposed an area of only 54 square feet to the chemical action which prepares such substances for solution in soil water, and thus for the use of plants, may be increased until it amounts to something like ten thousand times the original area. So far as frost action aids in comminuting the rock it is a beneficent agent of very great importance. The effect of freezing is naturally most conspicuous in the regions where the ancient soils have been removed by glacial action. In all the fields where the ice of the last glacial epoch has done its singular work of abrasion and has stripped away the ancient soils the expansive action of freezing water does much to help the restoration of the earth to the state where the higher plants can be fed. In the tropical and other districts beyond the action of the frost the process of soil-making lacks this aid, but there the generally increased rainfall and the absence of long-continued frozen condition of the earth which commonly attends frost action serves in part as a compensation for the absence of this rock-disrupting force (see Pl. x).

Before leaving this interesting portion of our inquiry, we should note the fact that the heaving or interstitial movement of the soil produced by freezing has an important influence on the ease with which water enters its mass. The action of gravity in the soil itself, combined with the weight of the winter's snows and that of the forest trees which generally cover fertile soils, tends to give to the earth a measure of compactness which is undesirable. By these actions the soil is often made so dense that the water does not easily penetrate it; when the frost leaves the ground, we find, as before noted, that the earthy matter is so open that it may contain a large amount of water which has found a place in the crevices formed by the heaving of the mass due to the expanding ice crystals. In this manner, in regions where the frost penetrates to a considerable depth, the soil is secured against the evils of excessive solidification. When the frost departs the ground is left in a state analogous to that which is given to it by the work of the spade or plow; the slender and weak rootlets which plants in the growing season put forth find their passage through the earth made easy, and the food-bearing water can easily range through the open-textured mass.

EFFECT OF ANIMALS AND PLANTS ON SOILS.

This division of our task concerns that part of the preparation and maintenance of soils which is effected by the plants and animals that by their habits are intimately related to the detrital coating of the earth. This group of results due to the action of organic life is to be classed as hardly second in importance to those brought about by the action of water. The influence of organic life on the soil is effected in a variety of ways, only the most important of which can be here considered. For convenience, these effects may be classed in the following groups:

First. The influence of organic species on the rocks from which the soil derives its mineral constituents.

Second. The modification of the soil through peculiarities in the life habits of animals and plants which occupy it.

Third. The contribution made to the soil by remains of the organic forms which have occupied it.

(1) The first of the above-named classes of action may for the present

be briefly dealt with for the reason that it will have to be again considered in some detail in the section of this paper concerning the relations of the soils to the underlying rocks whence in good part they are derived. Briefly, the facts are as follows, viz: The greater part of our rocks owe the measure of their fitness for producing good soils to the store of nutritive materials placed in them when they were formed on the sea floor by the creatures which inhabited its waters when they were constructed. The sediment of which these rocks are composed contain, in varying proportions, lime, phosphorus, potash, soda, and a host of combinations of these and other substances which to a great extent owe their deposition in the strata to the work of organic species which aided in accumulating the sediments.

(2) The immediate influence of living beings on the soil is exhibited in manifold ways; of these we shall first examine those due to the plants. When, as in the case of the lower forms of vegetable life, such as lichens, the individuals have no true roots, the effect of their growth upon the soil is purely secondary, i. e., it is due to the contribution they make by their death to the earth in which they grew and to the reaction brought about by the CO_2 which they contribute to the soil water. When, as is the case with the greater part of the plants which grow upon ordinary soils, roots exist which search downward into the detrital layer for their appropriate food, vegetation exercises a great mechanical effect upon the soil coating. Each root is, at the time of its beginning, a slender thread-like object, which extends itself through the interstices, between the bits of débris which compose the earth in which it grows. At first it has a very slight power of displacing the soil; when, however, it effects a lodgment in the crevices of the under earth and finds sufficient food to warrant its further growth, it rapidly increases in size and vigor of development. From a slender fiber, having a diameter of perhaps one three-hundredth of an inch, it may increase to be a foot or more in diameter, as in the case of our larger forest trees. In the process of growth the root, after it has gained a considerable thickness, energetically pushes outward; when it is even as much as half an inch in diameter it may exercise a powerful wedging action. By the larger roots of our forest trees the soil is often, in the course of a generation of growth, in a surprising manner moved to and fro. The effect of this movement is to grind the particles of soil against each other and thus to advance the work of diminishing their size and of making them more ready to pass into the state of solution (see Fig. 7).

When a growing root penetrates into a crevice in the rocks and expands in its further growth, the effect of its action in disrupting the mass may be very great. We may often find fragments of any kind of stone which affords plant food, especially those varieties of limestones of the richer sort, quite interlaced and shot through by the fibers. Where one of them finds a fissure and enters the mass it is almost certain to disrupt it in the course of growth. As fast as decay softens the stone and opens little spaces in the planes between the grains of which it is composed or along its joint planes, the small roots penetrate these fissures and break up the decayed portion of the mass, in this manner opening the inner portion to the access of chemical agents which promote decay. When the roots find their way down to the level of the bed rocks which underlie the soil, provided these strata are much divided by joints or bedding planes, divisions of extremely common occurrence in most rocks, the roots often find access to these incipient fractures in which the penetrating waters have already produced a certain amount of corrosion. Expanding in the crevice the roots which come first break

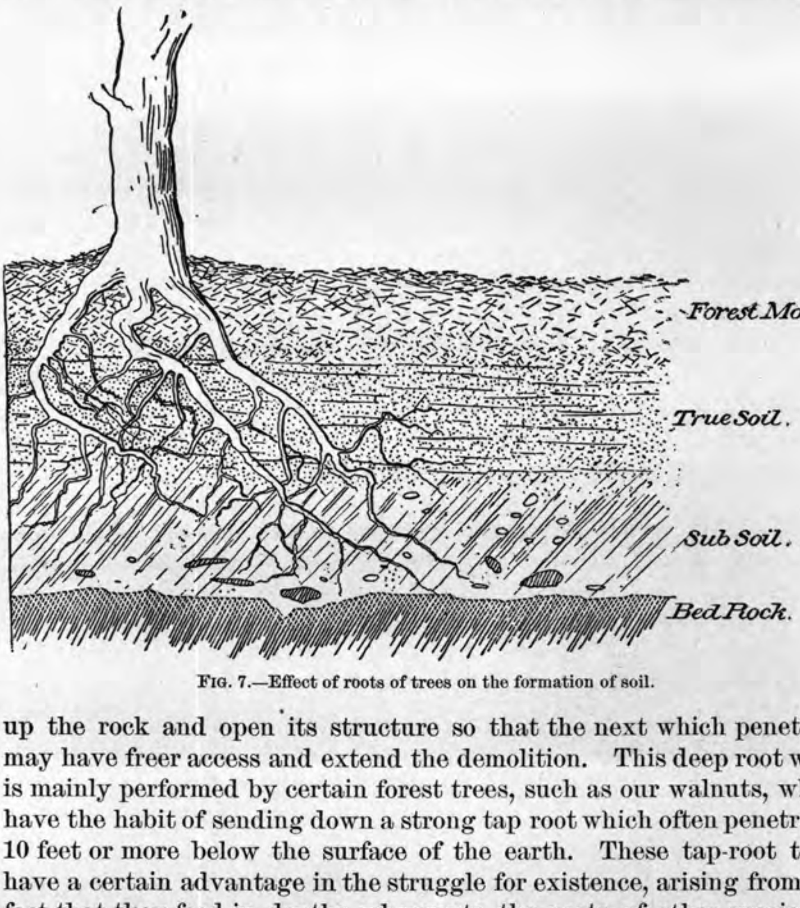


FIG. 7.—Effect of roots of trees on the formation of soil.

up the rock and open its structure so that the next which penetrate may have freer access and extend the demolition. This deep root work is mainly performed by certain forest trees, such as our walnuts, which have the habit of sending down a strong tap root which often penetrates 10 feet or more below the surface of the earth. These tap-root trees have a certain advantage in the struggle for existence, arising from the fact that they feed in depths whereunto the roots of other species do not attain, and they thus secure a field where they do not have to contend for food with a host of competitors. Where these tap-root trees grow in abundance the soil is generally deep, partly for the reason that such species flourish best on soils of this description, but in the main because they are by their habits the most potent agents which tend to disrupt the solid under rocks and give their fragments to the uses of the soil. As long as the bed rocks lie in a firm-set mass the agents which serve to rot them have little chance to do their appropriate work, for, as we have seen, the incidence of decay increases in a rapid ratio with the division of the stony matter. Serving as the roots do, incidentally, to break up the underlying rocks, they are agents operating to deepen and enrich the undersoil. They act substantially like subsoil plows.

When a district is occupied altogether by forest trees or other plants having roots which penetrate to no great depth the tendency is to divide the soil into two distinct layers, the true or upper soil and the false or under soil. The upper layer or the zone occupied by the roots exhibits that combination of decayed mineral and organic matter which we have found to be the essential elements in the construction of soil. In the lower-lying layer we have the mineral matter alone, which, while it exhibits the effects of the chemical action of the ground water, is much less easily penetrated by decay than that which is found in the true soil. The origin of this under soil is plain: its formation is due to the action of the agents of decay below the level to which the roots have penetrated; in certain common classes of rock, particularly in limestones, the chemical decay often advances downward at a much more rapid rate than the roots penetrate into the earth. We may thus have, as is the case in many parts of the country lying south of the glaciated region, very deep false or under soils, while the truly fertile layer, owing to the fact that the roots have not penetrated deeply into it, remains compact and unsuited to the uses of plants until it is artificially mingled with the vegetable waste as by subsoil plowing.

If the reader will examine any cubic foot of ordinary forest soil he will find that every part of it is occupied by the roots of trees; generally there is not a cubic inch of the mass but contains one or more of the fibers or terminal twigs of the underground branches of the tree, and often there is a branchlet of the roots in every cubic line of the mass. Many of these roots are in a way experimental; they are sent out by the plant in a reconnoitering manner to see if a particular part of the ground affords nutriment; if the search is successful they enlarge; if they fail to derive sufficient support then they die, and their organic waste is by decay added to the deposit. It is easy to observe that the open-air branches of the tree are continually dying and returning to the earth, though the plant itself may be in a flourishing condition. A similar pruning occurs in the underground branches of the roots. As these lop off, a portion of their substance decays and is absorbed by the water and yielded to other roots. It is indeed to a considerable extent to the decay of roots that the deeper part of the soil is supplied with the carbonaceous matter taken by leaves from the atmosphere in sufficient quantities to maintain the nutritive quality of the detritus. The decaying roots, when they are of considerable dimensions, serve also another curious function: as they rot away they leave open channels through the soil which sometimes extend for a distance of 30 feet or more, and occasionally, when they belong to the tap-root species, in a vertical direction for 10 or 15 feet. The compaction of the soil which is effected by the outward pushing of the root in its process of growth, especially where the earth has not been influenced by freezing, often causes these old root channels to remain open for a long time after the woody matter has dissolved away. Through these tubes the water finds a path down to the under soil, and by these means the excess of the fluid is to a certain extent removed as if by a drain pipe. In an old forest these water ways often serve the purpose of drainage in a singularly perfect manner, the water finding its way deviously but effectively from the path of one dead root to another until it escapes into an open stream.

While the roots are constantly contributing to the vegetable matter in the soil through their partial decay, the upper branches of the tree are sending down even a larger share of vegetable matter to decay in the bed of the forest mold, and at the death of the plant the whole of its substance returns to the earth. The amount of woody matter which a single forest tree of moderate size during its lifetime contributes to the earth is surprisingly great; it commonly amounts to many times the weight of the living tree at the date of its full maturity. This contribution of vegetable matter arises from the annual fall of leaves and the occasional and generally frequent dropping off of branches, and also from the exfoliated bark, which is considerable in quantity. It is safe to estimate that in the more luxuriant primitive forests, such as flourished in the Appalachian district of this country, the amount of this vegetable matter which falls to the ground each year is sufficient to make a layer of compact forest mold at least an inch thick over the area occupied by the wood. Although this process of accumulation has been going on for millions of years in the region south of the glacial belt, the sheet of decayed vegetable matter usually does not exceed a foot in depth, and even in rather moist woods, where the material is best preserved, it is rarely found more than 2 feet thick. This fact shows us that there is some process at work by which the layer of vegetable matter continually passes away from the surface of the earth.

The removal of the forest mold is accomplished by a simple chemical process. Woody matter is composed in large part of carbon, which the plants have taken from the atmosphere, where it exists in the form of CO_2. To obtain this carbon the plant breaks the gas into its elements, allowing the oxygen to go back into the air, while the carbon is built into the tissues of the plant. The lesser part of the woody matter consists of various substances, such as lime, potash, soda, iron, silex, etc., which the plant has won by its roots from the soil. The process of decay operates through a simple reversal of the chemical changes which took place in the formation of the wood. The carbon recombines with oxygen, forming once again CO_2, and the mineral substances dissolved in the rain water return to the soil and are ready to renew their work if taken up by the roots of plants. If we examine a section through the forest mold we may see every stage of this beautiful reversionary process. On the surface lie the newly fallen leaves and branches scarcely affected by decay; an inch or two lower down we find the débris which was accumulated a year ago partly rotted and breaking to pieces from decay; a little farther down we can no longer trace the original shape of the vegetable matter, and at the base of the section we observe that there is a mass of confused earthy and vegetable matter which shades downward into the true soil, where the roots do their work. It probably requires on the average not more than a score of years for the leaves and twigs entirely to pass back either into the soil or the air, so that the available matter which they contain is not long kept from the uses of life.

FIG. 8.—First effect of overturned trees in introducing vegetable matter in soils. *a*, leaf mold accumulated in pit. (See also Fig. 3.)

The intermixture of the leaf mold and the mineral matter is in part accomplished by the action of roots in the manner before described and in part by the operation of various agents which serve to bring considerable amounts of the surface accumulation into the soil. This process of inhuming organic matter is in a measure brought about through certain accidents which occur to the trees and in part by the action of various kinds of animals. When a forest tree dies by old age or disease its greater roots decay, leaving large openings extending from the surface to a considerable depth. While these cavities remain open the rains and winds bear fallen leaves and small twigs into them, and thus a certain amount of vegetable matter formed in the air enters deeply into the under earth. When a forest is overturned by a strong wind the trees, unless they be tap-root species, are commonly torn from the ground or uprooted, and thus it occurs that the soil about the base of the bole is rended away so that it lies at right angles to its original position. This mass of uprent roots is often as much as 10 feet in diameter, and contains a cubic yard or more of soil. The pit from which it has been torn is often 2 or 3 feet in depth. This cavity quickly becomes filled with vegetable waste, and as the roots decay the earth which they interlock gradually falls back upon the surface whence it came, burying, it may be, a thick layer of leaf mold to the depth of a foot or two below the surface. (See Figs. 8 and 9.) In certain parts of the country where hurricanes are of frequent occurrence the amount of vegetable waste thus buried is considerable.

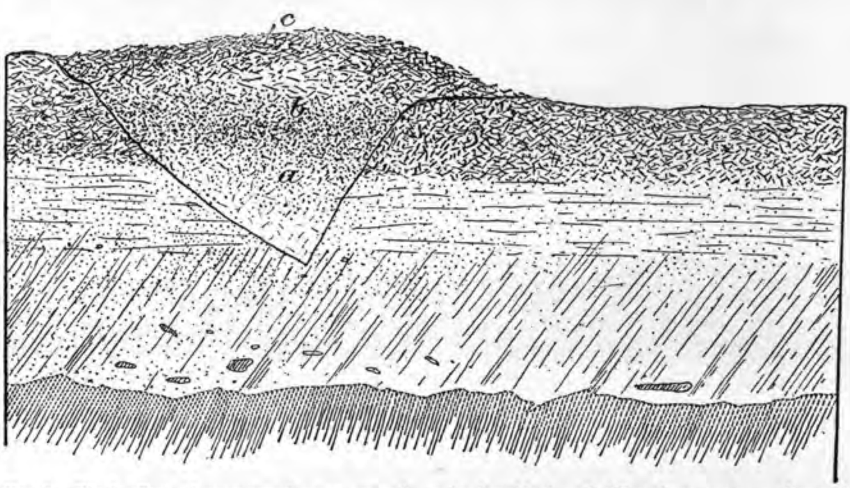


FIG. 9.—Final effect of overturned trees on soil. *a*, leaf mold; *b*, soil fallen from roots; *c*, decayed wood from roots.

By far the greater part of the work of mingling the waste from the aerial parts of the plant with the soil, at least on the upland districts of the earth, is accomplished by the action of animal life, particularly by that arising from the numerous species which burrow in the earth. So wide is the range of these actions that it would require a lengthy treatise to consider them in a detailed way. We can only note the influence which certain forms exert, and it will be convenient at the same time to consider some other effects accomplished by these burrowing species as well as their influence in introducing the vegetable matter into the under earth. We shall begin this study with the earthworms, a group which Charles Darwin has admirably shown is exceedingly effective in determining the conditions of the soil.

In common with many of their kindred which dwell on the sea floors these vermiform animals which inhabit the soil are accustomed to excavate burrows extending from the surface of the earth downward to a depth of 2 or 3 feet below the light of day. In their up-and-down journeying the creatures in part thrust the earth aside, but in larger measure they create the opening for the progress of their bodies by passing the soil through their alimentary canal. Taking the earth into their stomachs the process of digestion removes from it such nutriment as it may contain, while the remainder, nearly as great in bulk as that which was eaten, is thrown out as excrement. Every one is familiar with the casts or dung which these worms are in the habit of depositing on the surface of the ground near the mouth of their burrows when they for a little time escape from the earth. Each of these little heaps contains a portion of a cubic inch of soil which has been brought up from a depth of from 6 inches to 3 feet. As in single fields there are a hundred thousand or more individuals of these species to the acre, the amount of earth brought up to the level of the air is in each year considerable. In the regions where these animals abound they probably bring an annual contribution as much as one-tenth of an inch of earth from the underground to the top of the soil. There is thus laid upon the decaying vegetation or mingled with it in such a manner as to constantly bring the organic matter into the buried condition enough material from the depths of the earth to produce a slow overturning of the whole soil layer.

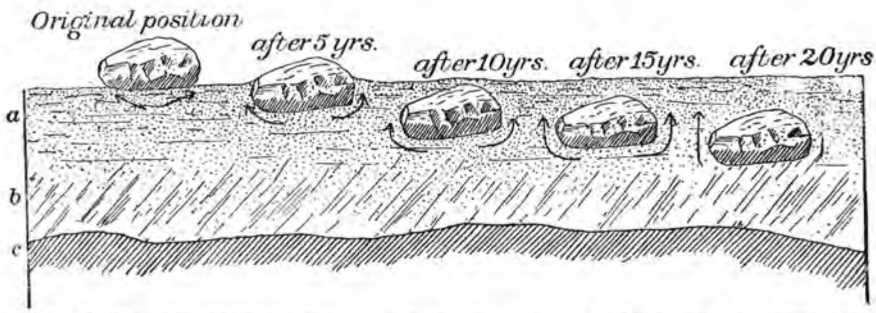


FIG. 10.—Diagram showing process by which a stone may be buried by the action of earthworms and other animals. *a*, true soil, 18 inches; *b*, subsoil; *c*, bed rock.

Although the effect of this action of the earthworms in any one season is slight, yet when continued for centuries the result is to bury all the objects of a small size which lie upon the surface to a considerable depth; ancient implements, such as stone arrow-heads which the early peoples have dropped upon the earth, are soon covered over wherever the earthworms abound. Old tombstones are gradually buried with the dust which they commemorate and even the smaller churches of England the floors of which were orginally a little above the surrounding ground, become in time so heaped about by the earth which the worms have drawn from underneath their foundations that their floors lie below the level of the soil (See Fig. 10).

The earthworms, as Mr. Darwin has admirably shown, have a singular habit of drawing down into their burrows the dead leaves which lie on the surface of the earth. In performing this work, though they are destitute of sight organs and imperfectly provided with any other kind of sensory apparatus, they exhibit a certain amount of discretion. They rarely seize on leaves which from their size or shape can not be dragged into the slender tubes which they inhabit, but they select for their use blades of grass and narrow-leaved forms, such as needles of the pines. The latter they generally lay hold of at the base where several leaves are joined together rather than at the extreme divergent point of the bunch, and in this they exhibit a certain amount of intelligence, for if they did not exercise this choice the fasicule of the blade would catch at the mouth of the burrow in such a manner that it could not be drawn downward. It is not certain what the end is which these creatures attain by this curious habit, but it undoubtedly serves to introduce a good deal of vegetable matter into the under earth.

The effect of earthworms upon the superficial detritus would be greater but for the fact that they rarely inhabit the forested parts of the country, and moreover they do not live in soils which are of a very sandy nature. The thick coating of decaying leaves in the woods evidently makes it difficult to escape to the surface in the manner which is required by their mode of life and the sandy soils contain too little nutritive matter to serve their peculiar needs. Where they do their work they are in many ways useful to the soil; besides introducing vegetable matter below the surface they greatly affect the earth by continually passing the mass through their bodies. In their stomachs they have certain hard parts which probably serve in the manner of a mill to pulverize the material. Moreover, the secretions which aid in the process of digestion operate to bring the mineral matter which they swallow into a state in which it is more readily dissolved in the ground water and thus put into the service of plants. As in the course of a century all the soil except its coarser parts is, in a field plentifully occupied by these worms, submitted to this organic process the aggregate effect on its fertility is great. The burrows which the creatures form in the earth also afford passages by means of which the water enters freely into the depths of the soil, and as this water settles down it draws in the air and so aids in that process of aeration which is favorable to the growth of plants.

The higher insects have very great influence in the development of soils, though on the whole it is less definite than that of earthworms. A large part of the multitude of species of this group of animals, particularly the beetles, for a considerable period of their life inhabit the under-earth. This subterranean condition continues while they are in the grub state, which in certain forms, as for instance in the 17-year locust, often endures for a year or more. During their tenancy of the ground they much affect its conditions by their movements and secretions. Many species of beetles while in the grub state burrow in the earth somewhat in the manner of earthworms. They devour vegetable matter and deliver the residue in their excrement to the soil; they often die under ground, and their bodies are added to the store of nutriment available for plants.

Certain groups of beetles have peculiar habits of conveying substances from the surface into their burrows where they are lodged at some depth beneath the earth. Thus the carrion species lay their eggs in the dead bodies of the smaller mammals and birds, whereby they provide for their young an opportunity for obtaining abundant food. After placing the eggs in the carrion they proceed to bury it so that it may not be consumed by other animals; the inhumation also serves to prevent the too rapid decay of the flesh. As this action goes on in forests and fields alike and in almost all countries, the soil receives a considerable amount of fertilizing materials which would otherwise be denied it.

Several species of beetles seek for the dung of the herbivorous mammals; this material they shape into balls, in which they lay their eggs. The rounded masses are often half an inch or more in diameter, and after these are shaped they are carefully and laboriously conveyed to vertical shafts which the parent insects have excavated in the earth to the depth of from 6 inches to a foot below the surface. In each of these little balls an egg is laid, the product of which is sheltered and nourished by the dung, so that the young creature is provided with a means of subsistence. A single pair of these beetles will in one season introduce into the earth several cubic inches of fertilizing material.

Although the solitary insects do a large amount of work within the soil, the principal influence exercised by this class of animals is brought about by the colonial forms, such as the ants, the ground bees and wasps, and the termites—white ants, as they are sometimes called. The greater part of the species belonging to these orders build their habitations and live the major portions of their lives in the detrital zone of the earth. They belong in nearly all lands, and are often so abundant and so active in their work that they much affect the character of soil in districts which they inhabit.

Of the forms above mentioned the ground bees are the least important. They excavate small burrows and fill their spaces with their winter stores, and a considerable part of their bodily and household waste is healthful to the plants. The shafts and galleries of their abodes, though generally protected with some skill against the entrance of water, help to provide the ways by which that fluid may enter and leave the earth. It is, however, characteristic of the bees that their colonies are never planted close together, and thus the aggregate effect of their underground life upon the soil is inconspicuous. It is otherwise with their kindred, the ants and termites, groups which often exist in amazing plenty and are found in most countries beyond the arctic circles, where the soil affords conditions which allow them to carry on their peculiar life; therefore, to this group we shall have to give somewhat special attention.

One species of social ant, the Myrmica barbata of Texas, commonly known as the "agricultural ant," appears, according to trustworthy authorities, to have the remarkable habit of clearing away the natural vegetation, or at least the slight annual undergrowth, from a bit of ground near its habitation. On this surface it plants particular species which afford nutritious grains. If the conclusions of the observers are correct, this creature is the solitary animal besides man which has invented any kind of agriculture. Singular as this habit appears to be, it is hardly more surprising than certain other customs of these curious insects. Where we find organized slavery and a well ordered system of keeping other insects, such as the aphides, which secrete nutritious juices, in well arranged dwelling places about the stems of plants on which they feed, it is hardly surprising to hear that the ants have come to a state of development in which they sow and reap. This peculiar relation of the agricultural ants to the soil is, however, limited to a small area, and is therefore without much effect on the conditions of the earth.

In general it may be said that the several species of ants dwell only where the soil is of tolerable depth and fertility and where it is at the same time of a somewhat sandy nature. They avoid the tough clay because it holds so much water as to menace the drowning of the colony. Where the soil is extremely siliceous and therefore barren, they avoid it, for in such very arenaceous districts there is a lack of sufficient food. In regions where the winter's cold is great these creatures construct their permanent habitations so that they may be lodged in chambers at a good depth below the surface, and thus be protected from the frost. In tropical countries some species of true ants, as well as the so-called white ants or termites—which are not indeed ants at all, but belong to the order Neuroptera—build their habitations altogether on the surface of the ground. Other species, such as the ordinary black ants of North America, have their dwellings partly above and partly below the surface. However varied the architectural habits of these creatures may be, and the variety in this regard is exceedingly great, they are all fashioned so as to take large amounts of earthy matter from the depths of the soil and heap it upon the surface. Thus our ordinary brown ants, which have their dwelling places entirely below the surface of the earth, may be seen after every season of rain, and to a certain extent after periods of drought, busily engaged in dragging up grains of sand from the subterranean chambers of their dwellings. This mineral matter they store about the mouth of the vertical shaft which gives access to the abode. On a field in Cambridge, Massachusetts, observations made during two summer seasons showed me that the average transfer of soil matter from the depths of the surface of the earth was in the aggregate sufficient to form a layer each year having a thickness of at least one-fifth of an inch over the area on which the observation was made, which is about 4 acres in extent.

The common species of American crawfish have, in certain parts of the country, developed a peculiar habit of boring long underground tunnels in soils which are at once of a moist and clayey nature. These openings are generally about an inch in diameter and consist of horizontal galleries occasionally extending for a distance of scores of feet and terminating at the end either in the margin of a neighboring stream or in a shaft which extends upward to the surface. These tunnels sometimes serve in a remarkably effective way to drain off the excess of soil water and permit the entrance of air into the earth—a process which, as we have heretofore seen, is of importance in the interests of plants. It seems to be commonly believed in the countries where these creatures abound that they are in some way the cause of the marshy character of the fields which they inhabit; the land they occupy is termed crawfishy and the blame for its over wet condition is laid upon the animals, although the effect of their action is often so far to remove the excessive water that the area is forest-clad instead of being a characteristic marsh.

Along the banks of the Mississippi and its tributaries, particularly those which drain into its principal affluent, the Ohio, crawfishes once abounded in great number and did good service in promoting the escape of the ground water from the clayey alluvial soil. Of late the pigs, which in this part of the country are allowed free range of the forests, have acquired the habit of feeding on these crawfish, particularly at the season of the year when they haunt the stream-beds. At such times pigs may be seen busily occupied in turning over the stones and drift wood beneath which their prey seek a refuge from their natural enemy, the water birds, but which afford no protection to these modern pursuers. The influence of this destruction of these natural drain-makers appears to be already visible in the increased wetness of many tracts of low-lying alluvial soil where trees once flourished, but where they are now dying out from excess of water.

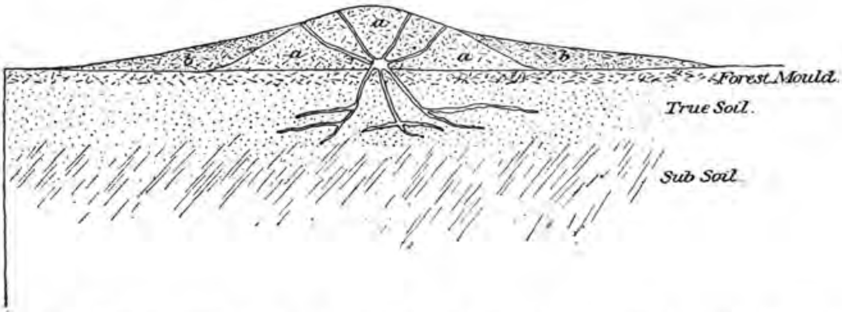


FIG. 11.—Effect of ant-hills on soil. *a a*, sand accumulated in hill; *b b*. material washed from hill. mingled with vegetable mold.

The effect of this transfer of material from the lower levels of the soil to its surface is perhaps even greater in the case of the larger species of the insects known as termites which build dwellings in part or in whole above the level of the soil. The edifices erected by the termites are often 10 or 15 feet high and a score or more feet in diameter. Although composed of earthy matter mainly taken from below the surface, the hillocks formed by our common black ants which abound in the temperate regions are not uncommonly from 18 inches to 2 feet in height and of a diameter of from 4 to 5 feet. In the case of this familiar species, the earth brought up from below becomes much intermingled with leaves and twigs which may fall upon the hills from the neighboring forest trees. (See Fig. 11.) As the mass of these hills is of very incoherent material, it is subject to a constant washing from the rain water, and so the material is gradually distributed over a wide circle about the elevation. In some cases the sand accumulated in the hill amounts to as much as 2 cubic yards in volume and when distributed by the water it is of considerable thickness over a radius of 5 or 6 feet from the center of the hill. Where these structures are numerous, as they are in certain districts in the United States, by their constant deposit of matter on the surface of the ground they bury a good deal of vegetable waste in the soil; at the same time the animals are constantly conveying into the earth large quantities of organic matter which serves them as food and the waste of this, including the excreta of the animals themselves, is of considerable importance in the refreshment of the soil.

One of the most curious effects arising from the interference of the ants with the original conditions of the soil consists in the separation of the finer detritus from the coarse mineral elements of the detrital layer. I long ago had occasion to observe that in certain parts of New England, where the sandy soils had not for a long time been exposed to the plow or agents of tillage, certain fields were covered to the depth of some inches by a fine sand without pebbles larger than the head of a pin, while the deeper parts of the section, say below the level of a foot in depth, were for a foot or so further down mainly composed of pebbles of various sizes with little finer material among them. This distribution of materials was not to be explained by the supposition that the original deposition led to the peculiar arrangement. It was easy to see that the ancient order of the deposits must have been disturbed by tillage, but it was clearly accounted for by the action of the ants. These creatures to the number of tens of thousands on an acre are during each season of activity industriously occupied in bringing the fine sands and tiniest pebbles to the surface, thus taking away small movable bits from among the coarser pebbles which they could not manage to move. It is evident that this process would in the course of a century bring about just such an arrangement of the fragmental matter as we need to account for. (See Fig. 2.)

In general, the work of ants in the sandy soils resembles that of earthworms in the clayey ground; both these groups of animals serve to bring lower parts of the soil to the surface where it is more rapidly subjected to the decay brought about by atmospheric action. As it is fine materials which are best fitted for the duties of nourishing plants, it is an advantage to the plants to have them brought near the top of the ground, where the roots of ordinary vegetation may seize upon them. In the work of the ants, however, we do not have that peculiar effect due to the characteristic habit of the earthworm, which takes the soil into its digestive ducts. Nevertheless, because they are much more widespread than their lower kindred, these insects in the aggregate produce a far greater influence on the soils.

Among vertebrated animals are a hundred species or more which by their habits modify soil conditions. Although the number of kinds in the backboned group of animals which occupy the soil is probably not the fiftieth part as numerous as the list of insects which live for a time or altogether in the realm of the under-earth, and the number of individuals is, it may be, not a ten-thousandth part as great, yet owing to their relatively large size, the ground-haunting vertebrates exercise an influence on the soils which is perhaps quite as great as that of all their lower kindred. This work of the vertebrates is effected in a great variety of ways: by burrowing in the earth, by storing vegetable matter underground, by overturning the surface of the soil in a search for food, and incidentally by the contribution of their excreta during life and their bodies after death, they greatly affect the conditions of the earth.

Some of the reptiles have the habit of boring in the earth, but their excavations as compared with those made either by the insects or mammals are of small importance. The most considerable work is done by the various species of tortoises, which generally have the habit of going under ground for winter quarters, and also to a certain extent in their search for food, such as grubs. The large tortoise of the southern part of the United States, commonly known as the gopher, makes considerable excavations, the exact purpose of which are not well known, though they are accomplished with much labor. All of our serpents find in the winter a refuge under ground, and although this is generally in some decayed root or beneath a sheltering stone, the effect on the earth is of some importance, because they frequently perish in their winter retreat.

A number of species of birds have the habit of burrowing to a certain extent in the earth. A great part of these, however, use the earth only as a place of shelter in their nesting time. The prairie owls, commonly credited with the habit of burrowing, appear usually to usurp the excavations formed by the so-called prairie dogs. It is not likely that the owls have any share in the formation of the excavation which they frequently inhabit. The bank swallows usually build their nests in a layer below the level of the true soil in places where a stream has exposed a steep face of the earth. The excrement of the parent birds and of the young contributes a considerable amount of material to the earth in which they dwell, and this store of nutriment may be sought by the roots of the trees which grow in the superincumbent soil.

It is, however, only where the birds resort to some districts for breeding purposes that they considerably influence the character of the soil. When, a few decades ago, the passenger pigeons existed in the Mississippi Valley in very great numbers, they had the habit of nesting in a gregarious manner, millions of them occupying the same tract of wood. This area of timber they possessed for 2 or 3 months while they reared their young. Feeding through the forests over a wide range of country, and often extending their search for food for 20 or more miles in every direction from their roost, these swift winged creatures, able to fly at a speed of 60 or 80 miles an hour, supplied their young with food conveyed in their crop and spent the night at the nesting place. The quantity of the excrement voided by these birds on the ground beneath the trees in which they nested was very great; at the end of the season it often formed a layer of guano-like material over a district perhaps a thousand or more acres in extent. The result of this action was after a few years to provide the under earth with an important store of plant food; at times the quantity of this material was so great as to destroy the lesser vegetation by the manurial salts which, although of utmost value to plants, can not be tolerated by them in excessive quantity.

Where these birds resort in great numbers to a shore for breeding they are sure to contribute a large amount of plant food to the soil. If the rookery be thinly occupied, as is generally the case with the eider duck and some other water fowl, the sufficient but not excessive manuring may produce a rank vegetation which shows that the soil has a profit from the contribution; on the other hand, if the birds be crowded together, the quantity of dung is generally so great as to destroy all vegetable life. When the breeding place is in an arid country, such as that wherein lie the guano islands of the Pacific Ocean or the Caribbean Sea, the accumulation of organic waste, dung, dead birds, egg-shells, etc., is so great in quantity that it can not be in any degree absorbed into the soil, but slowly accumulates and forms a coating which may in time attain the depth of scores of feet. Although this deposit can not in its pure state sustain any vegetable life whatever, it affords in the guano of commerce the very best material for refreshing soils which has been worn by tillage or for stimulating plants to very swift growth.

Of all the vertebrate animals the mammals are the most effective in their influence on the soil. Some hundreds of species have the habit of burrowing in the earth and most of these forms spend a portion of their lives under ground. It would require too much space to trace the extended variations of this habit in different species: we shall therefore only note its effects in the case of a few of our American forms. The larger part of our burrowing mammals belong in the two groups of moles and rodents or gnawing animals. Of these the moles are most interesting, because of their peculiar ways and the consequences of their underground habits. The moles include the only mammals which have adopted a purely underground habit of life and which, although they occasionally come to the surface, are not compelled to emerge from the ground for any organic purpose. They dwell for the most part in the upper layer of the soil where they subsist mainly on insects. They are accustomed to seek their food by extensive journeys through this superficial portion of the earth which can easily be displaced by a burrowing motion. They find their movements easiest and most profitable in the layer of soil which lies just beneath the roots of the grass and other lowly vegetation, for there they can make their way partially by pushing the earth behind them by the movements of their short stout legs and partly by uplifting the surface in the familiar ridges which to the eye mark the paths they follow. A single mole will in one season break some hundred feet of these ways beneath the sod. Where they find an abundance of food they will form a network of open passages, so that the solidity of the earth is materially affected by their action. Between these selected feeding grounds, in which they wander deviously, they form longer and straighter passages, utilized year after year in their journeys to and from their regular haunts.

The effect of the movement of moles through the soil is to stir the upper part of the layer somewhat in the manner in which this is effected by the plow or spade. Sometimes for a season this action appears to harm the plants whose roots are near the surface, yet on the whole the delving work done by these creatures appears to be eminently profitable to growth. It stirs the soil about the roots and favors the entrance of the air.

There is, however, another effect from the mole burrows which is not so advantageous. We have already noticed the protective action of vegetation which serves to greatly diminish the erosion accomplished by rain water upon the incoherent matter of the soil. The mat of superficial roots and the coating of decaying vegetation makes it difficult for the water to gather into distinct streams and yields the fluid gradually to the large brooks. When a mole burrows beneath the layer of mold, or the roots of the sward descend a steep incline, the water is likely to enlarge the channel so that it becomes open to the day and may develop into a deep ravine. In this manner the moles in certain districts favor the degradation of the soil coating and their action in this regard is often extensive and important. Owing, however, to the large part which these creatures play in the destruction of insects that prey upon the roots of plants, as well as to their activities in stirring the soil and opening it to the air, their general influence must be regarded as beneficial.

The greater part of the rodents—an order which includes more species than any other order of mammals—to a greater or less extent dwell underground; by far the greater portion of these, however, unlike the moles, derive their subsistence from the overground vegetation or from the roots of plants, resorting to the earth mainly for protection from their enemies or from the winter's cold. Some of these, as for instance certain species of field mice, dwell almost altogether beneath the surface, resorting to the open air only for such food as the plant roots fail to afford them; others, such as the hedgehog, habitually resort to their burrows in summer only for sleep, although in winter they occupy them during a period of some months. In certain parts of the country, notably in regions where weasels and other small predaceous mammals are absent or rare, the species of field mice exists in amazing plenty. Thus on the island of Marthas Vineyard, Massachusetts, the wild mice are so abundant that brushwood areas, often acres in extent, are completely honeycombed by their burrows, and many species of plants whose bark affords nutritious food in winter are almost extirpated by their attacks. All these species of rodents which dig underground shelters have a notable influence on the soil; they drag out the earth which fills those places and heap it at the mouth of the openings, and in this way they turn over a great deal of the soil and mingle the vegetable matter with the mineral material. A burrow affords an easy and extensive passage for rain water, and when the occupant deserts it it becomes filled with decayed leaves and other vegetable waste, and thereby much organic matter is mingled with the earth.

The underground habits of field mice serve to hide the measure of their activities from even the observant eye. A good conception as to their numbers and the extent to which they may affect the earth may be formed by a simple observation which can readily be made in any region where the snow accumulates in considerable drifts. It is the habit of these creatures to resort to the surface of the earth beneath the snow banks, especially where these accumulations lie upon grassy ground. Gathering to the number of hundreds in these parts of the surface where they are well sheltered from the cold by the thick nonconductive covering, they construct an amazing tangle of burrows cut in the sod and roofed by the snow. These excavations seem to be made in a certain order, mainly to procure the food which the roots of the plants afford. In certain places, particularly in the Berkshire Hills of Massachusetts, I have observed that, in addition to the narrow runways, each wide enough for the admission of one individual, they also make considerable clearings, sometimes as much as a foot across, which seem to serve as assembling places, where, crowded together, they may indulge their social instincts and perhaps help each other by their mutual warmth. Where field mice are abundant the skillful observer may with a little care in removing the superficial coating of vegetation disclose the burrows thus formed. These usually lie in the upper 6 inches of the earth, and are often so abundant that over extensive fields no square foot can be found which is not intersected by them.

All the species of wild pigs have the habit of uprooting the upper part of the soil layer in their search for seeds, nutritious roots, and grubs. Where these pachyderms abound they turn over the top soil often to the depth of several inches in a singular way, and by so doing they mingle decayed vegetation with earth. One individual of this group will in a year turn over an acre or more of any ground which tempts him to exercise his strength upon it. Various other mammals and some birds also have the habit of scratching or pawing the earth to obtain food. Some species wallow in the mud or in dry soil, seeking thereby to kill the insects which infest them. Various forms of the larger herbivora have the habit of resorting to dry ground, which they toss up into the air with their feet so as to dust their bodies with the powder. The stamping grounds of the ancient bison or buffalo of this continent were once frequent and conspicuous features in the regions which they inhabited, and the beasts can still be traced, even in Kentucky, from which they were driven more than a century ago, in the fields thick set with the curious ragged pits long ago excavated.

While we are considering the beneficial effects upon the soil brought about by animals which have the habit of conveying fertilizing matter to the earth or of overturning it, we may note the partly injurious influence which the beaver exercises in the country where it abounds through its curious custom of building dams across streams. When this continent was in its primitive state these rodents, the largest of their kind, occupied with their habitations the valley of almost every small stream of tolerably gentle declivity. At each of these beaver lodges there was a barrier or dam a few feet high which they constructed across the brook. This held back the waters of the pond, which had an area ranging from a few square rods to many acres in extent. On the line of a brook these dams were often placed one above the other in tolerably close order to the number of dozens. The result was that a great deal of the level land near the water ways was inundated when the white man came to the country. Until these creatures were extirpated or driven to seek secluded places by the incessant pursuit of hunters and so were forced to give up the habit of dam-building and until the structures which they had erected had been removed by decay or by the hand of man, it was almost impossible to journey through many valleys which are now moderately dry. The influence of the dam-building habit of the beaver was not altogether prejudicial to the soil, for the reason that while the swampy places they created were unfavorable to soil-making, they served to restrain the descent of the flood waters, and thus in a measure spared the greater rivers the inundations to which they were subjected after these industrious creatures were expelled; moreover, their reservoirs served to retain the soil materials brought down by the mountain torrents and thus diminished the waste of the precious material to the sea.

All the vertebrate animals of the land when they die leave the precious store of nutriment contained in their bodies as a heritage which is sooner or later to come to the soil; in the greater number of cases this waste immediately goes to satisfy the hunger of other wild animals, but the smaller forms are generally buried by the carrion beetles and the bones of all are left to decay on or in the ground. In time these hard parts are dissolved by the water and conveyed to the roots. The quantity of nutritious bone dust which is thus contributed to the earth is, when measured in terms of geologic time, very great. If all the skeletons of vertebrates which have thus gone into the soil since the close of the last glacial period had remained upon the surface they would probably cover the land with a layer of bony matter some feet in depth, but the return of this material is so rapid and constant, that it is rare that the observer remarks the presence of bones in the wilderness places.

Before leaving these considerations as to the effect of organic life on the soil, we must study the action of certain peculiar groups of lowly creatures known as bacteria, forms which are classed as of a vegetable nature and which are in general somewhat related to the ferment of common yeast. It is only of late that naturalists have begun to investigate the members of this group, for they are among the least visible things of the world; yet it is already determined that they play a very large part in the life and death processes of organic bodies. It is now known that they are the cause of most malignant diseases; they are also active in the process of digestion. Recently their operations in the physiology of the soil has received some attention; it has been found that they exercise an important influence on its economy. Thus the processes by which the nitrates of potash and soda are formed in the soil is believed to be due to the action of bacteria. The precise chemistry of the action is not yet well understood, but this is not a part of our inquiry. The result is of the utmost importance to the soil processes, for the fertility of the latter depends upon it to a considerable extent. In regions of ordinarily abundant rainfall these nitrates, being very soluble in water, are rapidly removed from the soil. While the solution is passing by the roots of plants the nitrogenous matter is seized upon and the rest escapes through the streams or else, by decomposition, is returned to the air. When, as in the arid lands of southern Peru and certain other parts of the world, the rainfall is only enough to nourish these creatures and not sufficient to leach away the nitrates, they accumulate and form a deposit so large in quantity as to be of great economic importance. Like other materials we have mentioned, which in small quantities are very helpful to plants, but in excessive proportions are very hurtful, these nitrates destroy the fitness of the area where they abound for the ordinary uses of vegetation. These nitrous soils are the source whence are derived the salts required in the manufacture of gunpowder as well as in many other important arts.

The supposed influence of the microbes in the production of nitrous soils is a matter of great interest, for the reason that thus far no other explanation as to the ways in which the nitrogen of the atmosphere can be brought into this form has been found. Should it be clearly proved that this important action is due to organic life, it will add greatly to our conception of its work in the processes of the earth.

In this further discussion of the soil problems it will be necessary somewhat to repeat the discussion of certain points which have previously been considered. As the points of view are different from those taken before, it will be better to restate some of the facts here than to refer the reader to the previous sections of this essay.

We have now considered, at least in a general way, the effect of animals other than men on the formation and preservation of soils. Our own species has in its civilized condition invented a set of relations with the earth the like of which do not exist in the case of any other being. It will, however, be well for us to consider the effect of human agencies on the soil coating after we have completed our study as to the geological phenomena which influence it. In this domain of our inquiry which now concerns us there remain for presentation the conditions dependent on the passage of water through the soil and those arising from the varied nature of the rocks from which the mineral elements of that coating have been derived. We have also to note the diversity and character of the earth due to the extent to which the materials of which it is composed have been derived from rocks immediately underlying the particular area or have been, as is the case with alluvial deposits, brought from a distance by the action of various transportative agents. These questions will form the subject-matter of the next chapter, and will complete our rapid study of the general physiology of soil deposits. It should here be noticed that so far our inquiry has concerned only soils whose mineral parts are directly derived from rocks which lie beneath a given area. We have now to consider certain classes of soil deposits which are of a different origin.

EFFECT OF CERTAIN GEOLOGIC CONDITIONS ON SOILS.

When the soils of a country outside of the glaciated districts lie upon bed rocks of gentle slope the mineral materials of which they are composed have generally been derived from deposits immediately beneath the surface. Although a considerable part of the soils of the earth belong to this group of accumulations of nearly horizontal attitude and therefore of immediate derivation, the larger part of them are more or less affected by the presence of substances imported from a distance, and probably much more than half the total soil areas of the earth have their mineral detritus composed of materials which have journeyed from afar and so may be classed as deposits of remote derivation. In this class come all the glacial soils the mineral matters of which have always been conveyed from a considerable distance. Here we must also place the whole group of soils which have been formed by the floods of rivers bringing sediments from the torrent portion of their drainage systems to the lower part of the valleys in which they lie. All this transportation, except the small amount which is affected by winds, is substantially due to the action of water either in its frozen or fluid form descending from the highlands to the sea. This carriage of soil detritus is accomplished by the action of solar energy, which is applied in the form of heat in the manner already traced. In most cases this carriage is effected by fluid water, but it is sometimes brought about by glacial ice.

GLACIAL AGGREGATION.

When the transportation of rock detritus is brought about by ice and the materials are deposited in the form of till or bowlder clay, the result generally is that the mineral components of the soil are in their chemical nature far more varied than where they are derived from rocks which lie immediately below that layer, because the ice carriage is effected under conditions which tend to mingle on a single square mile of surface the detritus worn from an area of ten or more square miles. On the other hand, where the glacially transported detritus has at the end of its journey been assorted by water, as is the case with much of the drift, the sorting action usually gives a singularly uniform character to the detritus found in any particular area. We then note that the material which the vegetation seeks to convert into true soil consists in the main of pebbles of sand or of clay, each with but trifling admixture with the others. The result is that the unassorted bowlder clays, even where very stony, generally afford fertile fields moderately well fitted for the needs of a great variety of crops and quite enduring to tillage. These bowlder clay soils are apt to have a fair share of all the elements which are demanded by plants. On the other hand, the stratified drift, because it is composed mainly of one kind of rock material, often affords nothing like the variety of constituents required by varied crops.

In New England, where the white settlers at first selected stratified drift areas for tillage for the reason that they were not encumbered with bowlders, it was soon found that such sandy soils, though easily made ready for the plow, were quickly exhausted and could be brought to yield fair crops only by extensive fertilizing. The greater part of these sandy soils have been abandoned, and people have resorted for plow land to the areas which are underlaid by bowlder clay. Such fields, though stubborn and demanding a great deal of labor to clear away the bowlders, are very enduring to tillage, because by the slow decay of their pebbles of varied mineral constitution there is constantly yielded to the soil something of the substances required by the different crops. The observer readily observes the fertilizing effect arising from the decay of bowlders in the soil indicated by the belt of exceedingly fertile earth accumulated in the form of a narrow strip around the base of the great erratics in New England pastures. We have already noted this feature in a previous chapter, but it is worth reiterated attention.

ALLUVIAL AGGREGATION.

Another class of soils of remote derivation is found in alluvial plains which border nearly all true rivers. The history of this group of detrital deposits is so important that it should be traced in some detail. To understand the formation and the physiology of alluvial soils we must begin our inquiry in the torrent sources of the river and observe what takes place in these fields where the débris of which alluvial deposits are composed is broken from the bed rocks. In this mountainous section of a river system we find that the slopes bordering the streams are generally very steep and bear but a scanty coating of detritus. Owing to the action of frost, rain, the expanding roots of trees, and of other inorganic and organic agents which aid gravitation in urging the incoherent mass down the incline to the channels of the stream, this mountain soil covering is in tolerably continuous motion toward the torrent beds. When the slopes are very steep the movement is often sudden, in the manner of avalanches or landslides; when the descents are less precipitous the motion is gradual but inevitably to the same end. At the base of the converging slopes which form both sides of the mountain valley the torrent is ready with its swift currents flowing down the steep slope to seize on all the detritus which is brought within its grasp; it urges the débris downward to the lower levels of the country. Unless the fragments of stone are very large they are hurried down the declivities in the times when heavy rains have swollen the brooks; beating against each other and against the rocky bed and sides of the channel the débris is constantly reduced to fragments of smaller size and thus becomes more readily transportable. In nearly all cases, however, the diminution in the size of the fragments is less rapidly brought about than is the reduction of the carrying power of the stream, which diminishes with the decline in the declivity of the descent. It is asserted by those who have carefully studied the subject that the capacity of a stream for conveying fragments of stone is in proportion to the sixth power of its velocity; although this is perhaps an excessive estimate, it will serve to show how rapid is the diminution in the ability of a stream to convey coarse detritus when its current is much slackened. (See Fig. 17 and Pls. XXIII and XIV.)

As the torrent emerges from the higher parts of the mountain district, where its rate of descent has generally been from 100 to 500 feet to the mile, and comes among the foothills of the range its fall usually diminishes to from 20 to 50 feet to the mile. The consequence is that the speed of flow of the water is rapidly slackened and it can no longer urge forward stones which it easily bowled down the steeper slopes whence they were riven.

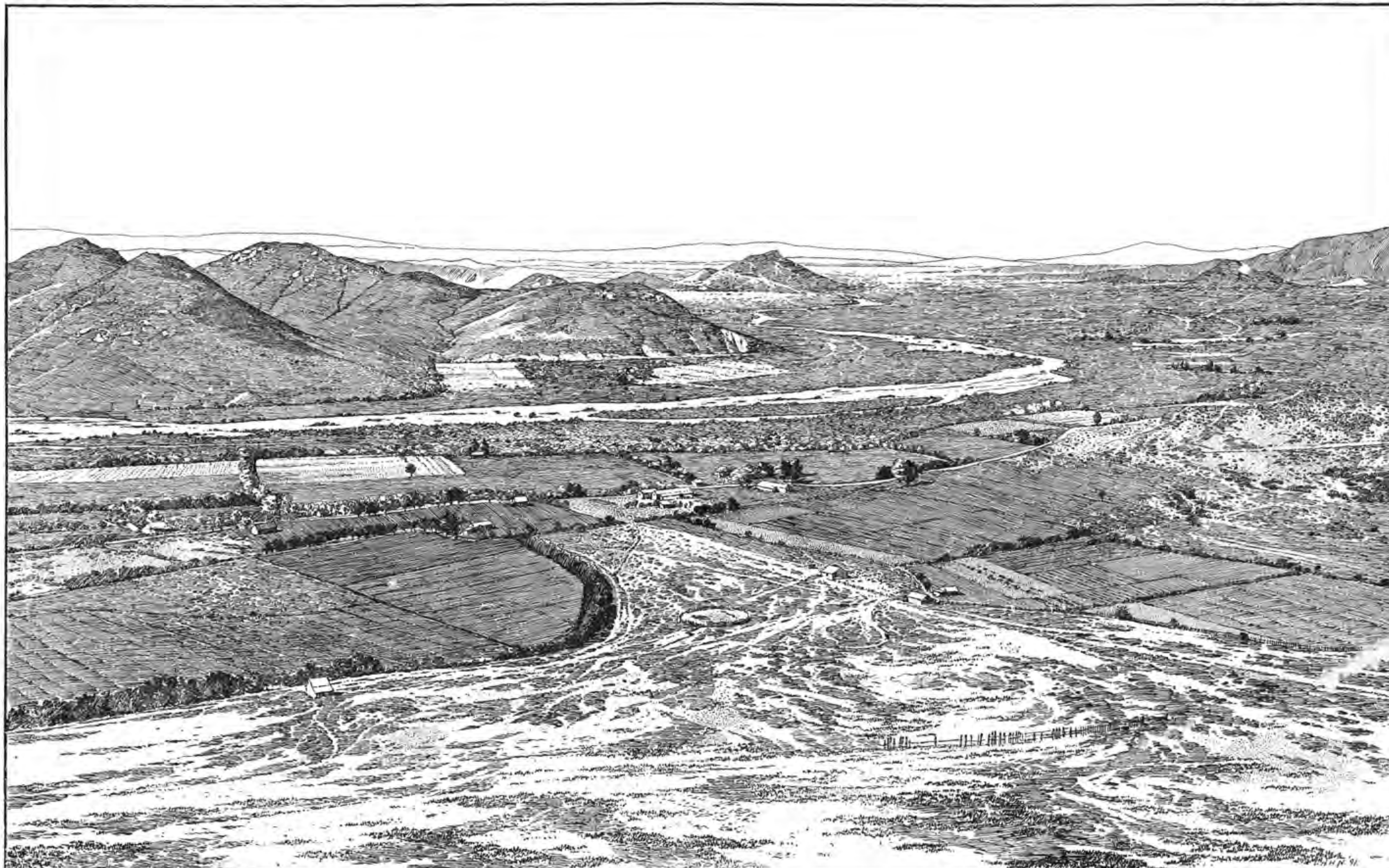
We can note the growing incapacity of the stream to dispose of the débris which it bears if we follow down any mountain torrent until its waters pass out upon the plain land where lies the river system into which it discharges. In the steeply descending portions of its upper path there is no margin or border of débris which is at rest on either side of the stream. Except here and there where some large mass of rock has become wedged in a narrow channel, all the materials on the mountain slopes and in the bed of the torrent are in times of flood in more or less motion toward the lower levels. When in descending we come to where the valley widens and the speed of the waters is lessened we notice that the larger stones even in the flooded state of the brooks are left stranded on the side of the channel where the current is less swift. If there be space for the accumulation between the stream and the neighboring steeps these fragments that are too large for the current to carry onward will form a little margin or terrace, the surface of which speedily becomes occupied by vegetation. Examining this mass, we find that it is essentially composed of large stones more or less rounded, the interstices to a certain extent filled with smaller pebbles and sand. This finer material has been lodged in the spaces when the waters have risen above the surface of the rough plain. (See Fig. 12 and Pl. XXV.)

Following down the stream, which, owing to the constant lessening in its rate of fall, is rapidly diminishing in the energy of its flow, we find that these detrital plains usually increase in extent, and are composed of finer and finer materials the farther we pass from the torrential system. When we attain to the true river section of the drainage where the

FIG. 12.—Section through the coarse alluvium formed beside a torrent bed. *a*, terrace.

stream flows smoothly with a descent of from 6 to 18 inches in a mile, the alluvial plains usually widen and exist on both sides of the channel: here we find the débris to consist of very fine gravel, coarse sand, and clay, the latter being in relatively small proportion. If the lesser river finally passes into one of the greater streams, such as the Mississippi, we observe that there is a progressive diminution of slope as we approach the sea until the decline amounts to no more than about half a foot to the mile. In this part of the river system the alluvial fields are very wide and the detritus of which they are composed is very fine grained, the greater part of it almost impalpable mud, and the few pebbles which occur rarely in size exceed a tenth of an inch in diameter. (See Figs. 13 and 14, and Pl. XXVI.)

The student who is observing the alluvial plains quickly notices that these masses of detrital materials are in constant course of destruction and renovation through the action of the river which built them. On the convex side of the great sweeping curves through which the stream marches the speed of the water is slackened and a portion of the sediment held in solution is laid down in the shallow water next the shore. Generally this débris is deposited in time of flood in the spring of the year. No sooner do the waters recede than certain plants of swift growth, which find their appropriate conditions on the verge of the river, extend their roots through it and cover it with their thick-set



BROAD ALLUVIAL VALLEY IN A MOUNTAINOUS DISTRICT, THE AREA PARTLY IMPROVED BY IRRIGATION DITCHES.

stems, and thus bind the new-made land firmly together. By this action a single flood may add a strip of land to the margin of the convex shore having the width of some score of feet, a length of several miles, and a depth of a foot or more. The next rise of the waters may find the willows, cottonwoods, and other water-loving plants growing thickly over the surface of the new-formed ground. The turbid water entangled among the stems has its current slackened, and another deposit of alluvium is laid down. Thus in the course of ten years the terrace may have risen to the height of 10 or 15 feet, and may be so far united to the general mass of the river plain that the process of its growth and its recent origin are not discernible. (See Fig. 14.)

When land is making on the convex side of the bank where the current is relatively slow, it is commonly wasting on the opposite side of the river against which the stream is impinging with swifter motion. Here it cuts away the alluvial matter which it has laid down in some previous state of its history. As the material falls into the flood many of the fragments formerly deposited because they were too large to be carried any farther in the waters at the speed attained may be observed to fall to pieces, owing to the chemical decay which has come

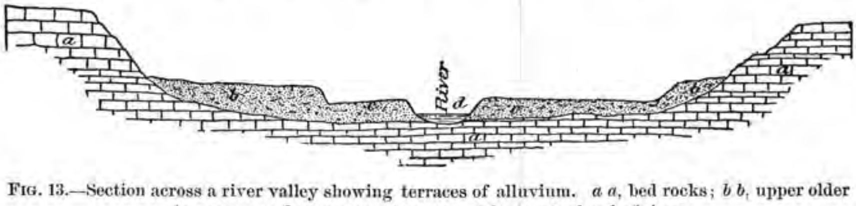


FIG. 13.—Section across a river valley showing terraces of alluvium. *a a*, bed rocks; *b b*, upper older terraces; *c c*, lower newer terraces; *d*, low-water level of river.

upon them during their repose in the alluvial plain. Much of the finer matter is so far oxidized that it can readily be taken into solution and borne away to the sea. The insoluble fragments are carried farther down stream until they attain a place like that before described, where they may again be built into the terrace. In this manner, cutting away the alluvium in one place and building into the bank at another, the river gradually swings to and fro over the whole width of the valley floor, slowly but continually destroying and rebuilding its marginal plain. Inasmuch, however, as in most cases the stream is steadily deepening its bed, portions of the old plain are occasionally left on the side of the valley above the level to which floods attain; sometimes these terraces lie at a considerable height above the latest level of the water, even in its time of flood. (See Figs. 13 and 14.)

The total area of these alluvial soils on this continent is probably over 200,000 square miles; of this the greater part is subjected to occasional overflows, not sufficient to destroy its value for tillage, and a small portion, perhaps one-tenth of the whole, consists of terraces not liable to inundations. The physical conditions of this interesting class of soils formed on alluvial plains are peculiar. Like glacial deposits, they fall into the class of materials which we have termed of remote derivation, that is, they are, for their mineral ingredients, not dependent on the bed rocks which underlie them, but are in this regard conditioned by the nature of the deposits in the upstream districts whence the river drains. In any one acre of alluvial soil on the banks of the lower Mississippi we may reasonably believe to lie some bits of matter which have been derived from every considerable field of the surface drained by the river above the point where the deposit lies. Thus, as regards their mineral materials, and to a certain extent also as regards their organic matter, river deposits are more composite in their nature than those originating in any other manner. Like glacial soils, they represent the waste from over a considerable area, but for the reason that the ice sheet, at least in its continental form, moved in a somewhat rectilinear manner while the streams of fluid water flow convergingly, alluvial plains have generally drawn waste from a far wider field than the glacial accumulations (see Fig. 14).

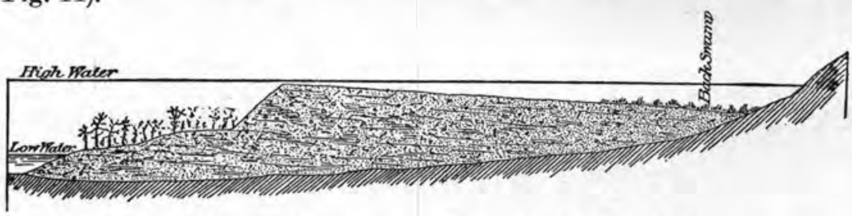


FIG. 14.—Section across alluvial plain on one side of a large river.

While glacial waste, owing to the lack of oxidizing agents in the ice or in the water which is produced by its melting, is generally undecayed, the material deposited by the river is usually somewhat advanced in decomposition when it is laid down. The conditions of this deposition tend to bring about a mingling with the mass of mineral matter of much vegetable and some animal waste. These interbedded organic materials, as we have already seen, serve greatly to promote the changes which lead to the solution of mineral matter in water, and its appropriation by the roots of plants. We may indeed consider these deposits of river-borne waste as admirable natural laboratories in which the great work of dissolving mineral substances is carried on. The gases engendered by the decay of organic materials favors this rotting action, and the porous character of the deposit permits the rainwater to pass freely through it. By so passing the water brings the soluble materials into a condition in which they may be appropriated by plants or flow forth with the drainage into the neighboring stream and thence to the sea.

Alluvial soils, at least when first subjugated, have in general a high average fertility. The variety in this regard is greatest in the deposits formed beside the banks in the headwater district of a river system, for in these situations the local peculiarities of rock in particular districts have a dominating influence on the chemical nature of the mineral

VIEW OF A MOUNTAIN VALLEY, SHOWING THE BEGINNINGS OF THE RIVER ALLUVIAL PLAINS.

elements of which the terraces are composed. In such an alluvial district as that of the Lower Mississippi, where the detritus represents an average of the waste from the whole of the great valley, there is naturally a greater uniformity in the character of the materials; yet even in this district there is a certain diversity due to the sediments brought in by the tributaries which join the main stream near the site occupied by the alluvial fields.

Soils of this nature are also liable to modifications due to a variety of special conditions. Where covered by vegetation, as is usually the case, and where visited by floods in the rainy season of each year, the current of the turbid water, having been checked by the resistance which the friction of the vegetation offers to its motion, deposits a layer of fine mud on the surface and thus affords refreshment to the soil. When a similar flood passes over open lands the motion may remain so swift that the most of the fertilizing matter suspended in the water will be carried forward, and only the coarse sand deposited, which is of little value to plants. In general, however, alluvial lands have proved themselves to be the most continually and largely productive of all the soils which have long been taxed by tillage. This endurance to the demands of agriculture is doubtless to be attributed to the great depth of the thoroughly oxidized materials which compose these deposits, to their horizontal position, which insures them against the risk of washing away, and to the fertilizing inundations which frequently visit then.

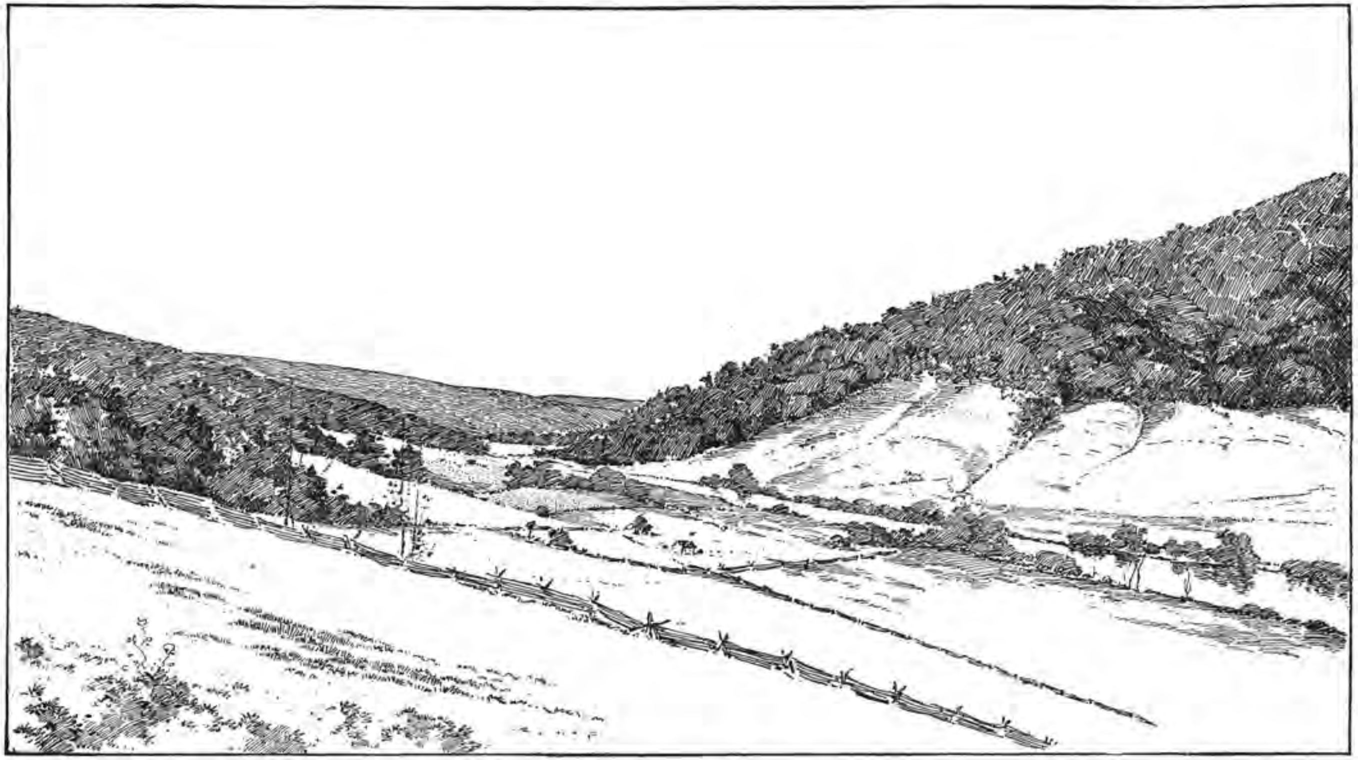
We shall now turn somewhat aside to consider the action of the water, which, after performing the important underground work which we have traced in preceding chapters, escapes from the soil, joins the streams, and passes in them to the sea. We have seen that all organic life depends upon the peculiar capacity which water has for taking a great variety of substances into solution. It is hardly too much to say that the truly vital parts of animals and plants are solutions containing that portion of the soil which is in condition to enter into living forms. The frames of such animals are built up of material which has passed or is ready to pass into the dissolved state. The insoluble portion of the soil mass is essentially without effect on life, except as a reservoir of water and a laboratory where the materials are preparing for the state in which they may be vitalized.

When rain water departs from the soil it bears away with it more or less mineral matter. Evidence of this may be had by the simple experiment of completely evaporating a pint of water taken from the rain before it has touched the earth, and at the same time another equal quantity from any spring which drains from an ordinary soil. At the end of the experiment we find that the rain water leaves little or no residuum except possibly a few bits of matter which, floating as dust in the air, has been caught in the falling drops, while the soil water leaves a layer of sediment on the bottom of the vessel. Analysis shows this material to have been derived from substances in the soil. A familiar instance of this action may be seen in a teakettle the water of which is supplied from a spring or well; after a time a crust will be found in the bottom, composed of the mineral matter originally held in the water, which has gone away in the form of steam.

The mineral matter dissolved in the soil is first offered to roots which in most cases plentifully interlace the path along which it escapes to springs and thence to streams. Each year the share of rain water which finds its way into the soil, amounting on an average to about 2 feet in total depth, goes through that layer and flows to the sea after gathering a considerable share of mineral matter. The amount of solid material suited to the needs of plants which is thus each year withdrawn from the land and given to the ocean is very great. It is probably in any one season nearly as much as is taken from the soil and built into the vegetation of the forest, and even that which enters the vegetation is but temporarily beyond the reach of this danger, for when the plants decay the mineral material is again ready to be dissolved.

At first sight this great excurrent tide of fertilizing material may seem to be a most unfortunate feature in the economy of the earth, but on closer consideration we find that the apparent loss is not real; the process, indeed, when considered in a large way, is seen to be of a conservative nature. The mineral matter which is taken from the earth by the percolating ground water is first turned to good account in supplying the roots of plants; when it has served these needs it is necessary that it should be drained away, for it would become charged with a deleterious excess of substances which are taken into solution, and which, if retained in the soil, would be injurious to vegetation. An instance of this is familiar to persons who have kept plants in pots. It is well known to all who have had the care of potted plants that it is necessary to provide for the ready escape of the water from the vessels. Some of the effects of an insufficient passage of the water through the soil may be observed in swamps, and will hereafter be noted in connection with observations on the arid land of the Cordilleran district and other places where the rainfall is not sufficient to provide the normal current of water through the soil. Although it is necessary for the plant to have a certion amount of mineral matter in the water which bathes its roots, any excess of such material appears to prove poisonous. When the water becomes saturated with the substances it may dissolve, even to the extent to which the sea is so charged with such materials, the effect on plants is generally destructive.

When water escapes from soil into rivers and goes thence to the sea it bears with it the mineral matter which it has in solution, and on entering the ocean becomes mingled with a great store of such substances which the deep holds in its keeping. We are in part made aware of this charge of dissolved mineral matter by the evident salinity and hardness of sea water. In this great storehouse of ocean it has been found by careful chemical tests that there is a share of the mineral substances



BEGINNINGS OF ALLUVIAL TERRACES IN THE UPPER PART OF THE CUMBERLAND RIVER VALLEY, KENTUCKY.

contained in soil water. In fact, practically all the elements which exist in appreciable quantities in the crust of the earth and a great variety of the compound substances which enter into organic forms, such as lime carbonate, potash, soda, etc., are known to exist in a dissolved state in the ocean waters. It is probable that in them is contained a variable proportion of every element which exists in the earth. From this great reservoir of the sea the marine plants, each after its kind, extract substances, appropriating them through their fronds in the same manner as the land plants take their share by means of the roots in the soil, but perhaps in greater variety. It may again be noted that, as sea weeds have no roots, the whole of their surface serves for this purpose of absorption, whereas in land plants the roots alone have this power of appropriation.

Sea weeds, like land plants, are mediators between the mineral realm and the animal kingdom. Animals are altogether incapable of taking mineral substances directly from the water; they appropriate them only at second hand, by feeding on the vegetation or on other animals which have obtained them from vegetation. Although at first sight marine plants appear, on account of their usually small size, to occupy a limited place in the sea, the volume of their life is vast; they grow rapidly, they appropriate mineral substances which are brought to the ocean waters, and so feed upon the materials which are placed in solution through the action of the land vegetation. Thus in a simple and tolerably direct way the removal of mineral matter from the soil serves to provide marine life with the necessary basis for its development.

There are other and important, though remoter, effects arising from this vast and ceaseless transfer of the minerals of the earth to the sea. The marine plants and some of the animals have the habit of appropriating large quantities of special substances, such as iron, lime, potash, soda, etc., and even particular metals, such as silver; and on certain fields of the sea floor, where the remains of marine vegetation are built into strata, the sea weeds form deposits remarkably rich in these elements which they appropriate during their lifetime. Thus the coral animals build great islands in the ocean and vast fringing and barrier reefs along the shores. The limestone of these creatures is derived from the store of that material which is dissolved in the land waters, mainly by virtue of the carbonic dioxide arising from decaying vegetation, and which is brought by rivers to the sea. In each cubic foot of this lime of the coral reefs it is likely that we could find, if we had the means of ascertaining the facts, one or more molecules derived from each of the river basins of the earth. So incessant has been this process of change that it is also probable that every cubic foot of limestone now lying in the beds exposed on the land contains elements which in their previous wanderings have journeyed through every sea, which have been in turn built into strata in all the quarters of the globe.

When animals possess, as many of them do, the habit of secreting in their skeletons or shells such important substances as lime phosphate, perhaps the most necessary of all the soil substances to the development of crops, the beds which are formed of their remains often afford most fertile soils. Thus in central Kentucky, where the soil of the country has an uncommon fertility and endurance to tillage, its quality is mainly due to the presence in the limestone beds which underlie the area of certain layers peculiarly rich in phosphoric acid. Some of these strata, from a few inches to a foot in thickness, contain from 10 to 20 per cent of lime phosphate, and as these portions of the horizontally lying rocks decay the fertilizing material is carried down the slopes of gently inclined hills and, dissolved in the soil water, is made free to all the plants. (See Fig. 15.) It is hardly too much to say that in each kernel of which wheat or other grain is temporarily stored the molecules of lime

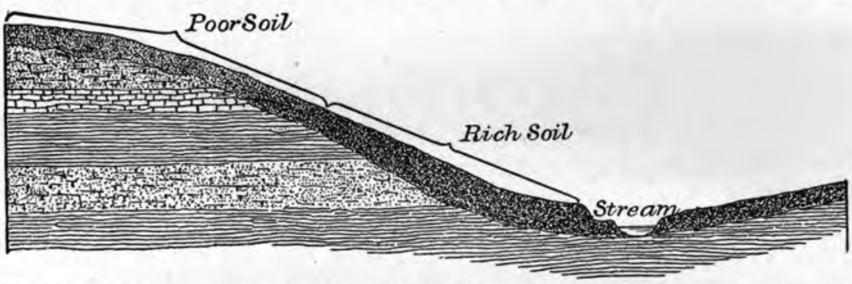


FIG. 15.—Diagram showing the effect of a layer of rock yielding fertilizing elements to soil. *a a*, sandstones; *b b*, clay slates; *c*, limestone yielding fertilizing materials.

phosphate which have been brought together by the action of animal or vegetable life on the sea floor. Our civilization in good part rests upon the grains we win from the field. It would not be possible, therefore, to maintain the status of higher men without the compact and nutritious foods which we thus obtain.

In the above considerations concerning the origin of soil fertility we have naturally found our way to a division of the subject in which we are to consider the effect of the diverse character of underlying rocks upon soils which are formed by their decay. The range of facts which will have to be explored in order to make a survey of the whole of this field is so great that it will be necessary to limit our undertaking to certain characteristic instances which may serve as types of the condition, leaving the reader to make his own application of the principles we thus acquire to the particular cases which he may need to explain. First of all we note the fact that the classification of soils as regards their mineral constituents into those of immediate and those of remote derivation, while true in a general sense, needs a certain amount of qualification.

OVERPLACEMENT.

Almost all soils except those on very level plains have derived their mineral parts in some measure from the rocks which do not lie immediately beneath their site. In the glaciated districts as well as those

OX-BOW SWING OF A RIVER IN AN ALLUVIAL PLAIN: THE GANGES, INDIA.

covered by river alluvium the transportation of mineral elements is from distant points and is in a way complete. In other soils, which may in general be accounted of immediate derivation, where the surface has a considerable slope, a certain migration of the detritus is brought about by the slipping of loose earth over the surfaces on which it lies. As already noted, this action is tolerably constant and may lead to journeys of the disintegrated rock for distances of a mile or more. Distinct evidence of this movement may often be found where a hilltop is capped by some layer of enduring rock, while its slopes are underlaid by a looser deposit, such as clay. In such a condition of the surface we often find masses of the capping layer which have separated from its steep face and have slowly journeyed down the incline below until they have attained the bed of the neighboring stream. (See Fig. 16.) It is easy to prove that these masses, which are often many hundred cubic feet in contents, have journeyed slowly over the distance they have traversed and with a very uniform motion, and not suddenly, as in the manner of a landslide. Examining the procession of blocks, we see

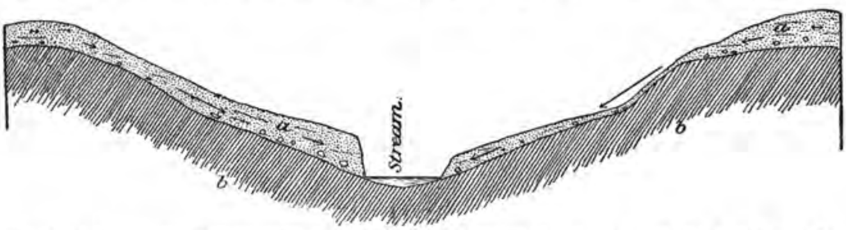


FIG. 16.—Diagram showing the direction and the rate of motion of soil. *a a*, soil; *b b*, bed rock. The arrows show by their relative length the rate of movement at various points.

that they have not been overturned, but that they generally lie substantially in the position of their original bedding. We also note a gradually and progressive decay of the fragments as they lie farther down the slope. Near the cliffs whence they came they have sharp faces and are very little decayed; a few hundred feet from the escarpment they are more rounded and the decay has penetrated deeper; near the stream they are often so rotten that when they actually attain the torrent bed they are easily broken up by its swift-moving waters. These facts confirm the conclusion that the whole of the soil layer is in gradual motion down the slope on which it lies. In this movement it is impelled by gravity abetted by frost action, the expansion of roots, the overturning movement of uprooted trees, and the burrowing work of a host of animals.

Excellent examples of this movement of soils down the declivities bordering a stream are afforded by the descent of blocks of stone from the hilltops in almost all districts where horizontal strata underlie the surface of a country. It is indeed usual in such regions for the harder layers to crown the elevations, for the simple reason that such beds, by resistance to decay, determine the position of the hilltop. Perhaps the best instances of this in this country are exhibited in the region occupied by the Millstone grit or the thick conglomerate which lies at the base of the Coal Measures. These beds often rest upon shales and form steep cliffs, such as are found along the western escarpments of the Appalachian coal field. Fragments from these cliffs, sometimes as large as an ordinary house, may be observed journeying down the inclines to the streams. They often bear trees and are surrounded by and partly imbedded in the soil. Less conspicuous instances of the same nature may be traced in almost any upland country south of the glaciated region. (See Fig. 17.)

Besides the migrations of mineral matter brought about in this manner, there is on steep slopes a constant movement of substances held in solution by the ground water. This water, creeping down the hill with its charge of dissolved material, serves to qualify the character of the nourishment afforded to plants by the substances extracted from the immediately subjacent rock. It thus often happens that the presence of a layer

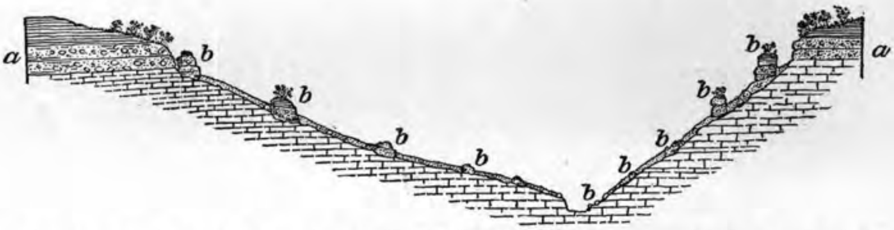


FIG. 17.—Diagram showing progress of fragments down a slope to a stream. *a a*, bed of hard rock; *b b*, fragments moving down slope.

of fertilizing material near the summit of a slope will serve to enrich the soil for a great distance down the incline. Thus in central Kentucky the layers of phosphatic limestone, even though their fragments do not slip down the hill, will be found to have effected the fertility of soil derived from rocks barren of nourishment which lie farther down the declivities in which the enriching layers outcrop. In this way, though the particular beds which afford the important mineral element may be so soft that they yield no fragments to the detritus below their level, the effect is almost as valuable to plants as where they contribute to the visible débris. It is a fact worthy of note that owing to this movement of materials down the slope the substances derived from a particular kind of rock may affect the soil at some distance below the site of the layer rather than that which immediately overlies the bed; the outcropping edge of the rock deposit may itself be covered to a considerable depth by the barren débris derived from beds which lie higher up the declivity. The mode of this action is indicated in Fig. 15.

Where, as in the case of hillsides sloping steeply toward the stream, the motion of the soil is rapid and the torrent at the base sufficiently powerful to wash the débris away as fast as it comes to the channel, the soil material may be so speedily removed that it does not accumulate in a thick layer, and so the chemical processes do not have time to bring the débris into the state where it may be taken into solution. Such slopes are often in the main covered with a rubble of angular fragments, mingled with a little true soil, which supports a scanty vegetation, the condition of the débris showing plainly the lack of sufficient time to bring the rock waste into the finely divided state in which it may be appropriated by the roots. If in a valley exhibiting these conditions, which may be said to be normal in mountainous districts, as well as in many countries where the hills are steep, we penetrate to the headwaters of the stream, where its dwindled torrents are not able to bear away the detritus which marches down the slope, we find very different soil conditions. In these "coves," as they are termed, the soil is often very deep and of great fertility.

In the state of nature the difference between the soil in the lower and the upper parts of a mountain valley is often attested by the character of the forest growth; on the rubble-covered hillsides, where débris is rapidly removed and therefore always shallow and imperfectly de-

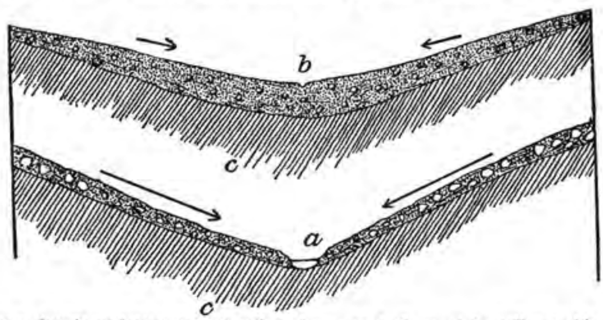


FIG. 18.—Diagram showing relative state of soils in lower part of mountain valley and in the "cove" at its head. *a*, section of lower part of valley; *b*, section of upper part of valley; *c*, *c*, bed rock. The relative size of streams is indicated by the section of the beds. The arrows show by their relative length the proportional speed of the soil movement toward the streams.

cayed, stunted red and black oaks and rigid pines mainly possess the field, and to the expert eye attest the barrenness of the earth. In the coves, however, black walnuts of gigantic size, tulip trees with their great boles, and other plants which grow only in deep and well decayed deposits of detrital matter show an entire change of soil conditions. If the land in the valley be cleared of its wood and cultivated we note an equally sharp contrast in the crops which it bears. On the steeper slopes, washed at their base by permanent and powerful streams, the fields afford only scanty pasturage and generally after a brief trial they are again abandoned to the natural growth, while in the coves the soil often proves excellent for the culture of grain, tobacco, or other exhausting crops. The reason for this fertility of the cove soil is to be found in the fact that the smaller streams, having near their headwaters but little cutting power, are unable to convey the detritus away as rapidly as in the lower parts of the valley; the débris thus has time to be comminuted by decay and converted into fertile earth. The difference between the above-described conditions is diagrammatically indicated in Fig. 18.

Without discussion it will be evident to the reader that where the underlying rocks of a district are in the horizontal attitude the soils will be much more uniformly distributed than they are where the strata are tossed about by the irregular movements which take place in the formation of mountain chains. In such disturbed regions the different beds often stand at high angles to the horizon, and the distribution of the débris from them is naturally extremely diversified. Thence it comes about that in a country of great mountains, such as Switzerland, where the population is dense and the people are driven to search carefully for every bit of tillable soil, small patches of earth of excellent fertility are often located in districts which are prevailingly unfit for tillage. Each of these bits of remunerative soil is usually due to the peculiar nature of the rock which is exposed to decay at or near the place where the fertile field exists. Wherever the beds which afford these conditions are by the twistings and breakings of the strata subject to the action of the atmosphere it is likely to give rise to the existence of similar patches of fertile soil. It often happens that when the outcrop of rocks is too steep to permit débris to remain upon its surface the materials falling to the base of the precipice will gather into a talus; there, broken to fine fragments by the violence of their descent, this rocky matter may afford the basis of an excellent soil. Many of the best vineyards and fields of Switzerland and of other mountain countries are upon slopes of this nature.

Owing to the fact that land in this country is still low priced, but few of the mountain taluses have been subjected to tillage, and therefore the peculiarities of soil which are due to the slipping of materials down the slopes of mountains have not been made the subject of inquiry. With advancing culture, however, it is certain that we shall have to imitate the peoples of the Old World and seek every opportunity to utilize rich lands, however limited in area or difficult of cultivation. When this stage of our national development arrives thousands of talus slopes in the Appalachians and the Cordilleras will richly repay care. Soils of this description are particularly well suited to vineyards. They serve also very well for orchards and generally for tree plantations of every description, and this for the reason that the stronger rooted plants, such as the vines and timber trees, are able to send their underground branches to great distances through the rubble in their search for an appropriate food supply.

INHERITANCE.

We have now to consider a peculiar feature in the history of soils derived from rocks upon which they lie, or at least from a place no farther away than the upper part of the slope on which they rest. It is evident that the continued wearing to which soil materials are subjected leads to a rapid deportation of their mineral materials, either by solutional action or by the direct cutting away by streams. The rate of this removal of soil can be quite accurately gauged by estimating the amount of water discharged from the mouth of a stream which drains a valley and determining the amount of mineral matter which it contains for each day in the year. This task has been approximately accomplished for all the great rivers of Europe and for the Mississippi in this country. The rate of the downwearing of the land, according to the diverse inclination and other conditions of the area, varies from about 1 foot in 800 years in some of the rivers which flow from the Alpine district in Europe to about 1 foot in 7,000 years in the Mississippi valley. Taking the world over, the lands are probably wearing down from the action of the rain at the rate of about 1 foot in from 3,000 to 5,000 years, the variation in the rate of erosion being due to the amount of rainfall, the steepness of slope, solubility of rock material, and other influences. The range in the measure of the action is doubtless great; it probably extends from 1 foot in 500 years to 1 foot in 10,000 years or more. In some rare instances, as in the very dry and rocky districts of desert lands, the rate of erosion may be even slower than 1 foot in 20,000 years. Although the subsidence of the surface may seem to the reader exceedingly slow, as indeed it is when measured in terms of human history, it is in a geological sense of a moderately rapid nature.

To appreciate the effect of this process of lowering the land surface through the action of ground water and streams in bringing about a downward migration of the soil we may consider the condition of that part of the Mississippi valley which has probably been above the level of the sea for almost all the time which has elapsed since the close of the Carboniferous period. It is likely that the section of the great continental valley, which includes the upland country of West Virginia, Kentucky, and Tennessee, has thus been in the condition of land through the ages from the end of the Coal-Measure time to the present day. This great interval can not well be reckoned at less than 10,000,000 years; it is indeed more likely that it represents nearly twice that duration. Although the rate of erosion in the Mississippi valley, considered as a whole, is at present not more than sufficient to lower the surface to the amount of 1 foot in 7,000 years, it seems likely that the rate of downwear in that portion of the valley which we are now considering is as rapid as 1 foot in 4,000 years. Assuming that the present rate of wearing is substantially that which has on the average prevailed since the region was finally lifted above the sea level, we find that in 10,000,000 years the original soil surface must have been lowered by the amount of 2,500 feet.

It should be clearly understood that the computation given in the previous paragraph is intended only to afford a very general idea as to the probable rate at which the downwearing of the surface of a country goes on; the average rate, as assumed, may have been several times greater or very much less than that indicated. It is not improbable that at various times in the geologic past the speed with which this surface has been worn away by the elements has been sometimes far swifter and again much slower than it is now.

At first sight it may seem extraordinary and hardly credible that such a great amount of rocky matter has gone away from this district; there are, however, many evidences which point to the conclusion that not less than this great thickness of beds has, under the processes of atmospheric decay, disappeared from this part of the continent. Among the many considerations which serve to substantiate this conclusion we may note that the coal fields of the Appalachian were undoubtedly continuous across the table land of central Kentucky where Silurian strata are now exposed. This is shown by the fact that the flinty and other enduring débris of these wasted beds are plentifully intermingled with the other soil materials which lie on the flat hilltops of this country in positions where it has been protected from the assault of the streams. The total thickness of this destroyed section can not well have been less than 2,000 feet and may have much exceeded that depth. (See Fig. 19.)

It need not be supposed that the region we are considering ever had a surface 2,500 or more feet above the sea level; it is more likely that

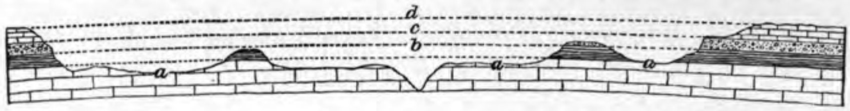


Fig. 19.—Diagram showing the successive variations of fertility in the soils of central Kentucky during the downward movement of the rocks. *a, a, a,* parts of the present surface enriched by decay of limestones; *b*, next preceding stage, when soils rested on Devonian shales and were moderately fertile; *c*, yet earlier stage, when soils were formed on millstone grit and were very lean; *d*, earliest stage when soils rested on the coal measures, and were moderately fertile. For simplicity of illustration several stages of variation are omitted.

it has slowly uprisen above the ocean as the beds which covered it have worn away; but it is necessary to conceive that the soil which we now find upon its surface has steadfastly moved downward as the beds have been removed by the action of the agents which wear away land. The descent of the soil coating has been accomplished by the solvent action of ground water and the cutting work of streams. It is likely that both these forms of erosion may at one time or another have operated on all or nearly all parts of the descending surface. Although at one time stream beds where the water does its rending work occupy but a small part of the surface, perhaps on an average not over one-sixtieth of the area, the streams are constantly swinging to and fro and so in process of down wearing they come to lie in positions far removed from their present sites. Only the main divides which separate the waters of considerable rivers can fairly be supposed to have been exempt from the action of these migrating channels. (See Fig. 20.)

As soil descends with the wearing away of its materials it of course is subjected to a constant change in its mineral character. Thus while soil of the district now occupied by the rich limestone territory of central Kentucky lay upon the Millstone grit it was doubtless of a sandy and rather sterile nature; when in its descent it came into the limestone bed it must have been fertile; still farther down, encountering the Devonian or Ohio shale, which, because of its mineral character, is rather unfit for plants, the soil would again have been reduced to a sterile state. Finally in downward migration the surface entered the rich fossiliferous beds of the Silurian age and from the storehouses of the ancient marine life it acquired the exceedingly nutritious character of the so-called blue-grass soil; thus with the process of down going the character of the superficial deposits which determined the fertility of the earth was subject to very great alterations. As forest trees and other plants are distributed in strict accordance with the character of earth they grow in, each alteration in soil brought about in the manner above noted leads to a change in the species which inhabit the area. In the field which we have been considering soils formed of the Millstone grit are occupied by stunted red

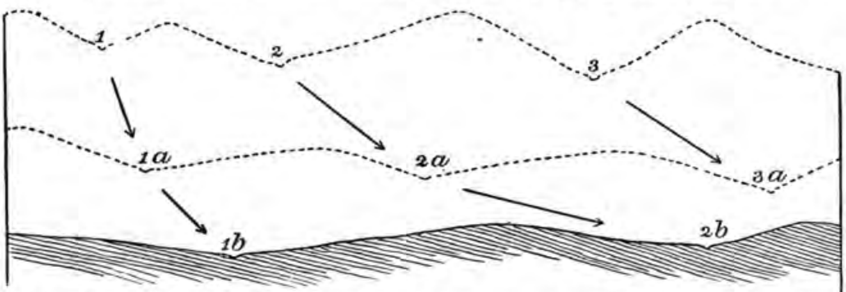


FIG. 20.—Diagram showing the lateral migration of streams in their descent through inclined rocks. *a*, present surface; *b*, *c*, former surfaces. The figures 1, 2, and 3 show the original positions of the streams; 1 *a*, 1 *b*, 2 *a*, 2 *b*, etc., show the successive positions of these streams. The arrows indicate the direction of the migrations of the streams.

and black oak and scrubby rigid pine; where the débris is of limestone we find walnuts, coffee nuts, and blue ashes, and other trees suited to the rich earth. We therefore perceive that each change in the nature of soil brings about a revolution in the character of its vegetation. (See Fig. 20.)

As soil migrates downward the greater part of the débris which it inherits from the rock through which it passes is dissolved and goes away to the sea. There are, however, certain materials which may remain for a long time in the soil because they are peculiarly insoluble. Thus in the limestone soils of Kentucky, the greater part of which are derived from the rocks on which they now lie, we often find many flinty and cherty bits which came into the layer when it was in a geological position a thousand feet or more above the site now occupied by the soil. Dense pebbles of pure quartz or flint, containing no admixture of other more oxidizable materials, may survive the assaults of the elements for an almost indefinite period. They are indeed almost completely insoluble in soil waters, and when buried in the dense clay they are little exposed to any agents of decay. It is often possible by the silicified fossils found in this material to prove that it has descended from a height of several hundred feet above its present position. Other evidence to the same effect is afforded by the occasional fragments of coal which are found in certain parts of the country lying upon the Lower Silurian limestone. One such deposit exists in the southern part of Campbell County, opposite Cincinnati, where frequent fragments of the material are found plentifully commingled with the quartz pebbles so characteristic of the Millstone grit.

It sometimes happens that the barren waste from vanished strata is inherited in such quantities upon the present surface of rocks which yield a fertile detritus that the soil has its fertility more or less impaired. The rocks which are now supplying newly made mineral waste may themselves be of an enriching quality, but the plants are embarrassed by the amount of pebbles through which they have to pass to gain the nutritious material at a lower level. It will be readily understood that these conditions are found only where the surface on which the soil rests is level or lies nearly in that attitude. Where the declivity is considerable the movement of débris towards streams inevitably leads to its destruction.

In consequence of the downward migration of the soil the oxides of iron are sometimes accumulated upon or near the surface in such quantity as to impair its fertility. Particularly in limestone countries these ores of iron may often be inherited by the surface from beds which originally lay over the country. It is characteristic of these ores of iron that they are readily dissolved in the soil water because of the charge of carbonic dioxide which the fluid contains. Under ordinary circumstances in this state of solution they are in small part appropriated by the plants, while the remainder is carried away through the streams; when, however, the soil water containing iron oxide comes in contact with limestone the iron is deposited in the form of a carbonate, while in its place the water takes a charge of lime which it bears away to the sea. In these conditions there may be only iron ore exposed to the action of the roots of the plants, and thus what would otherwise be a fertile soil becomes unfit for agriculture. As long as the detritus rests upon limestone these injurious conditions may persist. If in its down wearing it passes into clayey or sandy beds the excessive charge of iron may disappear.

If the soil be excessively humid, as it is in swampy districts, the iron, whatever be the character of the under soil, may, by virtue of another chemical process, be retained in the earth. The decomposing vegetable matter of the morass, by a reaction which it is not necessary to explain, takes the iron which is contained in the water and deposits it as an oxide in the form of an incrustation on the decaying leaves and other vegetable waste lying in the swamp water. As these vegetable forms crumble in their further decay the iron oxide may be accumulated as a sheet upon the bottom of the basin. When the downcutting of the stream which drains the swamp occurs, as it is pretty sure to occur in a brief geologic time, the ore is left as a deposit on the surface of the soil. These swamp deposits of iron ore are less detrimental to vegetation than those formed in the manner above described, for the reason that they commonly contain considerable amounts of lime phosphate, which is a most desirable substance in every soil.

Besides the iron ores, manganese is also inherited in much the same way from the rocks previously occupied by certain existing soils, but the oxides of this metal more rarely occur than those of iron, though they are often associated with them, and the effects of the accumulation are thus not so disadvantageous to vegetable life.

In general the downward movement of the mineral matter contained in soils tends to promote their fertility, and this for the reason that the variety of mineral materials in any one layer of rock is generally insufficient to afford the wide range of substances desirable for the uses of a varied vegetation. Within each area of ordinary soil we commonly find a share of the substances derived from the higher levels of the strata through which it has passed; in this manner it is likely to be supplied with a wider range of ingredients than the rock on which it lies can afford. There are also several curious equations of action which tend to prevent a soil from becoming surcharged with detritus of an insoluble character, such as flinty pebbles or fragments of chert. When the débris lies on a slope the constant passage of waste to the neighboring stream clears the surface of such accumulations; when the area is level the insoluble materials gradually sterilize the soil so that the vegetable growth becomes scanty and the consequent supply of the CO_2 to the water so small that the solvent action of the fluid on the bed rocks is much reduced, and so the surface migrates downward with lessened speed. With a diminished rate of descent the hard bits have a better chance to completely decay, and they are less apt to form a thick coating upon the surface. On this account we rarely find any soil completely sterilized by the insoluble fragments which it contains. Though it may not be fit for agriculture, it can generally support a scanty forest growth. But for this partial arrest of the downward working of the surface certain soils would be so thickly covered with insoluble rock débris that they would be entirely barren. We thus see that the character of a soil to a certain extent determines the rate of down wearing of the country, while conversely the speed of the descent in a measure fixes the nature of that layer.

The foregoing considerations should give the student a larger conception of the historic features of the soil coating than can be acquired by any more limited view of their conditions. He should clearly see that this mass of débris, which at first sight seems a mere rude mingling of unrelated materials, is in truth a well organized part of nature, which has beautifully varied and adjusted its functions with the forces which operate upon it. Although it is the realm of mediation between the inorganic and the organic kingdom, it is by the variety of its functions more nearly akin to the vital than to the lifeless part of the earth. It is not unreasonable to compare its operations to those of the plants which it sustains, for in both there are the harmonious functions which lead matter from its primitive condition to the higher estate of organic existence.

CERTAIN PECULIAR SOIL CONDITIONS.

So far our attention has been mainly given to the three groups of soils which are the types of the detrital coating in most parts of the world, viz, the alluvial, the glacial, and the locally derived deposits. In certain cases, however, we find soils which have been affected by local though it may be wide-reaching conditions, and which constitute fields affording problems of great economic as well as scientific interest. Among them we shall note the two divisions of arid and inundated lands, or those which suffer from an insufficient or an excessive water supply, and also those formed of materials transported through the air, together with certain other less important types of structure which will have to be at least incidentally considered.

It has already been shown that the prime mover in the formation of soils is the water which penetrates into and circulates through the superficial portion of the under earth; it is therefore natural that any great variation in the amount of this fluid should give rise to considerable differences in the constitution of the mass which it in good part creates and makes useful to plants. Such, indeed, we find to be the case. When the amount of the underground water and its other conditions are such that from time to time it fills the soil and then almost altogether escapes to the streams and air, we have what may be termed the normal conditions of the layer. Where the water is not supplied in such quantities as are necessary to these movements, or where the supply is so excessive that the earth is kept in a soaked state throughout the year, the effect upon the earth is perturbing and detrimental. Owing to the irregular distribution of the rainfall and in part, especially in the case of inundated lands, to the slope of the surface, about one-third of the continental areas have an imperfectly functioning soil coating. The arid lands or those which suffer from insufficient ground water occupy somewhere near three-tenths of the continental area. The swamps or other inadequately drained lands include about one-thirtieth of the surface which is above the level of mean tide.

The arid portion of the earth is mainly grouped into five great fields, which lie in central and western Asia, northern Africa, central and western Australia, western South America, and the Cordilleran district of North America so far as that field lies in Mexico and the United States. There are other portions of the earth which are desolated by drought, but they are all of small area. In none of these arid regions do we find that absolutely no rain falls; but in them the quantity of the fall is too limited to serve the needs of all save a few kinds of plants which have habits of growth fitting them to live with little moisture.

The amount of rainfall in desert countries varies from less than 1 inch to about 10 inches per annum, and in most cases the supply comes to the earth in some one season, sometimes in a single brief rainfall. When the rain is precipitated in this fashion, even as much as 20 inches falling in a season of 1 or 2 months, though it may nourish certain forms of plants adapted for development in the short time during which the soil is moistened, the region may be classed as arid, for it will be unable to maintain our ordinary forests and except when artificially irrigated will be generally unfit for tillage.

Arid soils commonly exhibit certain peculiarities which are not found in those of ordinary humidity; they are usually of more than average depth, for the reason that while the amount of water may be quite sufficient to promote the chemical decay of bed rocks, there is not sufficient passage of the fluid through the débris to bring about much deportation of the material in the state of suspension or solution. Even where the mass of débris is tolerably deep and open in its structure continued droughts preceding the time of rain and the general absence of a layer of vegetable mold commonly cause the soil to present a dense baked surface which may shed the rain like a roof. So, too, the lack of any but ephemeral vegetation, or of stunted plants which furnish little organic débris, diminishes the amount of mold which is contained in the detritus, so that the mineral elements of the soil are insufficiently mingled with organic matter. Held below the compact surface and with no great amount of transfer of the soluble mineral matter to streams, the soils of this arid nature in time become superabundantly charged with the various saline matters which are of much importance to organic life. Although the process by which these substances are brought into a soluble form goes on more slowly than in the case of ordinary soil, because their removal is not brought about, they slowly accumulate until they become in quantity far greater than in ordinarily humid parts of the earth.

When the potash, soda, and other soluble materials stored in the arid soils become excessive there is a curious action manifested by which they are uplifted to the surface and form a coating upon it. This coating may appear as a thick and enduring crust, such as occurs in certain parts of the well known alkaline plains of the arid region of the Cordilleras. The process by which these saline materials are brought to the surface is as follows: When in the season of brief rains the soil becomes for a time tolerably wet a large part of the alkaline matter is taken into solution in the ground water. The dry air evaporates a portion of the fluid next the surface, and this, passing into the form of vapor, leaves its mineral contents at the place where it went into the atmosphere. As the interstices of the soil are left empty by the disappearance of water, some of the fluid from below rises to the surface and in turn goes through the same process. In arid as in other soils the spaces between the grains act in the manner of those in a lamp wick to draw up the lower fluid to the point where it escapes by the action of heat in the form of vapor: as in the lamp the solid material contained in the oil forms a crust at its top, so the mineral matter of the soil water incrusts the surface of the earth.

In the manner described in the preceding paragraph, the alkaline materials of arid soils in times of drought migrate to the surface; if the rainfall be sufficiently heavy, it may in the next wet season dissolve the crust and return the material to a lower part of the soil; if the rainfall be less in quantity, it may happen that for at least a term of years the crust will remain on the surface of the soil. The effect of this excess of soluble material is gradually to add to the sterility of the earth in which it occurs; but this influence is frequently transitory; it endures but for a short time after the soil is by art provided with sufficient water to wash away an excess of soluble materials. These alkaline districts are in most cases admirably suited for betterment by irrigation; it requires but a thorough washing out of the excess of saline matter, such as can by irrigation be quickly brought about, to convert such a district into fertile ground. In general these earths which contain an excessive amount of soluble material lie in the more level portions of the country; where the soil is upon steep slopes, the effect of gravity, acting upon the surface water as well as that which penetrates the ground, is to urge the fluid more rapidly down the slope and thus to secure the deportation of the alkaline matter; consequently the more steeply lying land of the district may be exempt from alkaline crust, while the flat country may be covered with the coating.

It is a noteworthy fact that in the region of the great basin of the Cordilleras the valley deposits are coarse and pervious to water in their margins near the bases of cliffs, but fine and impervious in the centers of the several basins whereunto only the finer portions of the detritus worn from the mountains has been conveyed by the action of water and air (see Pl. XIV).

In many parts of the United States the ordinary brick used in masonry, after being built into a wall, frequently exhibits an alkaline crust, the formation of which is exactly comparable to that found in the arid plains of the Cordilleran district. When a wall composed of these brick becomes soaked by a beating rain various soluble substances are dissolved by the water which has penetrated the masonry. During dry weather this water evaporates on the surface of the wall substantially as it does on the surface of the soil, and a similar coating is formed. Unless pains be taken to scrape away this facing crust the greater part of the matter will be returned to the brick during the next spell of rainy weather, and so sometimes for 20 years or more the alkaline matter will perform a succession of journeys into and out of the baked clay.

It must not be supposed that the formation of this alkaline coating is altogether peculiar to arid districts, though its results are most evident in those fields. The same action takes place on all soils whatsoever in the change from wet weather to dry. Even in regions of ordinary rainfall where the earth is fairly rich in soluble salts the attentive eye will detect the beginning of such a coating. It is the frequency of rainfalls which prevents the sheet from becoming a distinct feature. It is perhaps worth while to note the fact, though it has been before adverted to, that it is to this constant elevation of the plant food nearly to the top of the soil which enables our grain-bearing plants to find sustenance in large quantity near the surface.

In certain rare cases the process of watering arid land, if a sufficient exit for the fluid is not provided, leads to the formation of an alkaline crust; thus in the delta of the Nile, where the quantity of water available for irrigation is scanty and the price set upon it high, people have endeavored to economize by providing insufficient exit for irrigated land. In this case the alkaline materials derived from the deeper portions of the soil form a coating on the surface during the long dry season, and the vegetation suffers from an excessive amount of mineral matter in the soil, which is in a state to be taken into solution. When these alluvial deposits were formed they contained no excess of soluble material, but lying for ages in the deposits they have become more decayed and thus a relatively large part of the mineral matter enters into the soluble state; it is evident that this affords an excellent example of the progressive decay of detrital materials deposited in the river plain.

Much of the exceeding fertility which characterizes the lands of the arid district when they are properly irrigated is doubtless to be accounted for by the peculiarities of climate of the region in which these fields lie. In such a district the sky is prevailingly cloudless and the measure of sunlight which comes to the surface is much greater than in humid regions. The result is that if their roots be well supplied with water, many plants flourish in the dry air with much greater luxuriance than where the moisture comes to them altogether from the rain which falls on their leaves or on the ground about them.

In most cases the soils which are now arid have not been in that state for any considerable geologic time. Their present condition is due to climatic changes which appear to have come about with the decline of the glacial period. This alteration is most conspicuous in the Cordilleran region of North America. It is also evident on the arid western coast of South America. It is especially marked in the district of the Rocky Mountains, in northern Mexico and the United States, where we find the surface dotted over with old lake-beds the waters of which once covered a large part of the area, making the country one of the most extended and beautiful lacustrine fields in the world. Many large lakes, like that in its shrunken form known as Utah or Salt Lake, occupied extended plains and valleys which now contain only the diminished remnants of those seas. In place of fresh water these lakes now present alkaline or salt pools of trifling extent. When these inland seas were full of fresh water there must have been a relatively great rainfall in this region now arid. The valleys which at present are the seat of streams only during the brief rainy season were then occupied by large and permanent rivers, so the soil generally must have been the seat of luxuriant forests. The result of these variations is that the existing detrital deposits of that region are in part at least derived from a time when soil-producing agents were more active than at present. It seems very doubtful if the existing soils of this area could have been formed in the conditions which now prevail.

The insufficiently leached soils of the arid region shade off indistinctly into the better watered soils which surround them. Sometimes, indeed, where the region is far too arid to permit the growth of forests or the use of the land for tillage, but where it is of an open texture, the rainy season being characterized by a brief but abundant downfall of water, the leaching process, though limited in duration to about a month, is sufficient to prevent the soil from retaining an excess of alkaline material. Whatever be the precise nature of these arid soils, and they are almost as varied in their qualities as those of normal humidity, they commonly prove of unusual fertility when redeemed by a proper system of irrigation. This fertility is due to the fact that they have not had their soluble material freely transported to the sea by the excurrent ground water. Moreover, a large part of their mineral constituents are in a decayed state, and thus readily pass into a condition fit for plant food as soon as the mass is supplied with water and intermingled with the waste of decaying vegetation.

Passing from the arid soils to those which are excessively humid, we traverse a wide gradation in the conditions of these detrital deposits as regards the amount of their water supply. The range is very great in the quantity of rain which falls upon the surface of soils classed as neither arid nor inundated; it may be taken as varying from 15 to 600 inches per annum. This difference has no such effect as would at first sight seem likely to ensue, for the reason that whatever the amount of water which falls upon the surface the excessive supply has no effect upon the deposit, after the interstices of the soil are filled, save to swell the streams and thus increase their carrying power. The soil takes in rain water up to a certain point, which is determined by the speed at which the fluid can drain from the detritus into the streams; any additional amount is surplusage and has no influence on the under earth. On the other hand, when the quantity of water in the soil is less than is required for the maintenance of its functions, unless, indeed, it has become baked by enduring drought, the pores of the earth greedily drink in not only the rain but even the dew which falls each night. This provision for the dew is generally disregarded in the account taken of the water supply of a country; yet it is often of as great value as the rainfall, and sometimes maintains a moderate fertility in a land which would otherwise be sterilized by drought. During the time when the dew is falling and lies upon the ground and the foliage, a period that commonly lasts for about half the day, evaporation from the earth and from the leaves of plants is arrested. Moreover, many of the lesser plants have their leaves and stems so arranged that their expanded surfaces gather the water and lead it down to the roots, and thus moisten the earth in the most advantageous manner.

When during any period of drought in the upper part of the soil, however dry, the capillary or wick-like action of the spaces between its grains causes the water to rise from the lower levels to the field occupied by the roots. Herein lies one of the advantages of securing a deep soil by proper methods of tillage; the water can be stored in the interstices of the lower levels, and when demanded can be brought to the upper levels where the roots can obtain access to it. Forest trees can penetrate the under soil and seek out the stores of water in the lower earth, sometimes to the depth of 10 feet or more; but more delicate annual plants, which afford the greater part of our crops, can not in their brief period of growth push their roots more than 6 or 12 inches below their crowns.

SWAMP SOILS.

As long as the measure of humidity is such that a soil may occasionally become moderately dry, so that the air can penetrate into the interstices, it may be regarded as still in the class of normal deposits of this nature, wherein the supply of water is such that the alternate wetting and drying can not take place, but the interspaces being continually filled it enters into the group of swamp soils. In this class of deposits the exclusion of air makes the matter unfit for the needs of most plants; their roots can not secure the æration which they demand; in fact, there are only a few rather singular species which can make their roots serve them in a soil which is continually filled with water during the growing season.

Swamp lands exhibit considerable diversity as regards the origin and nature of the deposits which constitute their soils; in all cases, however, they are characterized by a greater proportion of organic matter on their surface, or in their upper part, than is found in ordinary soils. This is due to the fact that when animal or vegetable matter is immersed in water it decays more slowly than when it is in succession wetted and dried. Woody substances when submerged in water gradually pass into the state of peat or muck, and beyond that stage of decay change goes on very slowly or is entirely arrested. The normal result is that in these inundated areas there is an ever thickening deposit of half-decayed plant waste, which generally contains not more than from 5 to 10 per cent of mineral matter—far too little, indeed, to give it the qualities of a good soil. Although the roots of certain plants find their needed sustenance in these swamp accumulations they are essentially unfit for the growth of the ordinary forest trees, and for nearly all the tillage plants until they have been drained and subjected to an exposure of the air for a considerable period. When unwatered and allowed to undergo a sufficient decomposition from the action of the atmosphere they invariably prove to be of great fertility, and endure the tax of culture remarkably well. A large part of the best lands in Europe have been won to tillage from ancient morasses. In this country the area of such lands which are suited to improvement by means similar to those which have been successfully adopted in the old world exceed 100,000 square miles. In general lands of this class constitute a most important reserve, from which extremely fertile fields may in time be obtained, capable in the aggregate of supplying food for a population nearly as great as that now contained in this country. It is therefore worth our while to glance at the history of these morasses, noting the diverse conditions under which they are formed and the effect of these on their possibilities of reclamation. A more detailed explanation will be found in the general account of inundated lands in the Tenth Report of the Director of the U. S. Geological Survey.

The simplest class of swamp deposits is formed where a thick forest growth, in a region of no great excess of rainfalls and of approximately level surface, leads to the retention of water in the soil to an injurious degree. In such an area the dead leaves and branches encumbering the ground so delay the passage of water to the streams that the clearance is not effected from one rainy period to another. In this case the plants, particularly mosses, reeds, and rushes, possess the ground; species of trees originally inhabiting the district are generally expelled, and the field remains deforested or is occupied by those varieties only which can live amid the hostile conditions. In many parts of the world this action leads to the deforesting of extensive tracts of tree-covered ground, a sheet of bog earth taking the place of the original growth. In earlier states of this process the pioneer may easily convert the ground into tillable earth by clearing away the forest and breaking up the thin sheet of swampy matter with the plow. When the deposit has so far thickened as to drive the forest trees away, however, the layer of spongy matter is generally too deep for immediate tillage, and the field must be improved by ditching. This class of wet woods is less common in the United States than in the region to the north; yet such areas, often of great extent, are common in the part of the country east of the Mississippi and north of the Ohio and the James rivers, and are of occasional occurrence in more southern and western fields. Morasses of this sort are most apt to occur in cold climates where the snowfall is great in quantity and where the summer is moist. Under these conditions the ground has not time to dry during the short summer season. They are particularly likely to be found where the area has newly been elevated above the level of the sea and has the characteristic nearly flat surface proper to ocean floors. Whenever the surface slopes toward the streams with a descent of less than 5 feet to the mile, unless it is

VIEW IN THE DISMAL SWAMP OF VIRGINIA, SHOWING CHARACTER OF VEGETATION IN THAT DISTRICT.
The growth on the right of the canal is a canebrake.

underlaid by very coarse porous soil, it is likely to take on this upland swamp character. The great dismal swamp of Virginia and North Carolina lies on a fine sandy soil with a slope of about 20 inches to the mile, yet it is covered by a thick layer of peaty matter (see Pls. XXVII, XXVIII and XXIX).

Next after the sloping upland group of swamps we may note those inundated lands which lie on the alluvial plains of our greater rivers. These are due to the frequency or persistency of floods which rise above the channel of the river. They are usually most extensive and difficult to win to the uses of culture along the lower banks of a river where its waters are checked by the nearness of the sea, and the height of the plains is lessened by the fact that the slowing current has allowed all but the finer sediments to lodge in the upper parts of the valley. As is well known, these fluviatile plains are almost always highest nearest the margin of the river, and they slope thence toward the hills which bound the valley in the manner indicated in Fig. 14. Although the elevated border of the terrace may have sufficient height above the river to furnish the drainage necessary for a normal soil, the lower lying back country is usually so depressed as to have a swampy nature. The waters from these "back swamps" are with difficulty discharged, for any small stream which may cut through the elevated strip next the river is likely to be from time to time closed by the sediments of the main stream or blocked by driftwood which readily enters the passage which its mouth forms through the alluvial plain. Generally the drainage of these swamps is effected by a gentle drift of waters parallel to the river which goes on until the volume is great enough to secure a permanent exit to the main stream. As this current is checked by the mass of living and dead vegetation through which it passes it often comes about that these back swamps are maintained when there would be dry land in case the path for the escape of their waters was free (see Pl. XXIX).

The fluviatile swamps include another class of morasses formed when the stream abandons a portion of its channel seeking a shorter way to the sea. These swamps do not differ from those formed in lakes and will be considered under the head of lacustrine deposits. It is characteristic of the back-swamp deposits of the river plain, as in general of all of this class of sediments, that they commingle organic and inorganic matter in a very perfect way. Thus these fluviatile swamps contain a much larger proportion of inorganic sediments than the commoner class of morassal deposits formed in lake basins. The result is that these soils when drained are in almost all cases at once fit for tillage without the time-consuming and costly process of removing the excess of vegetable mold. When adequately drained they can usually be made serviceable to the farmer at once. The greater part of the delta of the Mississippi is occupied by morasses of this nature. The fertile lands at the mouth of the Rhine are also to a great extent winnings from the same class of inundated soils.

The last group of fresh-water morasses which needs be mentioned in this paper is that which owes its character to the lacustrine conditions of its deposits. Whenever a water basin is formed without distinct current movement, a number of aquatic species of plants differing in various parts of the world, but all fitted for growth in very humid soils, seize upon the earth at the margin of the basin and proceed to accumulate a layer of vegetable mold upon and beneath the surface of the water. If the level of the lake be variable in a considerable degree, or if from its size and form of shore all parts of the coast line be subjected to strong waves, these plants may not succeed in beginning the work of filling in the basin with vegetable matter; but it commonly happens that in the shallowed parts of the shores the mosses of the genus Sphagnum and some few flowering plants find a foothold and create a layer of living and dead roots, leaves and stems, forming a tough peat. This deposit, though it begins to grow on the shore, gradually extends out over the surface of the water on which it floats. As it grows on the top it settles down into the lake and finally comes to rest upon the bottom. While this top sheet is forming and extending its margins by continued growth in its upper parts, it is decaying in its under portion and

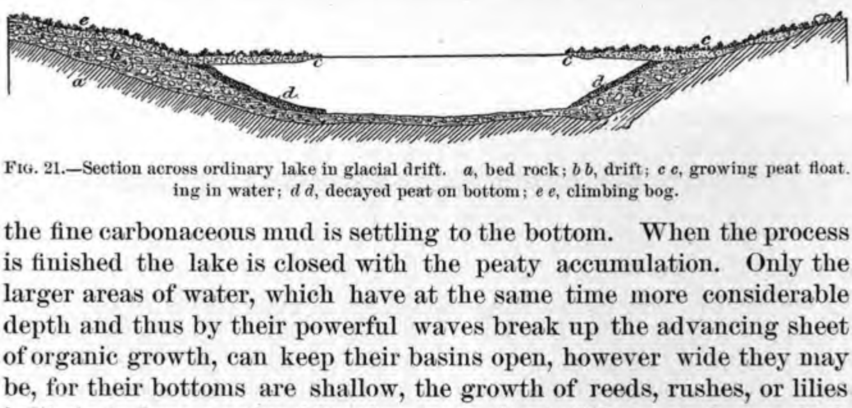
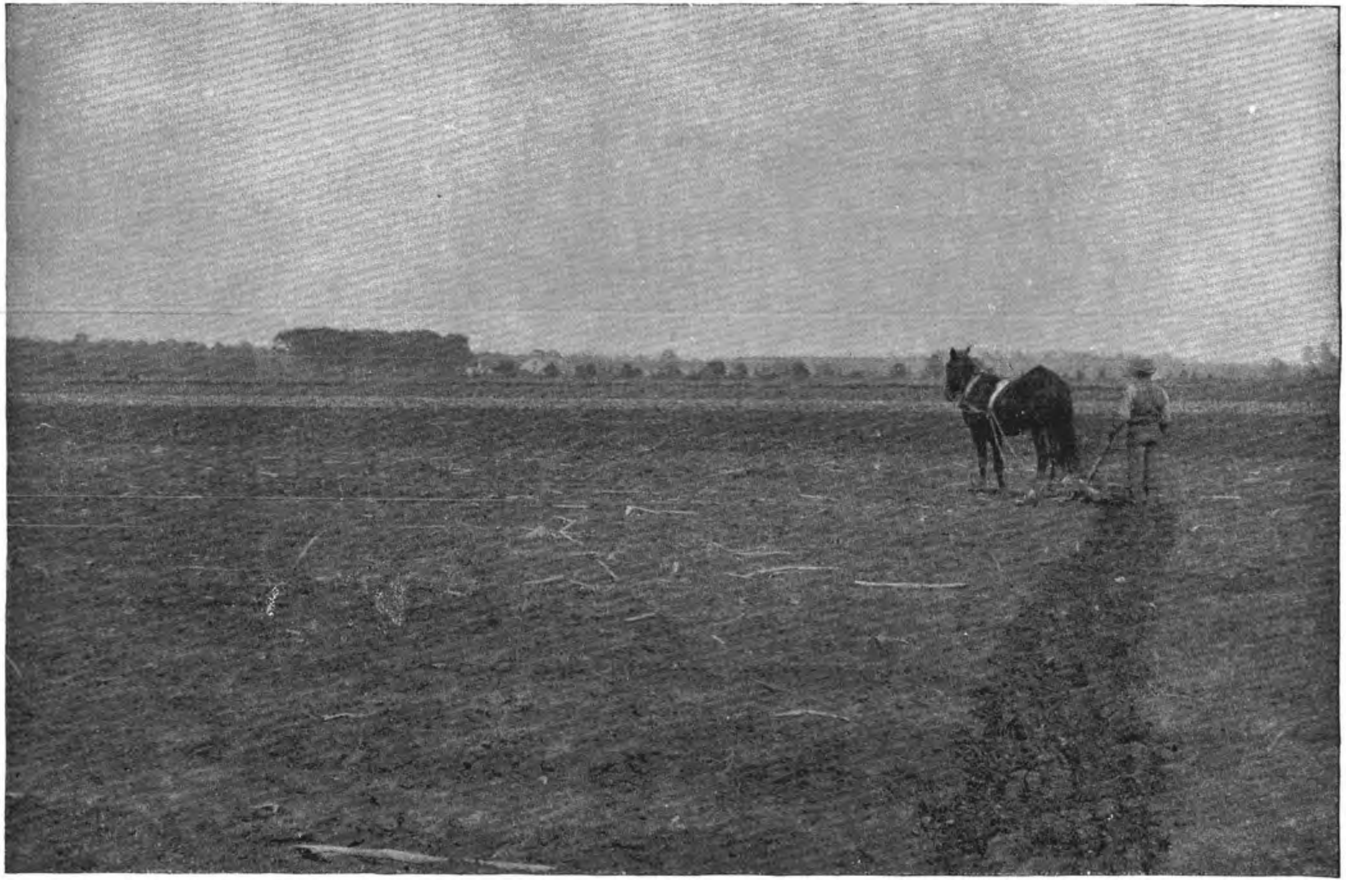


FIG. 21.—Section across ordinary lake in glacial drift. *a*, bed rock; *b b*, drift; *c c*, growing peat floating in water; *d d*, decayed peat on bottom; *e e*, climbing bog.

the fine carbonaceous mud is settling to the bottom. When the process is finished the lake is closed with the peaty accumulation. Only the larger areas of water, which have at the same time more considerable depth and thus by their powerful waves break up the advancing sheet of organic growth, can keep their basins open, however wide they may be, for their bottoms are shallow, the growth of reeds, rushes, or lilies is likely to form a natural breakwater in front of the peaty layer which serves to fend their assault from the spongy advancing shelf. In this manner at least nine-tenths of the very numerous lakelets which existed in the northern part of the continent at the close of the glacial period have been closed with organic waste. (See Fig. 21.)

Unlike the peat which forms in the swamps of alluvial terraces, that of the lacustrine swamps generally contain but little mineral matter. It is indeed so devoid of it that it can not be used for tillage until the ground is not only drained but the peaty layer burned away or allowed to decay in the slower manner in which atmospheric action effects this end. Deposits of this nature are often so deep that the task of removing the vegetable matter is practicably impossible of execution. In this case the only way in which these areas can be made of profit is by using them as nurseries of certain species of trees, to which they are often



RECLAIMED FIELDS IN THE CENTRAL PORTION OF THE DISMAL SWAMP, VIRGINIA.

well adapted. The juniper and the bald cypress, the tupelo, the water maples and the willows and the birches, as well as a number of other useful timber trees, have developed a certain endurance to the excessive humidity of swamps. In certain cases, as in that of the tupelo and the bald cypress, the tree has developed a peculiar form of roots which causes the aeration of sap in such a manner that it can withstand an amount of moisture sufficient to destroy many other species. It is probable that the greater part of our lacustrine swamps will in time be made to serve as nurseries of timber.

Another form of agriculture in which these peat swamps can be made of use is indicated in the method in which cranberries are extensively reared in Massachusetts, and elsewhere along the coast as far to the south as southern New Jersey. This form of tillage is perhaps the most original of any which has been invented in this country. In preparing swamps for this mode of culture, the top part of the original bog, that containing all the living roots and stems, is cut away, and the lifeless muck which lies below the removed layer is covered with a layer of sand several inches in depth, which is evenly spread over its surface. In this layer of sand the plants are rooted, and through it may descend to the underlying vegetable matter. The advantage of the sandy layer consists in the fact that the weeds do not readily root in it; moreover, it affords a firm footing to the laborer. It is likely that this method of tillage may advantageously be followed in the case of other economic garden plants, which, while they require dry ground for their crowns, luxuriate in a soil abounding in vegetable matter.

The soil bed of modern fresh-water swamps, the layer which lies beneath the accumulation of peaty matter, is commonly not of a fertile nature. This is owing to the fact that the movement of water which takes place through it is generally slight; little air penetrates into the interstices, and so the decay of its stony material goes on slowly; there is none of that constant overturning of materials, which, as we have seen, takes place in ordinary soils, such as those on our uplands. The deposit formed on the bottom of our swamps does not constantly descend by the process of mechanical and chemical erosion through the strata on which it lies, and thus there is no renewal of the fertility of the bed due to this action. Influences, however, are at work which bring about the formation, just above the bottom of the swamp, of a deposit of greater or less thickness which commonly contains a considerable amount of lime phosphate, a substance of great value in the production of most economic crops. The mode in which this accumulation is formed is not yet well understood, but it seems to be in general as follows:

In the water of most modern swamps as well as stagnant pools there commonly dwell a great variety of small crustaceans which have the habit of appropriating the phosphatic matter from the animals and plants on which they feed. This material they deposit in the outer coat of their body, or, as it is commonly called, the "shell." When these creatures die, their remains are doubtless in part dissolved and reappropriated by other organic forms, but in part they find their way to the bottom, and there along with other mineral materials form a layer rich in fertilizing matter. If the water which enters a morass is charged with iron, this layer generally appears as a bog ore; but in most swamps the amount of the oxides of this metal is so small that the deposit is not of that nature, and the phosphatic material is thus the more ready to serve the needs of the plants which call for it. The solubility of lime phosphate is much less than that of other compounds of lime, so that it is not borne away in solution as readily as ordinary limestone would be; in consequence of this limited solubility the bottoms of the swamps often come to contain a remarkable amount of grain-producing material. (See Fig. 22.)

The phosphatic matter which finds its way into swamps and is there stored in the deposits accumulated on their bottoms is doubtless in all cases derived from the rocks lying in the region whence the streams

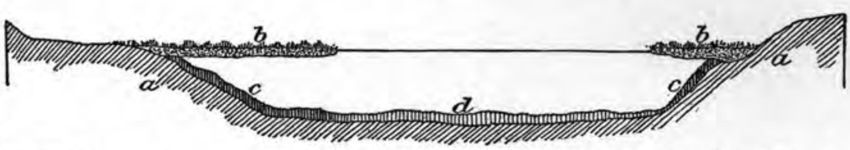


FIG. 22.—Diagramatic section through lake basin showing formation of infusorial earth. *a*, bed rock; *b b*, floating peat; *c c*, decayed peat; *d*, infusorial earth.

which flow into the morass drain. Almost all strata except the purer sandstones and flinty rocks contain a notable quantity of this substance, which was built into their masses at the time when they were accumulated on the ancient sea floors, the material coming to its position in the bodies of fossil animals and plants, which in turn obtained it from the sea water. Entering the swamp through the rivers the lime phosphate is first appropriated by certain water plants; these are eaten by fishes and crustaceans, and when these animals die their skeletons convey the phosphatic material to the floor of the bog, where it is slowly built into a layer.

It is through the local accumulation of phosphatic matter in something like the manner above described that the swamp soils accumulated on the sand of eastern Virginia and North Carolina have been made exceedingly fertile. In that region, through the enrichment which the organic forms of the swamp waters have contributed to the deposit on the bottoms of the morasses, the drained ground affords extremely fertile fields. Thus, while the sandy region about the Dismal Swamp is essentially worthless for grain crops, the dewatered swamp land yields even to a rude tillage exceedingly large returns. These fields often afford rich harvests for many successive years without any fertilizing whatever. (See Fig. 23.)

VEGETATION IN THE FRESH WATER SWAMPS OF CENTRAL FLORIDA.

The swamp lands of the United States, which are the most redeemable and which when won to the uses of agriculture afford fertile fields, lie mainly on that portion of the Atlantic slope between New York City and the mouth of the Mississippi River. Almost without exception these morasses lie at such height above the sea that by the use of simple engineering contrivances they may be effectively de-watered. In general these fresh-water swamps are covered with a dense growth of timber, which, owing to the fertility of the soil, is intermingled with a very thick growth of underwood, climbing vines, reeds, and other water-loving plants, so that the cost of clearing away the luxuriant vegetation must be added to the considerable expense which is afterwards required in draining the land by ditches. Nevertheless the quality of the soil is so good and its endurance under cultivation so continuous that the next great step in the economic development of the eastern portion of the United States will probably consist in the redemption of these inundated lands. In the general accounts of the swamp districts of the United States contained in a memoir published in the

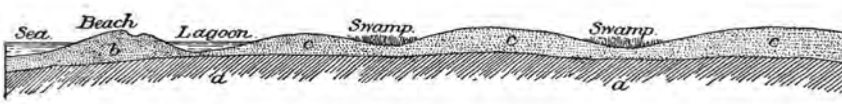


FIG. 23.—Diagramatic section from seashore to interior of district recently elevated above the sea level. *a a*, bed rocks; *b*, beach deposits and dunes; *c c*, marine sands with gently rolling surface.

Sixth Annual Report of the Director I have given a somewhat special account of these redeemable swamp lands. It may be here noted that some of the largest fields for the enterprise of the engineer lies in the State of Florida, where there exists about 28,000 square miles of country more or less adapted to such improvement.

Although, as before remarked, the larger part of these coastal swamps of the United States are covered by dense forests, certain fields which are destitute of arboreal growth invite improvement. Thus a large part of the Everglades in southern Florida is open land, but is almost covered by a growth of reeds and other relatively slight vegetation. There are also considerable areas, generally lying in the central portion ot timbered swamps, which are so far covered with water that they appear as tolerably permanent lakes, such as Lake Drummond, of the Dismal Swamp, of Virginia. In most regions these lacustrine areas will, when drained, afford fertile ground, but in some instances their bottoms have not received a coating of vegetation and remain as bare sands, scarcely more fitted for the uses of agriculture, even when thoroughly drained, than the general surface of the plains which lie without the limits of the morass.

MARINE MARSHES.

The last class of humid soils which we have to notice is that which includes the varied forms of tidal marshes which are formed along the seashore. These marine morasses are produced wherever there is a tidal movement of more than 1 or 2 feet in altitude. They accumulate in the indentations of the shore which are sheltered from the action of the greater waves, for the reason that in more exposed places these surges break up and scatter the frail accumulations as rapidly as they are formed. Like the lacustrine swamps, marine marshes begin with the growth of a fringe of vegetation next the shore; but while the mosses play the principal part in forming the peat deposits of fresh water, the grasses, certain species of which have the capacity of enduring salt water, do the work of constructing these marine deposits. The shelf they build is at such a height that its upper level falls just below the plane of high tide, so that with each oscillation of the waters a depth of a few inches is for an hour or two laid over the surface of the marsh. Each recurring tide not only refreshes the plants but it also brings in among them more or less floating débris, which catches in the tangle of the stems and gradually adds to the mass of the deposit. Beginning to grow, with water of considerable depth, the shelf in this manner gradually attains to near the level of high tide. This sheet of dense fibrous peat, composed mainly of plant remains, is mingled not only with the materials washed in by the tide, but is in part composed of the waste

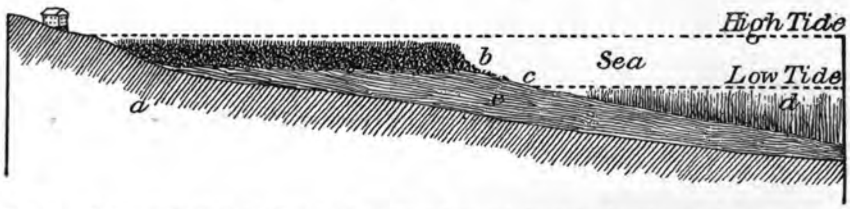


FIG. 24.—Diagrammatic section showing the origin and general structure of marine marshes. *a*, original surface at shore line; *b*, grassy marsh; *c*, mud flats; *d*, eel grass; *e*, mud accumulated in eel grass growth.

derived from the numerous small animals, such as shellfish and crustaceans, which dwell in the interstices between the plants. Unlike the lake swamps, this sheet of organic matter, formed as above described, never floats on the water; it lies upon the bottom and firmly adheres thereto. At the margin of this sheet of vegetation the waves from time to time break up the structure of the mass and distribute the waste over the bottom of deeper water, thus shallowing it and making it easier for the organic shelf to advance farther into the bay (see Fig. 24).

The construction of this tidal peat is still further favored by the growth of the interesting plant commonly known as the eel grass (*Zostera maritima*) a species of true flowering plants that has acquired the habit of living with nearly all parts of its body permanently below the level of water. Even a portion of its flowers are permanently covered by the sea. Growing in a densely crowded manner, this singular plant, by its remains and by the quantity of detritus which it gathers in its entangled foliage, shallows the areas of the bays in which it grows and so makes a foothold over which the higher lying turf gradually extends. Favored by these conditions, the tidal marshes gradually spread over the shoals of our bays, finally closing all the sheltered inlets of the coast except where the depth and width of the indentations is such as to permit the waves to beat against their shores with great violence. Thus along the coast between New York City and Portland, Maine, the growth of these peculiar marine marshes has diminished by more than one-half the area of the harbors which were occupied by tolerably deep water at the close of the last glacial period. The total area of these accumulations which are now bared at half tide along the part of the shore above referred to exceeds 350,000 acres.

Along the shore-line between New York and St. Augustine, Florida, these tidal marshes are very extensive and widely distributed; they contain an area many times as great as that presented by the shore of New England. The total surface which they occupy has not yet been well ascertained, but it probably amounts to some thousands of square miles. It is a noticeable fact, however, that the character of these marine marshes gradually alters as we go southward; with the change of species of the plants which compose them and the alteration in the energy of tidal currents due to the diminished height of oscillation they exhibit a marked change in their character, the plants grow less thickly, and the deposits often assume the character of muddy flats. South of St. Augustine and around the shore-line of Florida these marine marshes are generally covered with a growth of mangroves, a tree of curious structure and habits which by its peculiarities is able to grow in salt water. It is probable that within the limits of the United States the total area of marine marshes, including only the deposits which are bared at half tide and which owe their formation mainly to the growth of grass-like plants, is nearly 10,000 square miles.

The quality of the soil which may be won from these organic accumulations of the shore land is excellent. Owing to the abundant remains of animals, they are remarkably rich in those materials which are most necessary for vegetation and which are rarest in ordinary upland soil; lime, potash, soda, and phosphate are commonly present in relatively large quantities; in fact, these marine marshes in their excess of soluble materials in many ways resemble those which are found in arid districts. In both cases the excess of such matter is mainly due to the imperfect circulation of water through the soil; in the case of the arid land from the lack of water; in that of the marine marshes, from the fact that the fluid does not, during the brief time when the mass is exposed to the air, have a chance to discharge the water it contains.

When these marine marsh lands are won from the sea they afford soils of remarkable fertility and endurance to the tax of culture. It requires, however, a certain time after the surface has been barred from the sea before the soil of the marsh is fit for tillage; the tough layer of fibrous roots must first be destroyed by decay or by fire and the excess of saline materials removed by solution in rain water before the earth is adapted to the growth of plants which yield valuable crops. These changes will spontaneously take place in the course of from 3 to 5 years after the sea is excluded from the marsh, but by breaking up the surface with a plow and cutting frequent ditches through the plane a single year will often suffice to bring the soil into the state where any of our domesticated plants will grow upon it. At first, in just the manner of the arid fields of the desert region, and for the same reason, this marine marsh soil will in times of drought form a crust of saline materials on the surface. As the drainage becomes more complete this crust ceases to appear, as it does on the alkaline plain after a thorough irrigation. As the excess of organic matter decays the surface of the reclaimed marsh settles down until it comes to rest at a point of from a foot to 18 inches below its original level.

Some of the richest fields of this country are yet to be won from these salt marshes of the ocean shore. So far but little has been done to reclaim them. A few small areas in Massachusetts, New Jersey, and Delaware, probably not amounting in the aggregate to more than 5,000 acres, have been diked from the sea and reduced to subjugation more or less complete. Of these reclaimed areas the largest lies in Marshfield, Massachusetts. Here a district of about 1,500 acres has been separated from the ocean by means of a small dike. There are many other places along the shore between New York City and Portland, Maine, where areas of from 50 acres to 16,000 acres can, in a similar way, be reclaimed at a relatively small expense. By the use of proper machinery the cost of diking, ditching, and breaking up this class of soils will probably not on the average exceed $100 per acre. Considering the exceeding fertility of fields thus won from the sea and their remarkable endurance to agriculture, which permits them to be cropped for a generation without the use of fertilizing materials, they may fairly be regarded as remunerative investments even at this considerable cost of preparation. The experience of the seaboard states of northern Europe clearly shows that these marine marshes afford a most valuable resource for the future of American agriculture.

TULE LANDS.

Among the many local varieties of soil which have attracted attention and received special names we may note one of the most interesting varieties, known in California as tule lands. These deposits are to be ranked in the group of swamps. They mostly occur in the valleys of the San Joaquin and Sacramento and especially in the lower portion thereof. They consist of very extensive marshy districts which are subjected to inundations and which occupy in general the position of alluvial plains in other parts of the country. Near the level of the sea these marshes are mostly occupied by species of the round rushes; at higher points in the valleys is a greater variety of grass and rush-like vegetation.

It has been found that when these lands are subjugated by drainage or by burning the peaty matter in the dry season the ground is admirably adapted to grain crops. Even without plowing, after treatment by fire, the ashy soil yields remarkable returns of wheat.

It seems likely that the relatively very great fertility of these tule lands as compared with the reclaimed swamps of the eastern part of the United States may be explained by the comparative dryness of the country in which they are found. There are many reasons for believing that the climate of the California district is prevailingly drier at the present time than it was in the immediate geological past. It seems, therefore, likely that, although at many places still quite wet, these swamps have somewhat dried away; a good deal of their vegetable matter has decayed and the ashy waste thereof is commingled with the peat which remains, adding much to its fertility. Moreover, the quantity of dust transported through the air in this part of the country is great, and in the course of time the contribution of enriching sediment from this source has probably been considerable.

There appears to be more variation in the character of these tule lands than in swamp deposits in other parts of the country. Thus it has been noted that those which lie near Tulare Lake afford a heavier soil than similar deposits found elsewhere in California. A detailed discussion of these variations here would be out of place; moreover, the present writer has not had the opportunity personally to observe them.

ANCIENT SOILS.

Although the soil-coating of the earth is in a certain way an ephemeral structure and is commonly subjected to immediate destruction where it is affected by the action of the waves, by glacial wearing, or by other violent accidents, some parts of this detrital coating in certain times and places have by chance been preserved to us from a remote geologic past. The first clearly recognizable deposits of this nature are found in the rocks of the Carboniferous age, where, indeed, they plentifully occur; beneath each bed of coal we commonly discover a layer of material which was the soil in which began to grow the plants from whose remains the coal bed was formed. So as far as these coal-producing plants were rooted forms they generally drew their sustenance from these ancient soils. We can still in many instances trace their roots, and occasionally we find the tree fern or other plant to which they belong standing erect amid the swamp deposits which accumulated about it, and which now appears as coal. These soils of the Coal Measures differ from those now existing on the upland parts of the earth in certain important ways; they are generally of less thickness than are those of to-day which have been formed under similar conditions, and contain a rather smaller proportion of organic matter. These peculiarities are probably due to the fact that in the olden time there were few kinds of plants which had strong roots, and thus there was less opportunity for vegetable matter to become commingled with the earth (see Fig. 25).

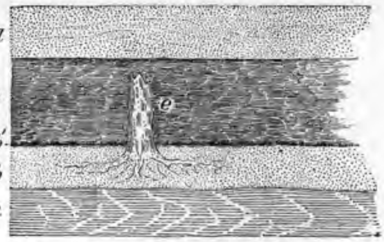


FIG. 25.—Section through coal bed. *a*, bed rock; *b*, under-clay or ancient soil; *b'*, position in which iron oxides often occur; *c*, layer of coal; *d*, sandstone or other bedded rock; *e*, fossil tree, with roots in under-clay.

The most peculiar feature of these ancient soils consists in the fact that they usually lack those materials, such as potash and soda, which are a conspicuous and necessary element in the greater part of the soils of the present time. The general absence of such material has led to the occasional use of these ancient deposits as fire clay, i. e., materials which will endure without melting the high temperature to which they are exposed in furnaces. In any ordinary soil a white heat will cause the siliceous element of the deposit to melt, for the reason that the lime, potash, or soda which it contains will combine with the silica when the mass is greatly heated, thus forming a glass or cinder. It is not likely that the present condition of the Carboniferous soils is that which they exhibited when plants first began to grow upon them; at that time they may have had the usual share of alkaline substances; but the very conditions which made these soils the seat of swamps secured the surface on which they lay from wearing downward in the manner common in ordinary districts, and so prevented the constant renewal from the underlying rock of the materials removed by vegetation. The result was that in time the earth below the swamp accumulation was deprived of the matter which could be removed through the action of plant roots. So far as these plants by their conditions of growth could take up soluble minerals of the soil, they removed them, storing the matter in their stems and leaves. When the plants decayed their waste fell into the peaty accumulation and gradually the mineral matter became leached out and conveyed away to the sea. As there was no means of restoring plant food, the soil gradually lost the power of contributing to the growth of plants. Thus while in the case of ordinary upland soils the process of decay in the underlying rock continually adds to their fertility, while the waste of vegetation is constantly returned to the earth, in most of these swamps of the Carboniferous time, on the contrary, all the conditions serve to pauperize the layer. Owing to various causes, however, some of which are to be noted hereafter, the soils beneath our modern swamps do not in the same complete manner undergo the process of exhaustion.

It is probable that the progressive removal of the soil matter from beneath the swamps of the Carboniferous period had much influence on the development of the peaty material which in time became converted into coal. The larger part of their carbonaceous material was formed from the waste of plants which required a certain amount of mineral matter for their support. This the plants had to obtain through their roots. After the swamp attained a certain thickness, the continual leaching away of these substances would gradually limit the growth of the plants which tenanted the morass, and finally the growth might be entirely arrested by lack of such material to support the vegetation.

PRAIRIE SOILS.

There is another important group of soils which owe their peculiarities not to any excess or insufficiency in their water supply, but to the circumstances of their geographic situation and organic history. These are the prairie lands of the Mississippi Valley, and the similar soils which are found in various parts of the world. The origin of the prairies of this country has been a matter of much discussion, and many theories have been advanced to account for their existence. In the state of nature from which they are now rapidly passing, these wide fields were generally unforested rolling plains with scanty woodland growth, which was mainly limited to the neighborhood of the streams, while their surface was covered by a dense and rank herbage of annual plants, mainly grasses springing each season from perennial roots. Along the banks of the permanent streams and in swales of their surface there were strips and patches of woodland, but it was often possible to journey for a day without seeing a tree. This untimbered country was in marked contrast with much of the neighboring land. Thus a large part of Michigan and Ohio and portions of Indiana were densely wooded, and these districts lie on three sides of the extensive prairie district which existed west of the Mississippi River. The soil of these prairie lands generally afforded a combination of mineral and organic matter exceedingly well suited to grain crops, so that when subjugated it yielded ample returns to tillage.

Among the several explanations by which it was sought to account for the treeless yet fertile nature of the prairies we may note the two which seem most important. It has been held that the prairies owe their unforested condition to the exceeding fineness of division which characterizes their mineral material, it being supposed that such comminuted matter was unfavorable to the growth of trees. This does not seem to be a reasonable supposition, for we find that when occupied by civilized man the prairie soil will nurture a great variety of trees quite as well as any other soil. There is therefore no reason to suppose that the condition of the soil can in any way account for the failure of the forest growth to take or keep possession of these districts. It has been supposed by some that these prairie districts have recently been occupied, in large part at least, by great lakes, the extension of the freshwater seas such as Michigan and Erie, or perhaps other basins of the northwest. While it is probably true that a considerable portion of the prairie districts have been thus recently submerged, it seems certain that this fact can not in any way account for the absence of forests, for the reason that a large part of the area in northern New York, Ohio, and Pennsylvania was also recently occupied by extensions of the great lakes which lie in the vicinity, yet these regions are abundantly timbered. It seems therefore certain that the forest trees have had time to return to the prairie district, especially as there are scant patches of varied wood along the streams and other wet places in prairie districts.

The most essential peculiarity of prairies consists, as is well known, in their treeless nature. This feature may be well explained in the following simple way: The region they occupy is characterized by periods of enduring drought, which reduces even the forest-clad portions of the country to conditions of extreme dryness. At such times forest fires will spread with great celerity and extend to vast distances; even in the relatively humid districts of Michigan such conflagrations, though opposed by all the arts to which the settlers can resort, often extend for scores of miles. The native Indians of this part of the country were in the habit, through carelessness or design, of firing the prairie grasses every spring. Such fires swept like a whirlwind over the plains and were rarely interrupted in their ravages by broad rivers or by swamps. They would extend into the margins of the forest, and if the vegetable mold was not very retentive of moisture would result in the destruction of all young trees in the wood. In pine woods such fires would destroy all the vegetation with which they came in contact.

It is likely that in the far West, near the foot of the Rocky Mountains, where the climate after the close of the glacial period became excessively dry, the soil may have ceased to bear forests because of its arid nature. The process of burning may then have extended the prairie country to the eastward until the condition of open ground was brought into districts where the amount of rainfall was sufficient to maintain forest trees.

Evidence that this timberless character of the plains east of the Mississippi river has been brought about by the spread of fires is afforded by the conditions which existed in Kentucky during the latter part of the last century. While the Indians used this region as a hunting ground, the district between Louisville and the Tennessee line, extending thence westerly along the southern border of Kentucky to the Cumberland river, was mostly in the condition of prairies. Except near the streams and on the margin of this so-called "barren district," the forests were scarred by fire. There were no young trees springing up to take the place of the old and thick-barked veterans of the wood, which from the hardness of their outer coating could resist flame. When these mature trees died they had no succession, and so the prairie ground became gradually extended over the area originally occupied by forest. After the Indians were driven away about 50 years elapsed before the country was generally settled, and in this period the woods to a considerable extent recovered possession of the areas of open ground. The periodic firing of the grass having ceased, seeds were disseminated from the scattered clumps of wood, and soon made them the centers of swiftly spreading plantations. It was the opinion of the late Senator Underwood, of Kentucky, who had seen this country in the first years of the present century and who was a most intelligent observer, that the timberless character of this district was entirely due to the habit which the aborigines had of firing the grasses in the open ground.

It is an interesting historical fact that the first settlers of the country deemed the untimbered limestone lands of western Kentucky infertile, and therefore gave to them the name of "barrens." They were led to the conclusion that these lands were sterile by the fact that in their previous experience the only untimbered lands with which they had come in contact were unsuited to agriculture. It is not likely that the Americans or their British forefathers had ever seen any soil which was, before it was subjugated, in anything like the condition of the prairie lands, unless it may have been inhospitable fields near the seashore or certain small areas of a fertile nature in the Shenandoah Valley, which had been deforested by Indians, probably also by means of fire. Several years passed after the settlement of Kentucky before the true character of the so-called "barren" lands was ascertained and they were found to be generally of a very fertile nature. Meantime young forests rapidly extended and much of the country which was in a state of prairie had to be stripped of this woodland growth before it was ready for the plow.

The extremely fertile nature of prairie soil when it is first tilled is easily explained. Owing to the generally level character of the district occupied by these open lands the soils were deep, for the reason that they did not have the chance to slide down to the streams in the manner which we have seen to be common in hilly districts. The frequent burning of the rank growth of vegetation constantly returned to the soil large amounts of potash, lime, soda, and phosphatic matter in the soluble form which is suited to the needs of grain-giving plants. As the deposit lay on nearly flat surfaces and the rainfall was moderate in quantity, the ground water did not bear the soluble materials away to the stream as rapidly as they were formed. The result was that when these prairie regions were submitted to the plow they yielded in a few years the store of plant food which had been garnered during many centuries of preparation. Unfortunately, their primal fertility has not proved very enduring; the layer of fruitful earth is generally of only moderate depth, and with the reckless agriculture which commonly characterizes this country they have been in most cases within 30 years brought to a state where they afford only a moderate return for the labor bestowed upon them. The crops of wheat which originally were 30 or 40 bushels to the acre are, after a generation of culture without artificial replacement of fertilizing materials, reduced to an average of about 16 bushels. It should be noted, however, that even where the original fertility of these prairie soils has been materially diminished they are readily restored to something like their pristine condition by a proper system of tillage, in which deep plowing and a reasonable use of fertilizers alike find a place.

The effect of the vegetation which occupied the prairies for many centuries before the coming of white men was to draw the soluble portion of the fertilizing substances to the upper part of the soil, and to leave the subsoil unaffected by any of that peculiar work which is accomplished by the strong roots of forest trees. These, as we have seen, tend to draw mineral substances from the deeper portions of the subsoil and from the bed rocks, accumulating the material in the growing vegetation, whence its return to the upper part of the soil by process of decay. Much can be done to help these soils by deep plowing and by the the process known as subsoiling, whereby deeper layers are opened to the access of air. In a word, we need to imitate in the prairies the peculiar task which has been performed in most districts by the roots of trees.

WIND-BLOWN SOILS.

Last among the soils of peculiar history we may consider those where the mineral materials have been brought to their position by the action of wind. In most countries this group of soils is of small importance, and in North America the blown-sand areas do not occupy in the aggregate more than two or three thousand square miles of surface. The most easily recognized accumulations of this class are those which form along the seashore, where winds blowing inwardly to the coast carry the dry sands from the beach and deposit it in the form of hill-like masses, termed "dunes." These heaps of blown sand often march slowly and with a variable movement far inland. The blast of the wind drives the grains up the more exposed side and over the summit, where they drop in the lee of the mass of the hill. These "dunes" sometimes rise to the height of one or two hundred feet above the base. Wherever they are formed on open ground they have a ridge-like character, the long crest lying transverse to the direction of the prevailing winds. Where the dry sand enters the forest lands the accumulation is often in a more sheet-like form, and this because the close-set trees destroy the movement of air currents. (See Fig. 13.)

When they first start from the shore the dunes are usually composed of very clean sand, the grains of which are of about the same size in each layer of the deposit. The material is of a finely divided nature, but occasionally the stronger winds convey to the mass pebbles as large as ordinary peas. As the dune advances farther from the shore they come into a region where the energy of the storms is rapidly diminished by the friction of the air upon the surface; the pebbles are then left behind in the path of the dune and only the finer materials are conveyed onward. As this motion of the marching sands is usually at the rate of a few feet each year, the matter is partly decomposed by the action of air and rain, so that vegetation finds a chance to take root upon it. As the living mantle grows thicker it gradually restrains the action of wind, until finally the mass is brought to rest.

Migrating sands are formed not only along the seashore and along the shores of the greater lakes, but also beside the banks of rivers, which cut through deposits of glacial drift, where the sands have been separated from the clay. Thus some of the most extensive, or at least the most widespread, dune deposits occur along the eastern sides of the greater New England rivers, as for instance in the district bordering the Merrimac, between Nashua and Concord, New Hampshire. They are less conspicuous and characteristic beside the rivers in these districts, for the reason that the areas are generally forest-clad, and so the deposit appears in the form of a broad sheet accumulated between the trees.

As compared with Europe, deposits of blown sand in the form of dunes are relatively rare on this continent, because on the eastern coast, where alone sandy shores abound, the prevailing winds are from the west and air currents thus serve to prevent the extension of the blown deposits for any distance into the interior. A narrow strip of dune sands borders the Atlantic coast from Cape Florida to the eastern end of Long Island. They are tolerably abundant on Cape Cod and the islands which lie south of that cape. The northernmost point at which any considerable deposit of this nature occurs is in Massachusetts, immediately west of Cape Ann. At no point, however, do these dunes extend for more than about 3 miles inland from the sea, though there are some lying at points farther inland, accumulated when the seashore lay somewhat farther westward than it does at present. The slight incursion of these dunes is due to the great violence of wind during easterly gales. The rate of movement of the storms, however, does not persist for any distance from shore, and the material thus imported is subjected to the constant attack of the less violent but more prevalent westerly breezes.

The most important interior deposits of dune sand are found along the borders of the great lakes in the Laurentian system of waters. Of these the largest and most interesting area lies at the south end of Lake Michigan.

Although a portion of the sand included in these dunes has been derived from the existing beach of the lake, it is probable that the greater portion came from the ancient shore of that water which, during the last or Pleistocene geologic epoch, lay at a higher level than at present.

Similar deposits of blown sand, essentially like dunes in origin, though commonly of a more sheet-like nature, are apt to be formed in regions where the surface is covered with fine débris, but where there is not enough rain to support a vegetation sufficiently luxuriant to protect the detritus from the action of wind. This is the case in the Sahara and other deserts, where a large part of the detritus was formed on ancient sea floors or accumulated when the climate permitted the construction of soils, but where the arid conditions now prevent the growth of plants.

In such desert regions the winds are continually bearing away large amounts of sand and other finely divided rocky matter which accumulate in marching dunes within the desert region and often invade the better watered countries on its margins. Thus the sands from the Sahara, marching before the west winds, have already entered and devastated considerable portions of the valley watered by the Nile. The general effect of these movements of air-driven detritus is to impoverish the surfaces which they cover. The deposits themselves, owing to their very siliceous nature and their extreme permeability to water, are of little service to plants, and therefore are worthless for the uses of man.

It should be noted that the dunes formed by the disruption of soils which, though once well watered, have through climatic changes become extremely arid are less infertile than are those which are formed from the coast detritus. The reason for this is readily seen. While the coastal sands have by washing been deprived of all their clayey matter and are thus generally of a nearly pure siliceous nature, the detritus of the desert contains a large part of the finely divided and fertilizing materials which belonged to the soil before it was broken up. Owing, however, to the action of the wind, this finer material is commonly driven to a much greater distance than the coarser débris. The result is that in many of the desert areas in the Cordilleras the pulverized rock matter has blown away from the surface leaving a sheet of pebbles and other rock fragments where there was once a distinct soil. In the eastern portion of Asia, about the head waters of the great rivers of China, there are vast accumulations, sometimes a thousand feet or more in thickness, composed of fine dust which has blown from the desert area of that continent into the more humid region of the eastern part of the continent. The masses accummulate in the form of a table-land, sometimes filling deep valleys which were excavated in a time before the dust invasions began. Deposits of less extent and thickness essentially like those in China have been formed by the migrations of dust in several other parts of the world. In the western Mississippi Valley, especially in the northern portions of that area, are considerable accumulations of fine-grained detritus evidently brought from a great distance. This material is commonly known as loess; its origin has been a matter of much debate, but it seems likely that it is in part at least due to the action of the wind blowing the fine detritus from the region about the eastern face of the Cordilleras into the central portion of the continental valley.

In larger part, however, the loess of the Mississippi Valley probably owes its origin to conditions which existed during the last glacial period, when the region in which it lies received the fine flour-like sediments ground up beneath the ice and borne forth to the margin of the glacier by streams of fluid water which flow beneath such ice masses. This fine-grained and therefore easily transported detritus appears to have been distributed over wide areas adjacent to the main stream in the northern part of the great valley. As these soils, which owe their origin to drifting dust, are generally formed by the descent of the particles into interspaces between the growing vegetation much in the manner in which it accumulates in alluvial terraces, the mass commonly takes on a horizontal distribution well suited to the uses of agriculture. The mineral substances of which it is composed are usually much oxidized before they enter on their journey, and owing to the way in which they are laid down amid the growing vegetation they become thoroughly mingled with decayed vegetable matter. Thus while the march of the wind-driven soils is in an immediate way devastating, the movement of the lighter part of the débris may be advantageous to the soil of the districts in which it comes to rest.

None of the dune deposits in this or other countries have any value for tillage purposes. In fact their only human interest consists in the dangers which they may bring to fields and habitations. In Europe this is often serious. In the region at the head of the Bay of Biscay an extensive territory has been covered by these sands and reduced to a state of sterility. It has required a large amount of official care to restrain the march of these blown sands in that part of France. In eastern England a considerable village known as Eccles was, more than a century ago, overwhelmed by the vast marching dune. So thick was the accumulation that not only were all the houses deeply covered, but the parish church was buried beneath the mass. After more than a century of inhumation, the subsequent march of the wandering hill has begun to disclose the houses of the village, and it seems not improbable that in the course of another century the heap may pass by the site of the town.

We have now completed our general survey as to the effect of the varied conditions which operate in the formation and preservation of soils. This account is incomplete as regards details, but it is to be hoped that it may give the reader a general idea as to the balance of the organic and inorganic actions which affect this admirable life-giving coating of the earth, the zone from which all the higher life springs forth, and to which, after the appointed term of existence, it quickly returns. We have seen that the adjustment of these conditions permits the soil to form and do its appointed work in varied states of the earth's surface. We have now to consider some of the effects of human culture on the soils, and also in a measure the reactive effect of this envelope upon the estate of man. In this field of inquiry we shall find a large and varied set of problems which can be considered only in a very general way.

ACTION AND REACTION OF MAN AND THE SOIL.

The primitive men, at least in their savage state, had very little influence on the soil—much less, indeed, than many species of lower animals. As long as men trusted to the chase, to fishing, or to the resources afforded by wild fruits and grains for their subsistence, and to chance stones picked up along the stream for their weapons, they were practically without influence upon the soil. When, however, our kind took the first long step upward in the arts and began to till the earth, a new and momentous influence was introduced into the assemblage of soil conditions. Even in its simplest form tillage requires that the natural coating of vegetation shall be stripped away in order that the plants which have been selected for culture shall have entire control over the nutriment which the earth affords. Agriculture, moreover, requires that the soil shall be overturned in order that plants may in the open textured earth have a better chance of pushing their roots easily and swiftly through the mass in search of food. Both these processes are exceedingly subversive of the original conditions of the soil. They manifestly tend to break up the adjustments by which the deposit is created and preserved. While in the wild or natural state the surface is generally covered by an assortment of trees of varied species, as well as of lesser undergrowth, the roots of which are always deepening the detrital layer and winning new and lower-lying stores of nutriment. Moreover, in this condition the earth is well protected from the detrimental action of the rain by a coating of decayed organic matter which is constantly working down into the true soil.

In its primitive state the soil is each year losing a portion of its nutrient material, but the rate at which the substances go away is generally not more rapid than the downward movement of the layer into the bed rock. Thus from age to age the detrital mass, save by unusual accidents, is neither thinned nor impoverished. But when tillage is introduced, the inevitable tendency of the process is to increase the rate at which the soil is removed until the destruction begins to trench upon its depth and fertility. When mantled with its coating of vegetation, which in its natural state is never violently disturbed, the earth yields to streams only that part of dissolved matter not seized upon by the dense tangle of roots, which in most cases occupies the whole of the detrital layer. Except for the undissolved sediments worn away along the banks of the stream or the shores of lakes and seas, no part of the soil, while it remains in its normal condition, goes away in the state of mechanical suspension.

If the reader would acquire a distinct eye impression of the difference between the conservative conditions which prevailed in the soil before man's interference and the destructive state which exists afterward, he should during a time of continued rain resort to some of the numerous valleys of the Appalachians where the country is but partly subjugated by man. He will there observe that the streams which drain the district where tillage prevails are charged with a burden of detritus won from the soils. This is shown by the reddish yellow hue it has imparted to the water flowing from the valleys where tilled lands lie. While most of the tributary brooks send out such turbid waters to the main stream,

FORM OF SURFACE IN AN ELEVATED REGION SOUTH OF THE GLACIATED BELT.

The fourth ridge from the foreground lies in a field which has been for some time untilled, and which is beginning to be gullied by the rain.

we here and there find one which, though swollen by the rain, lacks all such coloring matter. The stream is either pellucid, or, if stained, has the brown hue which decayed vegetation may impart. On investigation it will always be found that streams which flow clear water drain from valleys in which the primitive forest is unbroken, while those charged with a load of detritus are from districts where there are extensive tilled fields. After a little practice in observation it is possible from the share of mud in the waters of a brook to tell how far the clearing away of the forests has extended in the valleys whence it flows. Where, as in the valley of the upper Missouri, the vegetable coating is extremely incomplete, owing to the present arid state of the country, the torrents which form in times of rain may, from the ease with which they wear the unprotected surface, convey large amounts of detritus in their waters. This, however, is an exceptional condition of the natural soil (see Pl. XXX).

In this country, where the lands have been tilled for a relatively short time, the evils arising from the waste of soil when it is bared of vegetation are not so pronounced as in many parts of the Old World, where extensive districts have to a great extent been devastated by this action. Thus in many parts of the Mediterranean region, particularly in Italy, the soil upon the slopes of steep hillsides, which once bore luxuriant forests, and which might with due care have been made the site of rich pastures and orchards, are now reduced to the state of bare rock. In the region immediately north of Florence there are upland districts where it is possible to walk for miles without setting foot on anything in the way of soil which has any arable value whatsoever; yet in this section but a few centuries ago there was a thick layer of fertile forest mold, which, when the woods were swept away, was quickly washed down upon the plains or into the sea.

The effect of the extensive culture of European soils is shown in the proportionately large amount of waste carried out in the form of mud by streams which drain that country. The Rhone and the Po, which flow from two of the most completely tilled districts of the world, discharge with their waters enough detritus to lower the surface of the country which they drain to the amount of about 1 foot in each thousand years, while the Mississippi, which drains from a valley as yet imperfectly tilled, carries to the sea only about enough detritus to lower the surface by one foot in 7,000 years. Although the evils arising from the washing away of the soil in America have not as yet been very serious, a close reckoning of the loss would probably show that it already amounts to the practical destruction of that coating over an area some thousands of square miles in extent. These depauperated districts lie almost altogether in the region to the south of the glacial belt, and mainly in the hilly portions of the so-called Southern States, especially in Virginia, the Carolinas, Kentucky, Tennessee, and Mississippi. There is scarcely a county in these States where it is not possible to find a number of areas aggregating from 300 to 500 acres where the true soil has been allowed to wash away, leaving exposed to the air either bare rock or infertile subsoil. Where subsoil as well as the truly fertile layer has been swept away the field may be regarded as lost to the uses of man, as much so, indeed, as if it had been sunk beneath the sea, for it will in most instances require thousands of years before the surface can be restored to its original estate.

Where tillage, without due care for the needs of the soil, has led to the destruction of the superficial layer, while the subsoil is retained, the damage is remediable, provided pains be taken to smooth over the ridges and furrows with which the earth is seared, and to clothe the surface in grass. Those who find themselves charged with such care will do well to observe what happens when any steep slope is deprived of its forest covering and is left unprotected by such a coating as is formed by grass roots. As soon as a surface of this nature is laid bare, the rain, gathered into rills, begins to cut in the manner of mountain torrents, the separate channels often being separated from each other by intervals of only a few feet. As long as the beds of these rivulets are in the friable earth they wear rapidly downward, and thus keep

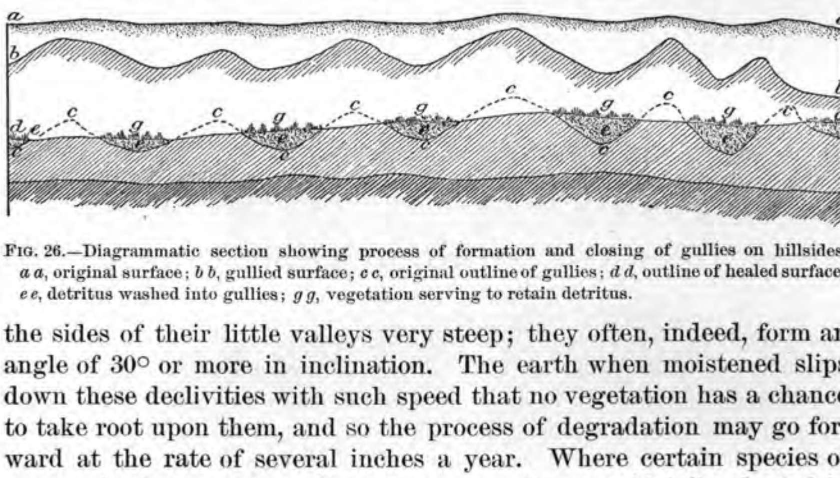


FIG. 26.—Diagrammatic section showing process of formation and closing of gullies on hillsides. *a a*, original surface; *b b*, gullied surface; *c c*, original outline of gullies; *d d*, outline of healed surface; *e e*, detritus washed into gullies; *g g*, vegetation serving to retain detritus.

the sides of their little valleys very steep; they often, indeed, form an angle of 30° or more in inclination. The earth when moistened slips down these declivities with such speed that no vegetation has a chance to take root upon them, and so the process of degradation may go forward at the rate of several inches a year. Where certain species of trees or bushes, such as willows, are naturally or artificially planted in the furrows in so close-set an order that they may check the rapid currents, and by their roots prevent the down-cutting of the streamlets, the erosion may be checked and in a few years the surface will again become smooth. The mode of this action is indicated in the accompanying diagram, which represents successive stages which have taken place in a rain-furrowed field in the limestone district of northern Kentucky in a term of 10 years (see Fig. 26 and Pl. XXX).

It is most important that the conditions of this rapid erosion, which is likely to take place on a large part of the lands of the earth, should be clearly understood and its consequences distinctly apprehended. The prime cause of this danger is due to the reckless effort to win for

VIEW SHOWING THE GRADUAL PASSAGE FROM ROCK TO SOIL.

In the right foreground is a small recent talus formed since the excavation was made.

plow-tillage land which is fit only for other and less unnatural forms of culture. Wherever the inclination of the slope exceeds about 5° of declivity (or one in twelve), except where the soils are remarkably permeable to water, it may in general be said that justice to mankind demands that the field be as far as possible exempted from the influence of the plow. Such land should be retained in grass or in orchards, or used as a nursery for timber.

Although our land is still almost of virgin fertility, a heedless neglect of our duty toward it has led to the destruction of the soil over an aggregate area of probably not less than 4,000 square miles. This means the loss of food-giving resources which would be sufficient, with proper care, to support a population of about one million people. Besides this annihilation of the earth resources in the area where the soils have been allowed to wash completely away, a vastly more important though less visible damage has been done by the partial destruction of the nutritive layer, in the course of which it has been thinned and worn to a point where it will no longer pay the cost of tillage. When brought into this impoverished condition it is, in the common phrase "turned out," or, in other words, committed to the slow process of redemption which the natural agents of soil-making may bring to bear. It is fortunate that over the most of this country, perhaps over three-quarters or three-fifths of its tillable land, the surface has such a gentle inclination, and the native grasses form so firm a sod, even on exhausted land, that these abandoned fields do not wash away, but are allowed slowly to recover from the brutal ill usage to which they have been subjected.

The total area of these abandoned fields which lie in the States of Virginia, Tennessee, and Kentucky alone amount, according to the estimate I have made with some care, to between five and six thousand square miles, or about one-thirteenth of the total tillable surface of these States. Taking the lands of the United States as a whole and basing the estimates on numerous local inspections of the conditions of diverse areas, I am satisfied that at least five per cent of the soils which have in their time proved fertile under tillage are now unfit to produce anything more valuable than scanty pasturage. The average impoverishment of the area which has been subjected to the plow is not to be computed; but from the statistics of grain production, as shown by the successive censuses of the country, it seems not unlikely that it amounts to 10 per cent or more for the whole country. It is greater in the South and in the new States of the Mississippi Valley than in the eastern portions of the Union, because careful tillage has long been made possible in the last-named section by the high price of farm products.

A portion of this waste of our soils has been inevitable and not blameworthy, for it has been due to the rapid extension of the population over districts so remote from markets that it was only by methods of tillage which taxed the earth to the utmost, that any profit could be had from farming. We have, indeed, thus paid away much of our birthright in the fertility of our soils as the price for a swift expansion of our population. Although there may be a certain justification, as above noted, for a portion of our soil-wasting, a larger part of it has been brought about by an ignorant neglect of certain simple but inexpensive precautions which to a great extent would have saved the progressive decline in the productive value of the earth. Although these precautions are almost self-evident, it may be worth while to set them clearly and briefly before the reader.

First of all, every husbandman should clearly understand that the process which he follows in obtaining crops from the soil is essentially unnatural. In the state of nature all that the vegetation takes from the earth is promptly returned to it by the processes of decay. Therefore it is evidently necessary to limit as far as possible the tax laid upon the earth in our artificial treatment of it, and to provide in every practicable way for the replacement of the substances removed by the harvests. The details of methods by which the pauperizing of the soil may be avoided belong in the main to the science and art of agriculture; there are, however, certain questions in relation to these matters on which the geologist may be allowed a word of comment. The natural method of preventing the progressive thinning of the soil due to the material removed by crops and to the washing away of its substance in the state of mechanical suspension is by deepening the layer of detritus and making it as open-textured as possible. This end can best be attained by thorough tillage, especially by the process known as subsoiling, whereby the compact lower layers of the soil or even the decayed portions of the bed-rock, if they be near the surface, may be disrupted and the matter put in a condition to become dissolved and made available to plants. In this way, while the surface may still wear down at a rate much more rapid than when it is forest-clad, the lowering of the base of the soil may be made to keep pace with it. Moreover, by keeping the detritus near its original thickness and also open-textured, a larger portion of the rainwater will enter the earth and, moving slowly toward the open drainage channels, may not scour away the débris. By this downward extension of the soil the mass of detritus within a given area which can yield plant food is likely to be increased, and so the earth becomes better fitted to the peculiar drain which tillage imposes on its mineral stores (see Pl. XXXI).

Our common method of shallow plowing continued year after year to the same depth tends to create a few inches below the surface an artificial hardpan formed by the pressure of the base of the plow. At best this instrument of tillage is a rather clumsy contrivance for the end it seeks to accomplish: its action is that of a wedge driven through the earth, which divides and overturns the soil above the share while it compacts and smears the lower portion over which it slides into a mass which, if the material be at all clayey, as is the case with all good soils, becomes in a few years almost as impervious to water as a roof. The result of this action of the plow is to limit the penetration of the rain-water to the upper part of the detritus, which is loosened by tillage, and also to prevent the penetration of roots and increase the danger of the materials washing away.

These evils may be in a great measure avoided by a few simple expedients. When only the common plow can be used, the depth of the furrow should be varied from year to year so that the compressed level where the heel has trod may often be broken up. Where possible some subsoil-breaking implement should frequently be used to open the lower portion of the detrital layer to the entrance of water and of roots. Among the many means by which these ends may be attained we note the familiar device of sowing certain crops, such as red clover, the plants of which have strong tap roots; these, save in very compact earth, will penetrate to a greater depth than that to which the plow is ordinarly driven and thus serve to make water ways and paths for the roots of weaker species into the subsoil.

Although a certain amount of gain may be had by varying from season to season the depth to which the plow is set and a yet greater advantage from subsoiling, every description of plow is more or less injurious to the soil through the smearing and compacting action which it inflicts upon it. It is a most unfortunate limitation of agriculture that spade tillage is so much more costly than that accomplished by the plow. One of the greatest desiderata in connection with our farming is an instrument which will overturn the earth in the manner of a spade—that is, without compacting the lower portions of the deposit in order to overturn the upper parts. No one who has carefully compared the condition and product of fields which have been long tilled by these two instruments, the plow and the spade, can doubt the destructive effect of the first-named tool. There seems to be no essential mechanical difficulty in the way of the inventor who would seek to produce an instrument which would delve the earth as does a spade. The amount of power requisite to effect the overturning should certainly be much less than that expended in the rude rending work which the plow effects.

It is a common practice to remove all or nearly all the woody matter of our crops from the soil on which it has been produced. The result of this process is that in a few years the earth comes to lack that share of decaying organic substance which its normal functions require. It should be remembered that in the state of nature soils have commonly from 5 per cent to 20 per cent of their mass composed of such organic débris; any considerable decrease in the amount of this material will more or less completely arrest the processes by which mineral substances are gradually brought into a state in which the plants can make use of them. The introduction of this organic débris is partly accomplished in tilled fields by allowing the weeds and other wild plants to occupy the surface during a period of fallow. The waste from this growth when turned in with the plow serves in a certain but generally insufficient measure to secure by its decay the conditions necessary for the solution of rocky matter in the earth. When, as is often the case, this vegetable waste is burned before the ground is plowed, although the mineral materials are returned to the soil in the form of ash, the principal end is not attained. The only really effective way of maintaining the due share of organic matter in soils is to plow in well chosen green crops. Even where, as on a small portion of our American fields, barnyard manure is occasionally used, the quantity of vegetable waste thus introduced into the soil is likely to be inadequate.

Wherever there is a considerable exportation of crops from any district it is impossible, save with extraordinary care, to avoid a diminution in the fertility of the soil. The sale of each bushel of grain or other product of the fields permanently removes a part of the resources of the earth. However carefully the barnyard and other manures may be gathered and returned to the field, this progressive waste is inevitable. If the soil retains its fertility it is because of its speedy descent into the underlying rocks. The rate at which the exhaustion proceeds is generally in proportion to the immediate success of the agriculture. Farming is, in general, a process of selling the birthright of those who own the land.

A century ago it would have seemed to a considerate observer aware of the principles above laid down that the progressive decadence of our soils was something which could not be contended against, and that the process was sure in the end to bring every land to the state in which its food-producing resources would be exhausted; but within the last 50 years we have learned to seek in the mineral kingdom for various chemical substances which are removed from the soil by crops, and which may thereby be returned to it in quantities required to maintain its fertility. This use of mineral fertilizers, at least on an extended scale, began with the introduction of guano, the dried waste of bird life which had accumulated on the islands of a nearly rainless district off the west coast of South America. Guano appears to have been extensively used by the Peruvians long before the conquest of the continent by the Spaniards. It was first brought to Europe and introduced to the attention of agriculturists about the year 1840. Shortly after that time a very extensive trade in the substance was established, and in the course of twenty years it led to the substantial exhaustion of the principal fields of supply. Owing to the increase in the price of this substance the attention of chemists was called to the possibility of making similar fertilizing materials, using as a basis the geologic deposits of lime phosphate, soda, and potash. At first this new art was practiced for the purpose of adulterating the natural guano; but, unlike a majority of such sophistications, it has led to a new and most important industry—that of manufacturing mineral manures.

The greater part of these artificially produced fertilizers consist of a mixture of natural earths containing lime phosphates, etc., along with fish-waste, blood, and other materials which afford ammoniacal materials. It is now, however, becoming clear that excellent manures, though they act less quickly upon the soil, may be produced altogether from the mineral kingdom. Even the ammonia required to make compounds the most speedily effective may be obtained from materials formed in the process of making gas or coke. It seems likely that the principal ingredient of these fertilizing combinations most required in ordinary crops and most deficient in soils, viz, the lime phosphate, may soon be afforded in such quantity that it will be an easy matter each year to restore to the earth all the substance which is withdrawn by cropping. So rapid is the present advance in the arts whereby avail is made of the mineral manures, that we may confidently anticipate the time when from the rocks of the deeper earth we shall obtain the means for restoring fertility to all soils where a reckless neglect of the fields has not allowed the framework of débris to be utterly destroyed.

The amount of these mineral manures now known to exist is great enough to meet the demand which would arise if the fertility of our soils were to be perfectly maintained by their use for centuries to come, and it seems likely that we have but begun to discover deposits of this nature which exist in different parts of the world. Within five years, in Florida alone, areas underlaid by lime phosphate have been brought to the knowledge of the world which contain a sufficient quantity of that material to restore the fields of North America for generations to come. Soda may be had in limitless quantities from common salt, and potash abounds in a number of minerals, such as feldspar, from which the extraction is difficult, and in glauconite or green sand, whence it may readily be separated. It seems likely that in the progress of art the methods of preparing this last-named substance from common varieties of rocks will become cheaper, and so the last of the more indispensable and most easily exhausted of the fertilizing materials of the soil may be supplied to the needs of the husbandman. When these mineral manures come into general and skillful use agriculture will enter on a new stage of existence; it will no longer be an art so gross in its methods as to lead as now to a general destruction of the soil, but a science by whose well devised means the fruitfulness of the earth will be constantly maintained and enhanced.

The influence of soil products won by tillage on commercial and other lines of development deserves a more extended notice than can be given here. More than any other creature, civilized man has come to depend upon the earth for a variety of needs, of which the primal and most important are served by the soil. Although climate, geographic position, and the resources of the deeper earth have much to do with the prosperity of our kind, the character of the soil as regards endurance of tillage and the crops which it nurtures is of the first importance. It is impossible for us to consider this matter broadly, but a few instances may be given which will serve to show the reader how on this continent the characteristics of soil have affected the history of its population in various regions.

One of the first of the peculiar effects on the history of civilized man in America brought about by the nature of the earth is found in the circumstances attending the culture of the tobacco plant. This vegetable proved peculiarly well suited to the soil of Virginia and Maryland, and therefore, even in the first century of the history of the colony, it became the principal staple in their trade with the Old World. On the returns given by this industry the political and social culture of the central colonies of the Atlantic coast chiefly rested. To it also in the main was due the profitable and rapid extension of African slavery. In a similar manner the soils of the more southern States proved in the present century well adapted to the culture of cotton, a crop which led to the establishment of large and numerous plantations, and thus to the further diffusion and firmer establishment of the slaveholding system. Though in part due to climatic features, this system by which the descendants of Africans were held as slaves is principally to be accounted for by the characteristics of the earth in southern States. If that part of the country had been provided with soils like those in New England it would have had a very different economic and political history.

We perceive the effects of soil on the diffusion of slavery in a yet clearer manner when we examine into the features characteristic of the local distribution in States in which it was by law established. In the plain lands, where the soil is adapted to cotton or tobacco, slavery was dominant, indeed we may say universal; but in mountain areas, where the small fields could not be profitably tilled by slaves, the institution never found a place. In eastern Kentucky and in parts of western Virginia and North Carolina negroes have always been exceedingly rare. There are populous counties in this region where no member of that race has ever been a resident either as slave or freeman. This absence of slaveholders in the hilly and mountainous portions of the South naturally had a great effect in the issue of the civil war which that institution caused. The people of this rugged country of the Appalachians did not to any extent sympathize with, and often took up arms against, the slaveholding communities of the lowlands. As this nonslaveholding district almost cut the South in twain, its influence on the conditions of the contest were momentous. Something like the same effect was perceptible in single States. Thus in Kentucky we find that a majority of the people on the richer lands where it was profitable to keep slaves were led to cast their lot with their kindred of the same class in other parts of the South, while those dwelling on poorer soils, where they knew nothing of the institution, were overwhelmingly on the Federal side in the debate. It seems almost certain that if Kentucky had been provided with a uniformly rich soil, suited to large plantations, it would have joined the other Southern States, to the great advantage of the Confederates and to the serious injury of the Federal cause. In a struggle so nearly matched this difference might have been of decisive importance.

Not only in the doubtful issue of the war but also in the more computable triumphs of peace the character of soil in this country has greatly influenced the history of its people. A striking instance of this effect may be noted in the advance of population from the seaboard district into the Mississippi Valley. Thus, while it required nearly two centuries for the English colonies of the Atlantic coast to break their way through the rough country of the Alleghanies and then through the dense forests of the lowland region in the eastern part of the Ohio Valley to the margin of the prairie land of the West, fifty years has served to win to their uses the yet greater area of the timberless or lightly wooded country of the Far West. Although something of this speedy contest must be attributed to the rapid diffusion of railway and steamboat transportation, yet more is to be allowed to the influence of the open nature and easy subjugability of the soil in these areas. It is clearly one thing to push forward the frontiers of a civilization where each acre has to be slowly and laboriously stripped of its timber and, if it be in a glaciated district, of its bowlders also, and it is quite another undertaking to extend cultivation over a prairie district where a plowman may turn a straight furrow for miles away from his starting point. An incidental but closely related effect of this open state of the land in the central and western portions of the Mississippi Valley is seen in the rapid increase of population in this country and the great commercial prosperity which it has attained. The influence of the breadth of this region has not only been felt in the States which have sprung up like magic in the Northwest, but in the Eastern States as well. The population of the Unites States would probably at the present time be some millions less than it is if the central part of the continent had been densely wooded as far west as the one hundredth meridian.

It would be possible very much to extend the citation of these instances in which conditions of soil have determined, in a certain measure at least, the history of our people; we can, however, instance but one other example serving to show how even the system in which the land is held in ownership may be shaped by the character of surface material. The island of Nantucket, Massachusetts, owing to the fact that nearly the whole of its area is composed either of glacial moraine or of extensive sand plains which usually attend these heaps of débris, has, save in limited parts, a very thin soil not generally fit for tillage. The result is that until within a few years the greater part of the land was held in common, or jointly by the people, each owner being entitled to a share in the pasturage rights of the area. If he held, for instance, twelve such rights, he could turn out a dozen sheep to graze on the uninclosed field. Thus, owing to the nature of the soil, we had here perpetuated, in the latter half of the nineteenth century, a form of land tenure which is a survival from a remote time and represents a generally disused system of holding real property.

EFFECTS OF SOILS ON HEALTH.

The influences of the soil upon the health of man and that of his domesticated animals, though perhaps less considerable than those which directly arise from climate, are still of great importance. The cause and nature of these effects are extremely varied and deserve more attention than they have received. It is only in recent years that the nature and origin of diseases have been to any extent accurately known, and therefore the time of such studies has been brief. It will therefore not be possible to make many definite and readily comprehensible statements concerning this division of our subject.

The action of soils in producing or promoting disease in animals or man appears to be due to at least three different causes, viz:

First. The quantity of water retained in the earth immediately determines the humidity of the surface of the soil, and this may have a direct effect on the comfort and health of man and beast.

Secondly. The conditions of this soil water, as well as of the organic matter mingled with it, have a decided influence on the nourishment of many forms of bacteria which it is now well known are sources of disease. The germs of such maladies as cholera, typhoid and malarial fevers, tetanus or lockjaw, and numerous other maladies appear generally to require a residence below the surface of the earth before they can propagate their effects. In fact the larger part of the diseases which occur among human beings and probably a great number of those which afflict our domesticated animals appear to be traceable to the action of certain microscopical organisms that inhabit the soil in the regions where the maladies occur.

Thirdly. Some influence of the soil upon health is due to the quality it gives to drinking water obtained from ordinary springs or wells. Although, for convenience of presentation, we may thus separate the influence of ground water upon health into these three classes, the groups are in fact not thus distinct, but are inextricably blended.

One of the immediate effects of excessive humidity of the soil is to keep the feet of creatures which tread upon it in a condition to favor disease. Thus sheep in wet pastures are more likely to suffer from foot diseases than those in dry fields, the continual moisture of the parts making them a suitable nest for the development of certain germs. Dwellings of men are made humid by excessive ground water, which also favors the growth of certain noxious organisms. This is well shown by the coating of mold which often forms in the lower parts of houses, where the earth is soaked with water. Although the more common forms of this growth are not detrimental to health, the circumstances which favor their development appear to lead to the multiplication of disease-bringing spores. There are other direct evils connected with excessive humidity. When the air is very wet, as is the case near very humid soils, it appears to have a lowering effect on the vitality of men—at least when they are in certain states of health.

From a sanitary point of view the direct effects of excessive ground water are evidently of small consequence as compared with the secondary influences of this evil, which are due to the nurture and dissemination of the germs which it induces. It appears probable that the spores, by means of which many diseases are propagated, undergo multiplication altogether in the organic matter contained in the soil. In the opinion of trustworthy observers the development of these germs takes place most effectively, and they are most likely to be discharged into the air in those regions where the vertical range of the ground water varies greatly, especially during the warmer part of the year. The reason for this is, probably, that when the vertical oscillations of the ground water occur the air is alternately drawn down into and expelled from the interstices of the soil. As this air enters it bears with it quantities of germs which, descending along with the rainwater, plant themselves upon decaying bits of animal and vegetable matter which the earth contains. If, after these spores have multiplied, the soil water again rises to the surface, it bears the crop with it, leaving the material on the top of the ground, where it may be scattered by the wind. When the soil water rises the contained air is expelled and may also bear with it a share of the noxious materials. Where the water of the soil remains at nearly a level the germs are not only less likely to enter the earth, but those which develop there are unable to escape from their underground prison and perish where they grew.

This view of the action of oscillating ground water finds much support from the experience of men in and around extensive morasses such as the Dismal Swamp of Virginia and North Carolina. About the margin of that great area of marshes, where the ground is alternately wetted and dried to a considerable depth, the people suffer from ague, a disease which is generally believed to be caused by some species of germ developed within the earth, but in the interior of the swamp, where the ground water varies little in its height from one season to another, there seems to be a relative, or, in cases, an entire immunity from this malady. Similar evidence is found in the history of intermittent fever in regions which have recently been subjected to cultivation; thus in many parts of the Ohio Valley the early settlers suffered much from this disease, but as obstructions to streams were gradually removed and wet places drained, so that soil water was no longer brought to the surface, this disease has to a great extent disappeared. There seems to be good reason to believe that where the earth has had a chance to become charged with seeds of disease, as about dwellings and cemeteries, any overturning of the soil may lead to the propagation of maladies through the mingling of the spores and the air thus brought about. In the open fields the same effect on germs of soil are doubtless produced, but in such localities spores probably belong to species which are not so likely to be harmful to man as those which develop about habitations or in the resting places of the dead.

The health of people in Holland, in the fens of eastern England, and in similar wet districts in many other parts of the world seems clearly to show that, whatever be the way in which it acts, a variable level of underground water tends to breed disease, while its permanent position, even if it remain near the surface, is not inconsistent with the good health of the inhabitants. So long as the fens of England and the swamps of the Netherlands remained in their natural state and underwent frequent and extensive changes of water level they were generally the seats of malarial disease. Now that the drainage system retains the ground water at about a uniform height these maladies are rare.

In the ideal condition of a tilled district the level of the soil waters is likely to be favorable to health. The aim of the husbandman is to maintain the earth in a state where the water rarely, if ever, rises to the surface. Care as to this point is most desirable, because where water emerges from the soil or stands upon it the effect is to take away by the leaching process a much larger amount of soluble materials than ordinarily escapes by drainage which passes to the stream by way of the spring. Thus the use of underground drains, which serve to keep the soil water at a tolerably definite level, is of great advantage to the earth by restricting the leaching process, and it incidentally serves to diminish the danger which may arise from the escape of germs.

There is reason to believe that the growth of certain kinds of germs within the soil is in a way helpful to fertility; it is indeed likely that the process by which various important substances are brought into a condition to be assimilated by plants is, in certain ways, dependent on the action of these minute organisms, so that the spore-breeding work of the soil, which now and then leads to the injury of man, is only an incidental part of what may be an essential function.

There is reason to believe that, owing to the peculiarities of certain soils, they become especially suited to the development of particular kinds of germs. Thus in certain districts in and adjacent to Long Island, New York, the disease known as tetanus, or lockjaw, is of unusually common occurrence among men and animals. It is the opinion of experts in medical science that this malady is caused by some species of soil-inhabiting bacterian which invests this part of the country. It is observed that a wound which is formed by any object covered with earthy matter is particularly likely to give rise to the disease. Although this malady has been common in parts of Long Island for many years, the evil has never spread to the contiguous portions of the shore east of Point Judith. As there must have been abundant opportunities for the spread of the germs in this direction it seems reasonable to attribute their failure to extend to some peculiarities of the soil covering.

The last effects of the soil upon health which we shall notice are those arising from the use of drinking water derived from this detrital layer. Injuries from this source are commonly due to the fact that ground water is usually full of germs of various kinds developed in that part of the earth from which the spring or well drains. It may often happen that the water flows through the earth for a distance of hundreds of feet before it attains the point where it is taken for use. In the course of this journey it generally becomes abundantly charged with spores. The greater part of these germs are innocuous, but if the earth contains the organisms which produce cholera, typhoid fever, or other ferment diseases, it is quite possible that a very small portion of the soil water can convey the disease.

Besides the disease-breeding organic germs, ground water also in many cases contains various mineral substances which may be harmful to man or the animals which he associates with his life. A familiar instance of this is found in the effects arising from the large amount of limy matter which exists in the ground water of most limestone districts. This substance comes into a state of solution through the capacity which carbonic-acid gas gives to water for taking up and dissolving various minerals. This gas is derived from decaying organic matter in the soil; but for the presence of this dissolved gas the ground water would have a mere trace of lime in solution, but owing to its presence the fluid is able to take up a notable quantity which, though invisible, makes its presence evident by the hardness and flat taste which it imparts. A common effect of this excess of lime is to produce in the bodies of men, and sometimes in those of domesticated animals as well, concretions of a calcareous nature which cause disease. In certain parts of limestone districts of this and other countries maladies due to this cause are of very frequent occurrence.

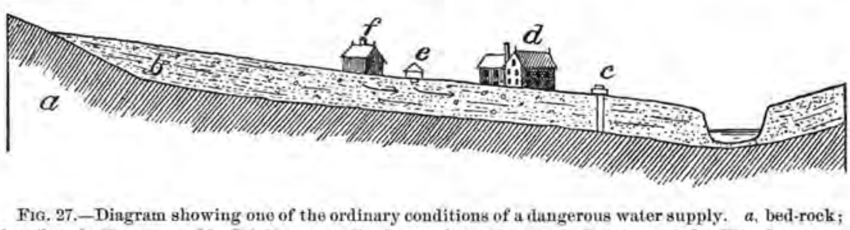


FIG. 27.—Diagram showing one of the ordinary conditions of a dangerous water supply. *a*, bed-rock; *b*, soil and other permeable detritus; *c*, well whence domestic supply is taken; *d*, dwelling house; *e*, cesspool; *f*, barn; the arrows show the direction in which the soil water moves.

Where the ground water is suspected of being the source of disease, the evils it entails may readily be avoided by the use of cisterns to which only the water draining from clean roofs has access. Except in cases where such a supply is defiled, as by a resort of pigeons to the roof or by careless construction of the reservoirs which permits the ingress of soil water, they afford absolutely safe sources for domestic use.

It seems likely that, with the advance of medical science on the lines of its present extension, many diseases of a geographical and limited nature, the causes of which are yet unexplained, will be found to be attributable to the action of the soil in the regions where they occur. Thus the peculiar malady called goitre, which is limited to certain mountain valleys, is now by some students explained as being due to the action of the water which the people drink. In the present state of the science of hygiene the only certain points of value which we have to consider concern the influence of the soil water on the development and diffusion of germs. Where the domestic supply is obtained from the earth it appears essential to the health of a household that the spring or well should be so placed that none of the waste from the dwelling, barns, or stables can contaminate it (see Fig. 27). It appears, furthermore, important that proper drainage should be so arranged that the level of the soil water is not liable to sudden alteration. Furthermore, it appears to be undesirable to have the soil near the dwelling overturned while the house is occupied. This is especially the case where the residence has been long in use.

Although the distance to which germs may be carried in the underground water is not readily determinable, it may be assumed that there is no safety in using the flow from a large spring where any part of the valley in which it lies is occupied by dwellings the sites of which are above the point of exit. The underground channels of such fountains often have a very extended and circuitous course; the water ways, so far as they are carved in the bed rock, are wide open, so that poisonous matter may in a few hours be transported through them for a distance of several miles.

If the space of this report permitted, many instances could be given in which cholera and other fatal diseases had thus been conveyed for great distances. Springs of slight creeping flow and ordinary wells where the water does not enter at one point but seeps in from the side of the excavation, do not usually drain from a distance of more than 200 or 300 feet from the point where the water escapes. It should, however, be remembered that there is sufficient evidence to prove that germs of certain diseases may remain in the soil for several years with undiminished vitality. These germs may by some chance journey go unexpected and considerable distances. Where ground water is used at all for domestic purposes, the only safe way is to take it from a level above all sources of possible contamination.

MAN'S DUTY TO THE EARTH.

The foregoing considerations concerning the origin and nature of soils, though but a brief and inadequate presentation of the subject-matter, will probably convince the reader that this part of the earth which at first sight seems to be a mere mass of ruin and abasement is really a marvelously well ordered and beautiful portion of this sphere. In it the celestial and terrestrial energies combine their work to lift the mineral elements up to the higher planes of sentient life. From it comes the sustenance of plants and animals, both of sea and land. The frame of man is the product of its forces; his form is indeed but a bit of soil uplifted for a moment to the noblest shape of life, then bidden to return to the garner of the earth. Through the ordered and harmonious interaction of the complicated forces which effect in the soil the combined decay of rocks and of organic bodies, materials which seem base and revolting to many fastidious spirits are made the unique basis of all sentient existence. When we perceive that civilization rests on the food-giving capacities of the soil, when we perceive that all the future advance of our kind depends upon the preservation and enhancement of its fertility, we are in a position to consider the duty which we owe to it. This obligation bids us nurture and care for this part of the earth with an exceeding tenderness and affection. It bids us ever remember that it is enriched with the dust of our progenitors, and is teeming with the life which is to come.

In shaping these motives to practice it seems first of all necessary to clear away those crude and indeed painful notions which lead men to look with contempt and disgust upon the soil. If there be any of the great truths of modern learning which more than any others deserve to be imprinted on the minds of youth, it is these lessons as to the nature and function of this beneficent part of the earth. Only through knowledge can we hope to bring men to a proper understanding of the value of the trust which is in their keeping. Until by education we bring people to a consciousness that the wanton neglect of their duty to their kind which an improvident use of the soil reveals is a form of treason to mankind, we can not hope to implant in them a proper sense of responsibility in the management of their great inheritance.

It is characteristic of our time that men seek to clear away evils by means of law. There is a general discontent with the results which have been obtained by the system of individual ownership of land and a growing disposition to qualify and limit the nature of that possession. In considering the questions as to the ways in which the earth's resources shall be administered, it is clearly necessary to bear in mind the needs of exceeding care in the preservation of the fertility of the earth. As long as lands are in the state of forest or prairie, the admirably adjusted forces of nature will insure their preservation. When they become tilled, it is imperative that they be peculiarly well guarded; any legislation concerning the tenure of land should be devised in view of the fact that we need to have not less but more personal interest and sense of responsibility in the management of these problems. It is not proper here to consider the probable effect of the various proposed modifications of the land laws. It seems, however, fit that any such changes as may be made should be planned with a clear understanding of the very serious nature of the needs. When in the future a proper sense of the relations of the soil to the necessities of man have been attained and diffused we may be sure that our successors will look back upon our present administration of this great trust with amazement and disgust; they will see that a state of society in which men took no care of the rights which the generations to come have in the earth lacks one of the most essential elements of a true civilization.

THE LAFAYETTE FORMATION.

BY

W J McGEE.

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ILLUSTRATIONS.

THE LAFAYETTE FORMATION.

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CHAPTER I.

THE AREA OCCUPIED BY THE FORMATION.

THE PHYSIOGRAPHIC PROVINCES.

Eastern United States falls naturally into five well defined provinces. Beginning on the west, there is the Mississippi valley, a low-lying land of prairies in the north, of woodlands in the northeast, and of luxuriant forests and smooth savannas in the south. Next follows the province sometimes called the Cumberland plateau, a land of rounded hills, rugged valleys, and deep ravines, generally forest clad. The boundary between valley and plateau is ill defined. Beyond the plateau rise the long, low mountains of the Appalachian system, which forms a notable physiographic feature, and one unique among the montanic tracts of the globe by reason of the length and symmetry of the component ranges. This constitutes the third natural province.

The Appalachian Mountains stretch from central Alabama, where their corrugated strata rise from beneath newer deposits, to southeastern New York, where the symmetric corrugations die out. Other mountains rear their massive bulk farther northeastward, but the Helderbergs and Catskills belong rather to the plateau province than to the Appalachian series; the Adirondacks constitute a unit by themselves; while New England, with its peaks and foothills and undulating plains, may be either a distinct province, as defined by the systemist, or a modified homologue and extension of the province next eastward from the Appalachians. The western boundary of the Appalachian province is commonly vague, for the flat-lying strata of the plateau become corrugated gradually; but the eastern boundary is commonly trenchant, since the easternmost element for many hundred miles is a rarely interrupted ridge of hard quartzite. This rugged range, broken only by the water gaps of the James, the Potomac, and the Susquehanna, and by a few wind gaps, lay beyond the realm of the mighty Powhatan, and, half hid in the hazy blue of the distance, was long the horizon of the Virginia pioneer; and all the way from the colony of Lord Baltimore, on the Patuxent, to the settlement of the Byrds, on the James, the haze-haunted and vision-limiting barrier became the "blue ridge." Long afterward it barred even the most adventurous home-seekers from the limestone-floored valley at its western base, the fair and fertile Valley of Virginia, or Shenandoah Valley, or Cumberland Valley, as designated by the settlers in its different portions.

East of the Blue Ridge lies an undulating tract, stretching from Georgia to New Jersey, lower and less deeply ravined than the Cumberland plateau, sometimes rising into scattered knobs or isolated hill ranges, but commonly inclining gently eastward, once among the fairest of the Indian hunting grounds; but the aboriginal hunters were displaced by the descendants of Lord Baltimore, Colonel Byrd, and their contemporaries that the game-filled woodlands might be transformed into tobacco fields. Clear rivers heading in the Blue Ridge or in the mountain fastnesses beyond traverse it; other streams gather their waters on the plateau itself, and the uniting waterways cut deeper their channels as they approach the eastern margin of the plateau on their way to the sea. So the configuration of the plain varies from west to east. Toward the western margin isolated hills, pygmy homologues of the Blue Ridge, relieve its monotony, though the valleys are shallow; toward its eastern margin the waterways are deep, though the hills are low and broad: in the west the features are embossed; in the east they are incised. This is the Piedmont plateau. It is the fourth principal province.

In the Mississippi basin the rocks are flat-lying strata of limestone, shale and sandstone, with many nodules and sheets of chert. In the Cumberland plateau the strata are similar, save that they are more sandy and are lifted higher, so that the waters have cut their ways more deeply. In the Appalachian region the strata are again similar, save that they are less cherty and coarser in materials in certain beds, and that they are corrugated and lifted still higher; but in the Piedmont plateau the rocks are ancient crystallines (schists, gneisses, and granites), sometimes without definite structure, again obscurely bedded and strongly tilted, and often cut by veins of quartz. These crystalline rocks are deeply decayed, and the principal product of their decay is the "red land" soil of Georgia, the Carolinas, Virginia, and Maryland.

Between the red lands of the Piedmont plateau and the waters of the Atlantic, in the latitude of Virginia and Maryland, lies a lowland tract trenched by broad but shallow estuaries, primevally wooded, and before the advent of the whites the home of aboriginal fishermen whose kitchen middens, village sites, and scattered stone implements yet remain to reward the seeker for unwritten history. The present seaward limit of this coastal plain is the Atlantic shore line of maps. The common boundary between the realm of man and his air-breathing kindred and the realm of the lower orders of life is a line of the class first recognized and most strongly drawn by the geographer; yet from the standpoint of the student of earth changes it is a fortuitous and curiously evanescent demarcation. The terrestial limit of the coastal lowland is not the true limit of the province, for the land surface continues with scarcely modified configuration and unchanged slope a hundred miles beneath the waters of the Atlantic to a great scarp, comparable in height and extent with majestic mountain ranges, forming the continental margin. Moreover, the sands of the sea are scattered over the land portion of the coastal plain, while river channels meander through the submerged portion, showing that during the more recent eons of geologic time the sea has alternately advanced and receded over the whole breadth of the plain; and this is true not only of the middle Atlantic slope but in nearly equal degree elsewhere along the Atlantic and the Gulf.

This physiographic fact is fundamental: the forest-clad lowland skirting the coast is but half of an essentially indivisible natural province, of which the other half is submerged beneath a few fathoms of sea water.

The Mississippi Valley is vaguely defined; the Cumberland plateau begins with the limestone uplands of northwestern Alabama and ends with the Helderberg Mountains in central New York; the Appalachians stretch from central Alabama nearly to the Hudson; the Piedmont plain runs from Georgia and the Carolinas with diminishing width to the mouth of the Hudson, where it is supposed to terminate or to cross that river in a narrow neck and then expand to make most of New England; but while the lateral limits of the coastal plain are more clearly drawn than those of any other province, its longitudinal limits are more vague and much more remote. All New England is skirted by its subaqueous development, and its bulk is lifted above the present waters of the Atlantic in Cape Cod, in Nantucket and Marthas Vineyard, in Long Island and its lesser neighbors. The subaqueous portion of the plain continues southward without break save by submerged river channels beyond Cape Hatteras to the extremity of the Florida peninsula, while the subaerial portion, insulated in the north by the Hudson, recommences with Sandy Hook and expands rapidly southward, and, although interrupted by the bays of the Delaware, Susquehanna, and other rivers, and by the Albemarle and Pamlico Sounds, makes the coastal lowlands in a hundred-mile zone sweeping around the continental bulge of Cape Hatteras to the Florida isthmus; and probably all Florida belongs to this province. Thence the land portion of the province continues westward, fringing the extremities of the Piedmont and Appalachian provinces, stretching up the Mississippi in a relatively narrow point to the mouth of the Ohio, and thence sweeping southwestward in a zone 100 to 200 miles wide to the mouth of the Rio Grande; while the shallow Gulf waters are shoaled by a submerged shelf 50 to 100 miles broad, forming its legitimate extension.

So the submerged portion of the coastal plain stretches from Newfoundland to Mexico; the subaerial portion, which alone is open to observation by the student of earth lore, runs from Cape Cod nearly to

Yucatan, while the continuous lowland, which is of first importance in the present connection, expands from Sandy Hook to the Florida isthmus, and continues with scarce diminished width to the national boundary on the Rio Grande. Attention may be confined chiefly to this lowland, but it is to be constantly borne in mind that the coastal lowland is but half of the coastal plain. The entire plain is depicted in the map forming Plate XXXII, in which, be it observed, the contours are located with care, yet can be regarded only as approximations, by reason of the dearth of definite data, as well as by reason of the small scale.

The common boundary of the coastal plain and the Piedmont plateau is usually trenchant, though sometimes inconspicuous. Between the Hudson and the Tuscaloosa (or Black Warrior) the rivers cross it in cascades or rapids, and the boundary is thus known industrially and geographically as the "fall line." Between the Raritan and the Roanoke the rivers cascade from rock-lined channels of the Piedmont type into tidal estuaries, but farther southward the fall line is above sea level, the pools below the cascades rising from tide water on the James to 100 feet on the Neuse at Smithfield, 125 feet on the Wateree near Camden, 125 feet on the Congaree near Columbia, 125 feet on the Savannah at Augusta, 210 feet on the Ogeechee near Mayfield, 220 feet on the Oconee at Mellville, 250 feet on the Ocmulgee at Macon, 210 feet on the Chattahoochee at Columbus, 175 feet on the Tallapoosa near Tuskegee, 160 feet on the Coosa near Wetumpka, 150 feet on the Tuscaloosa at the town of the same name. Then the drainage lines fail to mark the boundary to the Mississippi at the mouth of the Ohio, 270 feet above tide; and thence southward the fall line is less conspicuous, though the rivers cross it at large angles, as on the Atlantic slope. Between the rivers the lowland and the plateau merge through an intermediate zone from a fraction of a mile to a dozen miles in width; yet from the standpoints of the systemist and the settler alike the provinces are distinct, even strongly contrasted. It is true that the boundary is never a cliff, and seldom a well defined scarp; it is equally true that the terrace plains recording the last submergence of the lowlands sometimes overlap the line of junction; it is none the less true that there are hills on both sides of the boundary, and that sometimes, particularly in the south, the lowland hills are nearly as rugged and more than half as high as the Piedmont hills; yet the boundary remains, notably in the middle Atlantic slope, one of the most strongly marked physiographic and cultural lines on the surface of the globe. On the one hand lie the crystalline rocks, giving origin to a characteristic soil through which all the streams from the greatest rivers to the smallest creeks flow in narrow gorges as a succession of cataracts or rapids, while on the other hand there is a series of incoherent and undisturbed deposits of clay, sand, and gravel, through which the waters move sluggishly in broad tidal estuaries in the north and narrower canals of low declivity in the south. In the north the line of the falls is also a line of deflection in the rivers; the great waterways maintain their courses through Appalachian ranges and Piedmont highlands alike, yet on reaching the coastal lowland they are turned aside literally by a sand bank little higher than their depth, and thence hug the hard rock margin for miles or scores of miles before finding their way into the open ocean. In the south the same tendency is displayed by the Tallapoosa and Alabama Rivers, and again very curiously by the Tennessee, although most of the southern rivers maintain their directions in passing from the more elevated provinces upon the coastal lowlands. Viewed systematically, the physiographic facts of the adjoining provinces are diverse as the rocks. On the one hand the waterways, the valleys in which they lie, the hills which they have fashioned, all surface features, are the product of base-level planation with subsequent active corrasion effected as the land was lifted, so that the courses of the waterways, the forms of the valleys, the configuration of the hills, the entire topography, reflect the characters of the rocks; while on the other hand the waterways, the valleys, the hills, the entire surface, represent the work of streams born upon plains newly emerged from the sea, and to-day either flow upon these plains or are superimposed upon older plains laid bare by the erosion of the newer, so that the waterways, valleys, hills, and entire topography reflect conditions growing out of the general attitude of the lowland and are independent of the rock characters.

Along the fall line, as in other parts of the world, the natural features have materially affected man and his activities: In the north, where the boundary is most trenchant, this effect has already been pointed out.

The pioneer settlers of the country ascended the tidal canals to the falls of the rivers, where they found sometimes within a mile clear, fresh water, the game of the hills and woodlands and the fish and fowl of the estuaries, and as the population increased, abundant water power and excellent mill sites, easy ferriage and practicable bridge sites. Here the pioneer settlements and towns were located, and across the necks of the inter-estuarine peninsulas the pioneer routes of travel were extended from settlement to settlement, until the entire Atlantic slope was traversed by a grand social and commercial artery stretching from New England to the Gulf States. As the population grew and spread, the settlements, villages, and towns along this line of nature's selection waxed, and many of them yet retain their early prestige; for Trenton, Philadelphia, Wilmington, Baltimore, Washington, Fredericksburg, Richmond, and Petersburg are among the survivors of the pioneer settlements; and the early stage route has become a great railway and telegraph line, connecting North and South as they were connected of old in a more primitive fashion.[1]

Although the boundary is less trenchant in the south than in the north, yet it remains the most important structural line of eastern United States. It marks the junction of the unconsolidated and practically undisturbed Neozoic clastics on the seaward side, at first with the Piedmont crystallines, then with the corrugated Paleozoic strata of the

[1]American Journal of Science, 3d series, vol. 35, 1888, p. 123.

southern Appalachians, next with the flat-lying Paleozoic strata of the Cumberland plateau and the Mississippi Valley, and finally with the sometimes horizontal and sometimes disturbed Paleozoic strata and ancient eruptives between the Mississippi and the Rio Grande; and on reaching it most of the streams, great and small, are broken by rocky rapids, great falls, or cascades. Over the southern Atlantic and Gulf slopes the boundary is an important cultural line. Most of the leading southern cities are built at the falls of rivers, and their industries are determined by the water power which the rivers afford. The rivers are commonly navigable below and unnavigable above the falls, and the original means of traffic were thus diverse, and the diversity persists in some measure to-day, while the soil on the opposite sides of the boundary is essentially distinct, so that the industries growing out of the soil and its products are commonly contrasted. Among the southern cities located through the influence of this physiographic boundary are Raleigh, Camden, Columbia, Augusta, Macon, Columbus, Wetumpka and Montgomery, Tuscaloosa, Little Rock, Arkadelphia, Austin, and San Antonio. Originally in the southern Atlantic and eastern Gul slopes the coastal plain was the land of cotton and the Piedmont plateau the land of tobacco, but as man has modified his environment, including even the nature of the soil, to his needs and his likes, the old differentiation has partially disappeared; yet to-day, as during the early days when the pioneer wrested the acres from nature's sway, the natural conditions are fairly reflected in the social conditions.

In the middle latitudes the five natural provinces are represented by as many distinct episodes in the settlement and industrial development of the country; and when the history of the conquest of America by civilized man is fully written, they will be found represented also by as many cultural stages and social aggregations. The shallow and pacific waters of the submerged coastal plain invited maritime adventurers to land and explore, and favored the development of those shoals of food fishes that first stimulated and afterwards sustained navigation of the Atlantic; the broad estuaries were the most attractive of the avenues leading to the interior, and their waters yielded the oyster and the shad and a score of other edible aquatic forms, while the smooth lowland invited agriculture; and the white adventurer displaced the aboriginal fishermen from river and lowland, and agriculture, water traffic, and fisheries flourished while yet the red lands beyond the fall line were barely trodden wilderness. But the peaceful pursuits of the lowland palled on the adventurer, and he pushed westward, attracted by the game of the woodland, the desire for conquest over nature and more primitive man, and the hope of gain for himself and his descendants. Some of these pioneers, impressed by the agricultural capabilities of the Piedmont red lands, tarried long among the lower hills, and the less intrepid were sifted out of the current by the Blue Ridge; and both classes remained to initiate that sedentary agricultural stage which long characterized the red-land region. The limited number of adventurers who crossed the Blue Ridge in the first tide of white invasion were hunters and trappers, who occupied the mountain land until displaced from the fertile valleys by a later generation of planters; and even to-day their descendants haunt the rocky slopes and summits, the shadowy gulfs, and tortuous ravines of the Appalachian Mountains. A handful of the hardiest of this class found their way through natural obstacles and through aboriginal hordes into the fairer land beyond the mountains, which they with their descendants and successors of kindred spirit gradually possessed, first as nomads and squatters, then as settlers with fixed places of abode, and finally as agriculturists, artisans, and traders. Meantime manufactories were built up along the fall line; iron mines were opened in the mountains and in the plateau; the lowland folk came to be noted for their activity and enterprise in manufacturing and merchandising, in fisheries and in water traffic; the planters of the Piedmont red lands made place and representation for themselves in legislative halls, in institutions of learning, in social life, and gave emphasis to a distinctive phase of American character; the hardy mountaineers for a time contributed brawn, brain, and bone to neighboring classes, but their descendants frittered their energies in primitive ways of life, and too many became Ishmaelites whose influence on civilization has ever been nil or bad; while the boldest and most untiring of the pioneers reached the transmontane land in which more prodigal nature freely rewarded effort, and their descendants have long since repaid with ample interest the blood first borrowed from the east. To-day human invention has annihilated space and multiplied time to such an extent that the classes mingle freely and industries merge, and the old distinctions fail; yet, here as in other lands, the interaction between the conditions of nature and the state of man is strikingly exemplified.

The area of the Mississippi Valley east of the great river and south of Lakes Michigan and Erie is some 200,000 square miles, and the mean altitude is 700 or 800 feet; the area of the Cumberland plateau between the Tombigbee and the Mohawk is fully 100,000 square miles, and the mean altitude is probably 1,700 or 1,800 feet; the area of the Appalachian zone measured between central Alabama and the northernmost corrugations in southern New York, and between the westernmost ridges of Kentucky and Tennessee and the Blue Ridge, is nearly 100,000 square miles, and the mean altitude may be put at 2,500 feet, the greatest mountains reaching 7,000 feet; the area of the more clearly defined Piedmont plateau, measured from the Tallapoosa to the Hudson, is over 100,000 square miles, and the mean altitude perhaps 1,200 feet; while the area of the coastal plain between Sandy Hook and the Mississippi River, including Florida, is not less than 250,000 square miles, and the aggregate area of the subaerial development, measured from Cape Cod to the Rio Grande, approaches 400,000 square miles, the mean altitude being less than 300 feet. This is two-fifths of the cis-Mississippi country, or more than one-eighth of the national domain.

Over 90 per cent or more of this vast territory the Lafayette formation once spread in a continuous mantle; over 60 or 70 per cent of the territory it stretches to-day in an erosion-tattered sheet, often buried beneath the Columbia deposits; and over 25 or 30 per cent of the territory, or more than 100,000 square miles, the wide-stretching formation forms the present surface.

This is the land of the Lafayette formation.

THE CONFIGURATION OF THE COASTAL PLAIN.

While the coastal plain of the systemist extends from the fall line to the submerged escarpment 100 miles offshore, the coastal lowland is but half so wide, reaching from the fall line and from the crystalline and Paleozoic terranes to the coast and coastal islands; and, moreover, for present purposes the New England extension of the lowland—Long Island, Block Island, Marthas Vineyard, Nantucket, and Cape Cod—may be neglected. Perhaps the southern portion of the Florida peninsula too should be excluded; for while the whole of this peninsula is now North American mainland, and while it is probable that this extension of our continent has participated in the continental movements of later geologic time, it is but a few score miles beyond its shores to lines and congeries of islands which are apparently nearly submerged ranges and peaks of an ancient land whose history is unlike that of the mainland. Limited thus, the coastal lowland runs from the mouth of the Hudson to the Rio Grande, including half of New Jersey, nearly all of Delaware, two-thirds of Maryland, two-fifths of Virginia, about half of North Carolina, one-half each of South Carolina and Georgia and the northern half of Florida, three-fifths of Alabama, nearly all of Mississippi, one-sixth of Tennessee and one-twelfth of Kentucky, small portions of Illinois and Missouri, one-third of Arkansas, all of Louisiana, and fully one-fourth of Texas, or an aggregate of nearly 350,000 square miles. This area falls into six natural districts.

Peninsular New Jersey is a broad, low ridge trending nearly parallel with the fall line, 200 to 300 feet high in its culminating summits, sloping down gently nearly or quite to tide level on the northwest and still more gently toward and beneath the sea on the southeast. The peninsula comprising Delaware and the "Eastern Shore" of Maryland lies so low and slopes so gently toward fall line and sea that the homologue and continuation of the New Jersey axis is barely perceptible; yet it appears faintly in the higher eminences a dozen or a score of miles beyond the fall line skirting the northernmost stretch of Chesapeake, Bay. The peninsula lying between the Potomac and Chesapeake estuaries, forming the "Western Shore" of Maryland, rises somewhat higher and displays still less notably the ridging parallel with fall line; yet the ridging is perceptible between the Patapsco and the Anacostia, and becomes conspicuous on the eastern shore of the Potomac between the Anacostia and the mouth of Acquia Creek.

Perhaps the most impressive and certainly the most significant features in the district of the coastal lowland lying between the Potomac and the Hudson are the ridge rising gently from the plain in the south and culminating in New Jersey and the trough dividing the ridge from the fall line. On maps the trough is more conspicuous than the ridge, for much of its length is occupied by the estuaries of the Potomac, the Susquehanna, and the Delaware. The lesser streams, too, have estuaries, so that this portion of the coastal lowland is nearly insulated; the isthmuses between the Raritan and Assanpink Creek, between Claybank Creek and Northeast River, between the Patapsco and the Anacostia, and between Potomac Creek and the Rappahannock are low, and but 15, 10, 20, and 5 miles in width respectively, so that, measured directly along the fall line, the Hudson is barred from the Rappahannock, 250 miles away, by only 50 miles of land and unnavigable water. The significance in dynamic geology of this trough, of the hills and cascades bounding it on the northwest, and of the less prominent ridge bounding it on the southeast, has already been discussed,[1] but the peculiar configuration deserves emphasis, because it distinguishes this part of the lowland plain from the remaining and much more extensive portion.

From Sandy Hook to Cape Charles the shores are low and flat, and are flanked in general by wave-built bars, sometimes attaining the dignity of keys, separated from the mainland by inlets and straits; the lower courses of the smaller waterways are broad stretches of marshland, through which the waters wander aimlessly perhaps for miles before breaking through the bordering banks of sand in narrow gateways, while the larger streams and rivers embouch either through marshlands or shoal estuaries more or less nearly cut off from the open ocean by the prevailing sand banks of the coast. Indeed, the characteristic feature of the coast is the wave-built bank of sand dividing ocean water from fertile land; it stretches out northward a score of miles in Sandy Hook; it stretches southward two score of miles in Cape May, and in its submerged extension half cuts off Delaware Bay; on one or both sides of each of the lesser bays it reaches out for miles, straightening a coast line otherwise deeply indented; Cape Henlopen and Cape Charles, with the long sea islands between, are simple expressions of this vast natural breakwater hundreds of miles in length yet only a few hundred yards in width. The building of this barrier and the drowning of the shores of the waterways, together with submerged forests and the observed recession of the shores, tell alike of the encroachment of the sea upon the land not only horizontally but vertically; for as the land

[1] Seventh Annual Report U. S. Geological Survey, 1888, pp. 616-633.

goes down the rivers' mouths are drowned, and the coastal sands are thrown higher and higher by the advancing breakers.

On the estuarine coasts of the New Jersey and Delaware-Maryland peninsulas the lesser waterways embouch in like manner through reedy marshes or in shoal inlets, and pygmy banks and bars are built up by the feeble waves of the landlocked bays—Delaware and Chesapeake. So all about the peninsular shores the configuration is like in kind, though varying in degree of development; the river mouths are drowned, marshes prevail, shoal bays are common, and a wave-built barrier of sand marks the coast, save where low cliffs rise directly from the tidal waters.

Within the shoreward zone in the northern district of the coastal lowland there is a characteristic configuration growing out of a past relation between land and sea which has more than local significance. In general the land is a gently undulating plain of low and broad divides faintly sculptured by the waters collected upon them, a plain nearly as smooth as when the erstwhile sea bottom rose and became dry land. This undulating plain forms three-fourths or nine-tenths of the surface, and it is trenched to a limited depth by waterways, shallow yet so broad that their combined area forms the remaining one-tenth or one-fourth of the surface. Each waterway occupies but a narrow channel, and the channel meanders through the broad level plain marking the flood height of the waters, 10, 20, perhaps 50, feet lower than the mean altitude of the principal plain. So the entire zone is low and faintly sculptured; it is divided into uplands and lowlands, the uplands composed of the sands of the former sea and the lowlands of the alluvium gathered and dropped by the streams in channels which they excavated when the land stood higher than now; the uplands run down to the sea or bay, where they rise into the modern wave-built barrier, while the lowlands merge with the tidal marshes or with the bottoms of the shoal estuaries; and farther inland the uplands increased in rugosity and the lowlands contract to channels or constricted valleys. These faintly defined uplands and lowlands of New Jersey, Delaware, and Maryland correspond to the "high grounds" and "low grounds" of the Carolina coast.

The interiors of the three peninsulas are plains diversified in different ways. Sometimes the surface undulates gently but irregularly, with the depressions deepened by waterways when the whole surface is drained of superfluous waters; elsewhere there are broad terrace plains, built of loam, perhaps sandy and gravelly, sometimes so smooth as to be ill drained, but perhaps sharply incised by narrow ravines; again, the undulating plains and the terrace plains, which are veritable *planes*, merge in various combinations. One of the combinations results sometimes in an eminence or a larger remnant of the undulating plain, completely encompassed by a terrace-plane in such manner as to form a rounded islet rising sharply, not from sea waters, but from a formerly sea-washed surface. Such are some of the culminating crests of this low-lying physiographic province in New Jersey, in Delaware, and on the eastern shore of Maryland within sight of the Chesapeake Bay, Maulden's Mountain and Bull's Mountain being the most conspicuous examples.

In brief, the northern extension of the coastal lowland is a broad, low ridge, faintly defined in the south, well defined in the north, transected by the Delaware and Chesapeake Bays, sloping gently toward the fall line and still more gently toward the coast; the local relief is feebly molded, and represents combinations of undulating plains and terrace plains in the interior, and combinations of undulating plains with some terrace plains, but more alluvial lowlands, toward the periphery; the waterways are narrow erosion lines in the interior and broad alluvium lined estuaries or marshes toward the coast; and the shore line is marked by a wave-built sand bank, high and broad along the open ocean, low and narrow about the landlocked bays.

The first natural district of the coastal lowland lies between the Hudson and the Potomac; the second lies between the Potomac and Neuse. These rivers, with the fall line on the west and the Atlantic coast line on the east, bound a plain, not ridged as that in the north but inclining seaward throughout—a generally smooth and monotonous plain, characterized by long inlets through which the tidal waters reach far into the interior.

The seashore of this stretch of lowland is much like that lying north of Capes Charles and Henry; the rivers expand toward their mouths, sometimes in reedy marshes, but generally in broad, though shallow, estuaries; these marshes and shallow estuaries are all but barred from the open ocean by a wave-built breakwater stretching with scarce interrupted continuity from Cape Lookout nearly to Cape Henry; but the breakwater is higher and broader and is separated from the land by broader sounds than in the north, because along this bulging coast, of which storm-swept Hatteras is the culminating point, the winds have a longer sweep and the waves a stronger impetus than along the concave curves of the northern shore.

Within the natural breakwater there is, as in the north, a zone made up of uplands and lowlands, the former so little higher than the latter that they would be distinguished with difficulty were not the lowlands here almost at tide level. So the lowlands may be bay bottoms, more miles in extent than feet beneath tide-water level; or tidal marshes, half time land and half time sea; or broad savannas which the highest tides just fail to reach, while the uplands rise in crenulate scarps a yard or five yards high, though the interiors may be smooth as the tide-fashioned stretches at present sea level.

Still farther from the coast there is, again as in the north, a zone of undulating surface with the depressions emphasized by waterways; but the zone is vaguely defined, and the undulation is less conspicuous than in New Jersey and the lower Maryland peninsula. Into this zone the flat-surfaced uplands of the coastal zone extend along the waterways, while the older terraces of the interior project into it on the divides; and it is commonly but a little way from the plain-flanked arms of the sea to the interior zone of prevalent terracing.

Toward the fall line, particularly near the Potomac, and over much of the lower land all the way from the Potomac to the Neuse, the surface is characterized by broad terrace plains, crenulate as to margins, smooth and monotonous as to interiors, and invaded by the labyrinthine ravines of minor waterways, sometimes far but again so incompletely as to give but imperfect drainage. These plains are more extensive than in the north; sometimes they circumscribe isolated buttes of older materials than their own components, but commonly their continuity is interrupted only by scarps of higher members of the series until they gradually disappear toward the fall line; together they form a series of broad, low steps rising from the present tide level to the Piedmont margin.

The fall line, no longer accentuated by the coincident trough produced by modern displacement, is inconspicuous in this district; the waters of rivers and smaller streams indeed cascade through rocky gorges from a generally higher province to a generally lower one; but between the rivers the transition from province to province is seldom marked by bluffs, never by cliffs, and generally by slopes so gentle that the common boundary is a zone rather than a line.

The third natural district of the coastal plain stretches from the Neuse River in North Carolina to about the Suwanee River in southern Georgia and Florida; peninsular Florida, beyond a vaguely drawn boundary crossing the isthmus from the neighborhood of St. Augustine to Waccasassie Bay, being excluded. This is a land of easy slopes, inclining gently from the fall line to the coast and followed by a simple series of drainage systems, the rivers becoming sluggish yet remaining distinctly fluvial rather than estuarine nearly or quite to their embouchures into salt water. Its characteristic feature is the pine-clad sand plain making up the greater part of the area; and scarcely less characteristic is the bifurcate or dendritic drainage of autogenetic type into which the unnumbered waterways fall.

The seaward margin of the lowland is marked by a wave-built breakwater in the north, where the storms break against the southern flank of the Cape Hatteras bulge of the continent; farther southward the breakwater shrinks and nearly fails, to be replaced between Cape Romaine and the Florida line by the cordon of sea islands, once famous for cotton, now richest of rice fields; still farther southward the natural breakwater reappears in the line of long low islands locally known as "keys." The coastal sand bank in the north is breached by river mouths and peninsulated by narrow sounds, yet it protects the contiguous marsh lands from the storm waves of the ocean; the sea islands are insulated by a labyrinth of sounds and straits and channels of brackish water, into which the rivers embouch and which at low tide embouch into the Atlantic; while on the northern coast of eastern Florida the elongated keys are nearly or quite insulated by narrow sounds of wonderful length, tenuity, and parallelism—the troughs separating the wave-built sand barriers of half a dozen episodes in continental rise and fall.

Within the coastal barrier, as farther northward, the lands all lie low, yet are divisible into low and lower lands—the "high grounds" and "low grounds," respectively, of the vernacular. The "high grounds" are remnants of a once continuous and uniform plain, now dissected by a plexus of flat-bottomed channels rudely arranged in systems of dendritic type, each opening through a single main stem into the sea, but all merging and anastomosing in endlessly complex patterns; and commonly each channel has been expanded into a plain, rods or furlongs or even miles in width, through which a slender stream meanders. The sea islands, with their labyrinths of anastomosing sounds and straits and channels, constitute "high grounds," with the intervening "low grounds" submerged; and the intercoastal zone duplicates this condition, save that the "low grounds" are a few feet or yards above tide level. The condition of this zone records continental history in characters easily read through the aid of geomorphology; it tells that the lands, once sea bottom, rose until the waters drained away, carving dendritic channels and channel systems as they ran; that the new-born land rose so far and stood so long above its present level that the broad valleys were carved out; and that it subsequently sank so far that erstwhile active streams grew sluggish and lined their valleys with broad sheets of alluvium constituting the "low grounds."

Inland of the intercoastal zone lies the broad belt of pine-clad sands by which the district is characterized. This vast plain undulates slightly and its depressions are slightly accentuated by waterways; yet in general the undulation is but an expression of the old terrace scarps long since broken down because of the friable material, and of the wide-branching drainage ways, once sharp-cut ravines as in the terrace plains of the north, but now rounded as to bottoms and soft contoured as to sides.

Toward the Piedmont boundary the land stands higher, the streams are more active, and the valleys are deeper, while between the streams the surface undulates more decidedly, often rising into rounded hills. Sometimes the hills are isolated, sometimes they are flanked by terraces, and sometimes the terraces run a little way upon the Piedmont plateau; but in general the records of oceanic invasion are here but faintly inscribed on the face of the land. The common boundary of the plateau and lowland is ill defined save by the cascades of the water ways and by the change in soil character, yet the Piedmont hills are always the higher, the coastal plains always the lower.

There is a fourth natural district in the lowland plain, which is so diverse in its various parts that it might well be divided, yet so destitute of definite boundaries that it must be treated as a unit. It joins the third district along the semi-arbitrary line drawn at the Suwanee River, runs thence down to the Gulf, stretches westward and northwestward to the bluff rampart skirting the Mississippi flood-plain in Mississippi, Tennessee, and Kentucky, and is vaguely delimited from the Appalachian and Cumberland provinces in northwestern Alabama and in western Kentucky and Tennessee, as well as from the Piedmont plateau in eastern Alabama and northern Georgia.

In the New Jersey and Delaware–Maryland peninsulas the lesser streams run down the slopes, and thus by their direction indicate the configuration of the land; in the Potomac–Neuse district the stream courses measurably reflect the land configuration; in the district between the Neuse and the Suwanee all streams, great and small, run down the prevailing slopes and cross directly the successive geologic terranes, and thus at the same time express the general configuration of the land and indicate the course of evolution of the continent; but between the Suwanee and the Mississippi these simple relations fail. Throughout most of Alabama, it is true, the lowland inclines gently and with approximate uniformity from the Appalachian and Cumberland borders to the Gulf, and the rivers flowing down the slopes represent the general radial system of southeastern United States; but in western Alabama a differentiation of the surface appears, and this differentiation increases westward and northward to the margin of the district. In Mississippi the general seaward slope of the coastal plain is broken up by two great ridges. The first of these culminates in the extreme southwestern corner of the State and extends southeastward, contracting in width and diminishing in height, to fade out near the mouth of the Alabama River. This is the Grand Gulf hill land. The second ridge rises in the river bluffs overlooking the Mississippi and its broad flood-plain in extreme western Kentucky; nearly hugs the great river thence two-thirds of the way across Tennessee; then curves slightly eastward, crossing the Tennessee–Mississippi boundary 50 miles east of the river, and, curving still more strongly as it continues, thence forms the main Alabama–Mississippi watershed to within 50 miles above the head of Mobile Bay. This is the Lignitic hill land. South of the Grand Gulf hill land the surface slopes rapidly Gulfward to the alluvial plain of the delta and the coast; the culminating summits of the ridge rise 500 or 600 feet above sea level; between the two ridges there is a triangular depression averaging 200 feet lower than either upland; the Lignitic ridge reaches altitudes of 600 or 700 feet above sea level; toward the interior there is a trough often 100 and sometimes 200 feet lower than its mean height; then the surface inclines upward to the vaguely defined margin of the Cumberland plateau. Now, Pearl River and some lesser streams cut through the Grand Gulf hill land;

the Tallahatchee and other rivers of Northern Mississippi send a score of arms through the Lignitic ridge to rob the basins of the Tombigbee and the Tennessee beyond, and all the larger rivers of western Tennessee have cut their channels through its crest. Thus in this part of the district the main drainage and the configuration are discrepant, but even here the minor drainage commonly expresses configuration. Again, in southeastern Alabama and southern Georgia there is a vaguely defined ridge, coinciding with the Neocene terrane, bounded inland by a vaguely defined trough, coinciding with the Eocene terrane, and both trough and ridge are transected alike by the Chattahoochee and other rivers; but here, as in Mississippi, the minor drainage commonly conforms to the configuration. In both of these cases the configuration expresses structure; elsewhere it expresses general continental growth.

The Gulfward margin of this district is in general terms homologous with the seaward margin of the more northerly districts, but there are certain striking and significant differences in detail. Between Appalachicola Bay and Mobile Bay the coast, like that of eastern Florida, is commonly skirted by keys separated from the mainland by narrow sounds; but the keys are narrower and lower than those built by the trade-driven waves of the Atlantic, and the sounds are commonly broader, shallower, and less regular in outline, passing here and there into reedy or grass-grown marshes. West of Cape San Blas, where the gulf waves come in with longer sweep and stronger impetus, the barrier keys increase in size and both keys and sounds in regularity of outline, and at high tide a boat might be driven through sounds, landlocked bays, and meandering channels nearly or quite all the way from Appalachicola to Mobile. West of Mobile Bay the keys continue in scarcely diminished height, though in broken continuity; but instead of skirting the shore they lie 10, 15, even 20 miles in the offing, separated from the mainland by the broad Mississippi Sound. In structure, in position, in elongated form, in mode of origin, in geologic significance Dauphin Island, Petit Bois, Horn Island, Ship Island, Cat Island, and their neighbors are at the same time the homologues and the direct continuation of the keys fringing the western Florida coast; but here the land is sinking, and the feeble waves of the Gulf are unable to drive the narrow breakwater inland so rapidly as the still waters steal into the breaches made by the rivers. So the Gulf waters enter the mouths of the affluents in tidal arms like those of the northern Atlantic coast, transforming the embouchures of the larger streams into bays and those of the smaller streams into salt marshes. These bays or marshes are partly bound on the Gulf side by low sand banks built by the feeble waves of Mississippi Sound, while between the bays the friable sands and loams stand in vertical cliffs 5, 10, or 15 feet high; for here, as elsewhere, the encroaching waves bear into deeper waters the cliff talus as rapidly as it is formed. Thus, west of Mobile

Bay, the natural breakwater characteristic of nearly the whole vast stretch of the Atlantic and Gulf coast is divided: the older and stronger part lies out at sea a score of miles; the newer and feebler representative skirts the present shore line, half inclosing the bays and marshes, but failing along the headlands.

Next within the gulfward margin of the district there lies the usual lowland zone; but it is even lower than in the north, so that it falls into savannas and swamps rather than into "high grounds" and "low grounds," as in the Carolinas. The savannas, like the "high grounds," are broad tracts bounded by low scarps sloping steeply down to swamps or to sharp-cut but shallow ravines, and overlooking the larger bays and sounds commonly in low sea cliffs. About their margins they support shrubbery and forests of pine or magnolia, but their interiors are often broad and imperfectly drained tracts of flat grass land, with scattered yuccæ and here and there an isolated pine—the "pine meadows" of the pioneer southern geologist, Hilgard. The swamps, the homologues of the Carolinian "low grounds," are given over to reeds and sedge and coarse marsh grass toward the coast, with live oak groves along the coast ridges, and to canes and tangled shrubbery toward the interior.

Still farther inland, just within the subcoastal lowland zone, there is commonly found in southern Mississippi and Alabama and in the "pan handle" of Florida, a tract of curious hybrid topography congenetic with the configuration sometimes displayed near the Piedmont margin in other districts of the coastal lowlands. Just as the swamps of the subcoastal zone invade with octopus arms the higher savannas, so the savannas in turn invade the higher lands in scores of flat-bottom valleys and hundreds of narrow ravines; but this higher land, unlike the savannas, is a land of hills, knobs, crests, salients, wandering divides, and strong slopes. This relation between the savanna plane and the undulating plain is exemplified midway between Mobile and Pascagoula Bay. There occasional insulated hills—now rounded knobs, again elongated ridges, elsewhere smooth but distinctly serrate crests, or perhaps pygmy peaks running down into three or five miniature buttress spurs—rise above the flat savanna plane, while farther inland the hills blend in broader tracts of labyrinthine sculpture. The relation is exemplified again between the Apalachicola and Suwanee rivers at Tallahassee. Here there is a congeries of knobs, crests, divides, spurs, peaks, buttresses, all smoothly rounded yet distinctive in form, and all expressing the characteristic sculpture produced in a homogeneous terrane by active stream work, stimulated by a low base-level; while these positive relief features are divided by flat-bottomed valleys, bifurcating and breaking up into innumerable dendritic branches running up into ravines after the fashion of autogenetic streams. Streams, indeed, occupy these valleys, but except at their very sources wander through broad plains of sandy alluvium. The summits of the hills fall into a vaguely defined plain 200 feet above tide; the valley bottoms fall into a sharply defined plane 100 feet above tide. Here, as elsewhere in this zone of hybrid topography, it is evident to layman and expert alike that a rugose land, sculptured by active streams, was invaded by still waters rising to the present savanna level; that the waters remained until valleys, gorges, and ravines were clogged with the débris washed from the hills; and that the land finally rose just so far as to drain but not to deeply erode the savannas.

The western border of this district is the line of bluffs overlooking the Mississippi flood plain from the mouth of the Ohio to Baton Rouge. This bluff line is of compound character and complex genesis, but the diverse structural characters and the complicated genetic conditions may be discriminated.

In the first place the bluff line is a simple scarp of the coastal lowland, here so elevated as to become a low plateau, half eaten by lateral corrasion of the great river. So it is a series of truncated spurs and salients separated by ravines and broader valleys, each spur and each salient being the extremity of a divide—the low plateau was a rugose peneplain[1] of autogenetic sculpture, but was invaded by the great river and its western portion carried away in such manner that the boundary of the remaining portion gives a profile section of the peneplain. So the contour of each bluff exemplifies contours of the plateau; the form and depth of each ravine and valley at the scarp exemplify the elements of the ravines and valleys in the interior; and the depth and amount of erosion exemplifies the erosion to which the body of the plateau has been subjected. So, too, the height of the bluffs at each point in the scarp illustrates the general altitude of the plateau, and accordingly the Lignitic and Grand Gulf hill-land find expression in the scarp. The Lignitic ridge coincides with the bluff line in the northwestern part of the district, nearly from the mouth of the Ohio to just below the city of Baton Rouge. It begins with the Columbus Bluff, over 200 feet in height, and includes McLeod Bluff and the Hickman Bluffs in Kentucky, as well as the Fort Pillow (or Fulton), Randolph, Old River, and Memphis Bluffs in western Tennessee, the whole constituting the series of conspicuous headlands known among the early rivermen as the "Chickasaw Bluffs." Farther southward the scarp cuts the broad trough lying between the culminating ridges, and diminishes in height and prominence. At Memphis the bluffs are rounded and barely 100 feet in height; west of Hernando and Senatobia they are even lower; still farther southward they increase gradually in height, reaching 150 to 200 feet about Yazoo and over 200 feet at Vicksburg, just below the mouth of Yazoo River; the scarp is then reduced by reason of the modern and ancient work of one of the most efficient of the coastal plain streams, the Big Black River; it soon rises again to culminate in the Natchez Bluff, Ellis Cliffs, and Loftus Heights—the "Choctaw Bluffs" of the Mississippi boatmen—the last named eminence reaching, at Fort Adams, heights

[1] A term applied by Davis to undulating plains representing partial degradation to base level.

of from 350 to 450 feet; and thence the scarp inclines rapidly southward to 250 feet at Bayou Sara, 150 feet at Port Hudson, and 75 feet at Baton Rouge, above the river washing its base.

The simple aspect of the scarp as a profile section of a low plateau is complicated by characters significant of later genetic conditions, and recording one of the most interesting episodes in the geologic development of southern United States. During the latest continental depression affecting this region the entire bluff line was sometimes partly and sometimes wholly submerged, and became a line of active deposition of river-borne sediments. So the breaks between the bluffs are partly filled and the intervening crests are broadened and heightened by a mantle of fine, silty loam. Sometimes this modification of the primary configuration is inconspicuous, but again it is the most impressive feature of the local topography. Thus, at the Columbus Bluff in western Kentucky one may stand on the verge of the cliff and toss a pebble into the river on the west, or look eastward over a plain inclining gently downward for a mile and then passing into the smoothly undulating surface stretching thence to the mouth of the Tennessee River; and all the way from the Mississippi to the Tennessee there is no land so high as the verge of the cliff upon which he stands. Again, from Hickman, Kentucky, to the mouth of the Obion, in Tennessee, the river bluffs are the western margin of a ridge averaging 50 feet higher than the interior plain to the eastward. A part of this eastward inclination from the river cliffs is due to coincidence of the line of the "Chickasaw Bluffs" with the axis of the lignitic hill-land; but this is only a partial explanation of the phenomenon, as is shown by the facts that not only the highest summits but the thickest accumulations of the Pleistocene loam occur at the verges of cliffs rising from the water's edge, and that the elevated bluff line is transformed into a continuous rampart like the natural levees of the Mississippi, 250 feet below. This rampart affords favorite sites for roads. Much of the way from Hickman to the mouth of the Obion, past the tract made interesting through the memorable earthquake of 1811–'13 by which rivers were diverted and Reelfoot Lake was created, the roadway follows the crest of the rampart, because, albeit ravined and crevassed by the terrible quaking, it is yet the smoothest and most practicable route in the region. Moreover, in the lower portion of the bluff line, between the Lignitic and Grand Gulf ridges, a similar character is maintained. On both sides of Coldwater River the roads frequently run upon the long narrow ridges forming the culminating crests of the entire region, and the valleys are half cut off by the barrier of Pleistocene deposits, so that this stream and its lesser neighbors on the north and south embouch through narrow breaches in the nearly continuous rampart; at Charleston the two branches of the Tillatoba unite in a broad amphitheater walled from the "delta country" beyond by a similar barrier broken only in the narrow chasm through which the waters escape; at Yazoo the highest bluffs are those immediately overlooking the "delta;" and again at Grand Gulf the plain inclines inland from a rarely broken rampart. Still farther southward this feature of the bluffs gradually fails, to appear no more beyond Loftus Heights.

There is thus a certain similarity between the riverward and Gulfward margins of this lowland district. Along the Gulf shore the waves have cut off a segment of the country and laid bare a profile section of the portion rising above tide level, but have half concealed this profile by throwing up a natural breakwater against it; the wandering Mississippi in like manner cut off a segment of the land, laying bare a profile section through it, but afterward half concealed this profile by a barrier of its own sediments built when the waters rose higher. There is this difference: the Gulf waters have invaded the valleys and concealed the lower portions of the profile, while the Mississippi exposes the notches as well as the crests of its more rugose profile.

Within the subcoastal line flanking the Gulf, and within the bluff rampart overlooking the Mississippi flood plain, the configuration of this district is qualitatively similar throughout, i. e., it is in the large way a vast plain undulating gently in long, low sweeps, themselves sculptured into endless labyrinths of rounded hills and winding valleys, mainly of autogenetic type. The hills vary in height and steepness and the valleys vary in depth and complexity from place to place; on the Grand Gulf and Lignitic ridges the local relief reaches 200 feet, and the way of the traveler is an endless succession of hills so steep as to weary animals and retard progress; in the trough between these ridges the local relief is sometimes so low as 50 feet, and the way of the traveler might be easy and his progress rapid were not the routes (survivals of primitive conditions in which first horsemen and afterwards vehicles followed the trails beaten by cattle on their way to pasturage) commonly circuitous and aimless beyond belief. In general the local relief reflects in greater or less degree the characteristics of the local terrane. So the sandy formations are commonly characterized by short steep slopes and frequent ravines, the shales and other argillaceous formations by long slopes and gentle swells with few ravines, and the calcareous formations (particularly the "rotten limestone" of the earlier nomenclature; the Tombigbee chalk of modern geologists) by smooth ill-drained expanses colloquially known as "black prairies;" yet the height of the hills and depth of the valleys always indicate the proximity and size of neighboring water ways of primary or secondary order.

The isolated and perhaps terrace-circumscribed knolls of the northern districts find occasional parallel in this district. The insulated or peninsulated peaks and crests projecting above the savanna level in the south, indeed, represent this class of eminences; the same class is represented also by the low buttes locally known as mountains (Lumpkins Mountain, Gordon Mountain, etc.) in northern Mississippi and western Tennessee, save that the circumscribing terraces are indefinite and represented rather by smoothly undulating plains of sedimentation than by sharply defined horizons of wave cutting. These insulated knolls are always significant, since they afford a measure of continental submergence during a past eon; and in this district they are especially significant, since they indicate that the depth of Columbia submergence increased gradually and with approximate uniformity from not more than 30 feet above the present tide level in the vicinity of Mobile Bay to 600 feet above the same datum in northern Mississippi.

In general the inland margin of the coastal plain in this district is even less definite than in the neighboring district to the eastward. In western Georgia and eastern Alabama the rivers, indeed, cascade over hard rocks to form sluggish stretches in the lowland clastics; but commonly each waterway marks an arm of clastic deposits extending miles into the adjacent plateau in an ancient estuary, while between the rivers the transition is seldom sharp. In central Alabama, where the coastal plain overlaps the southern terminus of the Appalachians, the lowland sends long fingers into the valleys between the successive ridges, while the ridges project for miles into the general lowland area. Moreover, the intermontane valleys in the southern Appalachians stand so near base level that the local relief is faintly inscribed; e. g., in the valley floored by Cambrian shales and bounded by Red Mountain on the southeast and Flint Ridge on the northwest, the surface is so low and smooth as to be ill drained and so similar to a distinctive part of the coastal plain as to be correlated therewith in popular conception and terminology—it is the "northern flatwoods," the apparent homologue of the "southern flatwoods" lying midway between the Piedmont plateau and the Gulf. In northwestern Alabama the demarcation between the Cumberland plateau and the coastal plain is so ill defined that it may not, at least for the present, be drawn except as a zone a dozen or a score of miles in width. Still farther northward, in the extreme northeastern corner of Mississippi and in western Tennessee and Kentucky, the boundary coincides fairly with the Tennessee River, although the older rocks outcrop occasionally west of the stream, and the coastal plain deposits and configuration sometimes appear on the uplands some miles farther eastward.

The local relief of this district, and indeed of the coastal plain in general, varies from place to place with the local conditions residing in the character of the terrane, and with the proximity of the primary and secondary drainage ways, the present relation to base-level, the relation to base-level during past eons, etc.; but there is also a class of minor topographic features which are of temporary character, and result from temporary conditions residing chiefly in the relation between configuration and vegetation. These temporary relief features are of special interest in that they illustrate the mode of operation of certain geologic processes which commonly proceed with imperceptible slowness, but which are here proceeding with such rapidity that their effect can be measured not only from decade to decade, but from year to year, from season to season, even from storm to storm. The subject is one of the greater and more vital interest in that the temporary activity in this process was initiated, albeit unconsciously, through human agency, and in that it will inevitably affect materially human welfare in the district throughout the future.

It has been shown incidentally that the most conspicuous characteristics of the topography of this district represent three relatively recent episodes in continental history: First, the land stood high and the streams were thereby stimulated and cut deep their channels, developing a rugose configuration; then the land sank until half of this district was submerged, the energies of the streams were paralyzed, the valleys were filled with sediments up to tide level and clogged with alluvium above, and half of the hills were blanketed with a distinctive deposit; still later the land gradually resumed its present altitude and attitude, the rivers regained a part of their suspended activity, and the clogged channels were partly reexcavated. But the modern resumption by the land of its old altitude and attitude took place slowly. As the expanded Gulf gradually shrank to its present limits, forests followed the retreating waters, and clothed alike the soft-contoured hills and the smooth surfaces of the alluvium-lined valleys. This forest mantle persisted until the settlement by white men of at least a typical part of the district. First came a nomadic generation of men whose tools were the rifle and the hunting knife, and whose food was, like that of their Indian predecessors, the game of the forest; the men of the second generation were squatters, who cleared gardens, located petty plantations, and subsisted on the combined products of the soil and of the chase; during the third generation the slaveholding planter took possession of the land, cleared the forests, enlarged the fields, and not only subsisted upon but exported the products of the soil. So, over the uplands the face of nature was changed; the forests were transformed into fields; civilized man replaced the animals, and the hills smiled with bounteous harvests of corn, cotton, cane, and tobacco. Then came the moral revolution of a quarter of a century ago, and with it an industrial involution. The planter was impoverished, his sons were slain, his slaves were liberated, and he was fain either to desert the plantation or to greatly restrict his operations. So the cultivated acres were abandoned by the thousand.

Then the hills, no longer protected by the forest foliage, no longer bound by the forest roots, were attacked by the rain-born rivulets and gullied and channeled in all directions; each streamlet reached a hundred arms into the hills, each arm grasped with its hundred fingers a hundred shreds of soil; as each bit of soil was torn away the slope was steepened, and the theft of the next storm was thereby facilitated. Thus, storm by storm and year by year, the formerly fertile fields were invaded by gullies, gorges, ravines, "gulfs," ever increasing in width and depth until whole hillsides were carved away, until the soil of a thousand years' growth melted into the streams, until the fair acres of antebellum days were converted by the hundred into "bad lands," desolate and forbidding as those of the Dakotas. Over ten thousand square miles the traveler is never out of sight of glaring sand wastes where once were fields, each perhaps scores or even hundreds of acres in extent; his way lies sometimes in, sometimes between, gullies and gorges—the "gulfs" of the blacks, whose superstition they stimulate—sometimes shadowed by subtropical foliage, but often exposed to the blaze of the sun reflected from barren earth. Here the road winds through a gorge so steep that the sunlight scarcely enters; there it traverses a narrow crest of crumbling clay at the verge of a chasm fifty feet, perhaps a hundred feet, in vertical depth, into which he might be plunged by a single misstep.[1] When the shower comes he may see the roadway rendered impassable, even obliterated, within a few minutes; he always sees the falling waters accumulate as viscid torrents of brown or red mud; sees the myriad miniature pinnacles and defiles of the hillside before him transformed by the beating of the raindrops and the rushing of the rill so completely that when the sun shines again he would not recognize its features. Such is the modern erosion whose baleful marks lie deep in much of the erstwhile fair land of the coastal plain.

There is a fifth district in the coastal lowland which, in configuration as in the genesis expressed by configuration, stands by itself—the vast flood plain or "delta" of the lower Mississippi. In length it reaches from the mouth of the Ohio 1,100 miles measured along the river, or half as far measured in an air line, to the Gulf; it is bounded on the east by the bluff rampart separating it from the contiguous district; it is bounded on the west by a less continuous and less conspicuous rampart crossing the Arkansas River at Little Rock and gradually failing southward until this district and its more westerly neighbor nearly blend. The surface of this otherwise monotonous district is relieved by a few small tracts of higher land. Most conspicuous of these is Crowley Ridge in eastern Arkansas, a long belt of upland stretching from southeastern Missouri southward between the White and St. Francis rivers to the Mississippi at Helena. This belt of upland rises 100 or 200 feet above the insulating flood plain, and in its steepness of slope and rugosity of outline fairly simulates the eastern rampart overlooking the "delta" in corresponding latitudes.

The vast lowland tract comprised in and constituting most of this district is at once the most extensive and most complete example of a land surface lying at base-level or a trifle below that the continent affords. It is trenched longitudinally by the great river; it is trenched transversely by the White, Arkansas, Red, and other large rivers; between these greater water ways it is cut into a labyrinth of peninsulas and islands by a network of lesser tributaries and distributaries, the former gathering the waters from its own surface and from adjacent country,

[1] Photographs of some of these "gulfs" are reproduced in Figs. 45, 46, 48, and 49.

and the latter aiding the main river to discharge its vast volume of water and its immense load of detritus into the Gulf. The whole surface lies so low that it is flooded by periodic overflows of the Mississippi and its larger tributaries, and with each flood receives a fresh coating of river sediment; and much of the flood plain, fertilized by the seasonal, annual, or decennial freshet deposits, is clothed with luxuriant forests and dense tangles of undergrowth, or with brakes of cane, or with subtropical shrubbery, only a few of the broader interstream tracts being grassed. Partly by reason of this mantle of vegetation, the current of each overflow is checked as the river rises above its banks, and most of the sediment is dropped near by; and so the Mississippi, the White, the Arkansas, and the Red, as well as each lesser tributary and each distributary from the great Atchafalaya down, is flanked by natural levees of height and breadth proportionate to the depth and breadth of the stream. The network of waterways is thus a network of double ridges with channels between; and each interstream area is virtually a shallow, dish-like pond in which the waters of the floods lie long, to be drained finally, perhaps through fresh-made breaks in the natural dikes, weeks after the stream flood subsides. In the southern part of the district the interstream basins approach tide level and drain still more slowly; in the subcoastal zone many of the basins are permanent tidal marshes. In the western part of the district there is an area in which the interstream basins lie so high that they are invaded only by the highest floods and veneered with only the finest sediments; in some cases these sediments are so fine and so compactly aggregated and the surface is so ill drained and watered that trees may hardly take root, and these are either drowned by the floods or withered by the sun in the drought. Such portions of the surface are devoid of the usual forest mantle and but scantily covered with coarse grass; they are the "black prairies" of southern Arkansas and northwestern Louisiana.

In the northern part of the district there is a considerable area which was configured like the rest when the French and Spanish settlers began to displace the aboriginal hunters, but which was so shaken, depressed, and warped during the memorable New Madrid earthquake that extensive land tracts were converted into lakes, and flowing rivers were transformed into stagnant bayous, while some areas were lifted above the reach of the waters and some stream courses were diverted. This tract includes the so-called "sunk country" of Missouri and Arkansas, as well as the Reelfoot Lake district of Kentucky and Tennessee. It includes also the uplifted land of Lake County, Tennessee, the only part of the Mississippi plain beyond the reach of the highest floods.

While the lower Mississippi district of the coastal plain is in a general way unique, its shoreward margin is comparable to that of adjacent districts. The lesser rivers and the distributaries—the "bayous" of the vernacular—embouch into shoal estuaries or wander through reedy marshes ultimately to pour into the Gulf through narrow breaches in a natural breakwater built by the Gulf waves; but the breakwater is even less conspicuous than that east of the delta. Between Lake Borgne and Mobile Bay the Gulf is advancing upon the land so rapidly that the coastal keys are left far behind and nearly submerged; all about the delta the configuration suggests that, except at the very points of embouchure of the great river and its distributaries, the Gulf is encroaching upon the land with so much greater rapidity that the keys are either devoured by the waves almost as rapidly as formed, or else remain only as narrow mud banks, like the Chandeleur Islands, or as completely submerged bars and shoals parallel with the coast.

The sixth district of the coastal plain extends from the Mississippi flood region to the Rio Grande. Its eastern boundary is interrupted by the broad flood-plain of Red River, but in a general way extends southward as an inconspicuous line of low salients overlooking the water ways and jutting into the flood plain from the Arkansas near Little Rock across the northern boundary of Louisiana to Catahoula Parish in the central part of the state, and thence, beyond the Red River bottom lands, from Avoyelles Parish along the western banks of Atchafalaya Bayou directly to the Gulf; it is vaguely bounded inland by points of inflection in the waterways sometimes attaining the dignity of falls from Little Rock to Austin, and thence nearly to the Rio Grande by a displacement, analogous to that of the middle Atlantic slope, over which every river cascades; and although the Rio Grande marks its national limit the same district continues in a lowland shelf fringing the Gulfward bases of the eastern Sierra Madre in Mexico southward to Tampico and thence in a still narrower shelf to beyond Vera Cruz.

Like the districts washed by the Atlantic and the eastern Gulf, this natural division of the costal plain comprises three or more zones trending parallel with the seaboard. The coastwise zone, as in the east, consists for the most part of long wave-built keys separated from the mainland by sounds, and the keys are longer and the sounds broader and deeper than those of the eastern coast; for a single key (Padre Island) is 100 miles long and light-draft vessels from the mouth of the Rio Grande may ply behind it through the Laguna de la Madre, and thence through the shorter sounds to Matagorda, 250 miles away. East of Galveston the keys and sounds appear to fail; yet the wave-built barriers are continuous as in southern Texas and eastern Mexico, though submerged beneath the Gulf waters to form Sabine Bank, Trinity Shoal, Ship Shoal, and their connecting series of bars parallel with the coast. East of the Mississippi delta the Gulf is invading the land so rapidly that the wave-built keys are left far behind; west of the delta the invasion is so much more rapid that the coastal islands are drowned. The Mississippi Sound of the east finds a homologue west of the delta, but the outer barrier of the western sounds is overflowed by the Gulf waters.

There is an apparent diversity but real unity in the configuration of the coastwise zone bordering the Gulf; and this configuration is especially significant in its bearings on modern geologic doctrine. It is the current opinion among American geologists that areas subjected to degradation rise while areas of deposition sink. Now, the Gulf, considered as a unit, is an area of deposition from a very much greater area of degradation toward the east, north, and west; and the inference that it must be sinking is sustained by the evidence found in the vast extent of sounds separating the wave-built keys from the mainland; for the clearing of sea-cliffs, the building of strong keys, and the development of sounds are the characteristic works of a sea advancing on a low-lying land. Moreover, the width of the sounds is in a general way proportionate to the rapidity of deposition, being much greater along the Texas coast than along that of Florida and greatest of all about the mouth of the chief river of the continent. This general relation is indeed contravened about the mouths of the rivers, of which some embouch into bays while others push deltas into the Gulf; but the contravention is apparent rather than real, and only corroborates the general testimony. Thus the deltaform Appalachicola projection is greater than that of the larger Rio Grande and approaches that of the Mississippi; but the Appalachicola is the most active river of the southeastern part of the coastal plain, and at the same time represents the part of the basin in which general deposition is slowest. So, too, the Mobile, Pearl, Sabine, and Trinity rivers, which approach the Appalachicola in volume, embouch into bays instead of pushing out deltas; but all are within the influence of the Mississippi delta as proved by the lagging keys, now half drowned or completely submerged. Accordingly, whether viewed as a body or examined in detail, the evidence of the coastal configuration is consistent with itself and in harmony with the current doctrine; and it is just to observe that while some of the phenomena may be obscure or equivocal to such an extent as to become inconclusive when considered separately, no other region thus far studied has yielded so large a body of thoroughly consistent and harmonious evidence in support of the doctrine of isostacy.

The subcoastal zone extending inland from the shores of the sounds about to the head of tide in the estuaries and narrower waterways is much like that of the land lying east of the Mississippi—it is made up of savannas insulated and peninsulated by swamps or shoal bays, the former corresponding to the "high grounds," and the latter to the "low grounds" of the Carolinas, except that both lie lower. The "low grounds" are half submerged and either abandoned to reeds and sedges and croaking waterfowl or given over to fishing grounds, according to the depth of the flooding; the savannas lie so low as to be ill drained, and are commonly clothed only with coarse grass and dotted with scattered pines and yuccæ, like the "pine meadows" of southeastern Mississippi, or perhaps with scrub palmetto, like the coastward swamps of Florida.

Toward the vaguely defined inland margin of the zone both the "low grounds" and the "high grounds" rise and the former contract to stream channels, and along most waterways, broad, low, natural levees like those of the Mississippi flood plain circumscribe the savannas; these levees are commonly wooded, while the interstream tracts form prairie lands analogous to the "black prairies" of eastern Arkansas, and in the Calcasieu prairies of western and southwestern Louisiana and elsewhere agriculture has been adapted to this physiographic condition, and vast savanna prairies, bounded by narrow belts of forest along the water ways, yet so broad that their flat surfaces fade into the horizon, are converted into immense fields plowed, planted, and cultivated by implements attached to traction engines or drawn by steam-driven cables. Still farther inland the waterways contract and the natural levees fail, and the subcoastal zone becomes a continuous band of flat, monotonous prairie land—the "coast prairies" of the habitants—stretching from the Sabine to beyond the Nueces and interrupted only by narrow transverse belts of woodland along the principal waterways. This grass land is the geologic equivalent of the Carolina pine lands, but the soil differs even more than the vegetal covering—the sands of the east are replaced by muddy clays like those beneath the Mississippi flood-plain.

The gulfward boundary of the inland zone of this district passes through Sabine, Columbus, Beeville, and San Diego, while the landward boundary coincides with the more or less sharply defined fall line. Topographically this zone is throughout a land of autogenetic sculpture, moderately strong along the rivers which head in the higher interior, feeble and even faint along the waterways originating within its borders, the altitude corresponding fairly with that of the district east of the Mississippi, though the relief is less pronounced; but since the zone stretches from the humid region near the Mississippi to the subhumid or arid region toward the Rio Grande, its surface aspect is diverse. Along Red River it is well wooded with oak and hickory on the uplands, with poplar and liquidambar over the lowlands, and with cypress and tupelo in the swamps. One to two hundred miles westward the forests fail or give place to scraggy groves of blackjack and Chickasaw plum; still farther westward the mesquite appears in low, scant orchard-like groves scattered over the plains, with the hackberry and acacia along the streams; and toward the international boundary the mesquite gives place to the sage and cactus of the deserts, except where the rivers have been diverted and the land converted into fields through human agency. In addition to this general diversity growing out of climatal conditions, the zone is diversified in more complex fashion by the variety in soils expressing the composition of the several geologic formations represented within it. Yet, in spite of climatal inequality and soil diversity, the more recent continent movements have left a record in the flora of the province which yet remains legible—from the Sabine to the Nueces the coast flora is represented along the rivers by scattered and often puny and ill-favored cypresses and live oaks, even well within the gulfward margin of this inland zone.

In brief, the southwestern district of the coast plain is a segment of a broad, shallow basin, drained by rivers flowing radially from rim toward center; there is a coastal margin of estuaries, broad sounds, and long natural breakwaters of which part are submerged; there is a subcoastal zone in which the low-lying plain is divided into low and lower lands, the former sometimes expanding into the floor-flat fields, tens of thousands of acres in extent, such as form the marvelous steam-wrought farms of northern Louisiana; and there is a vast inland zone in which the configuration expresses characters of subterrane and drainage much as in the fourth district, lying east of the alluvial lands of the Mississippi. As a whole the district is homologous with and closely similar to the Atlantic Gulf district lying between the Neuse and the Suwanee, save that one is convex while the other is concave toward the coast, so that in one the waterways diverge while in the other they converge, and save that the superficial sands of the east are largely replaced by silts and muddy clays in the west.

The coastal lowland of southeastern United States thus falls into six districts, sometimes sharply demarked, sometimes separated semi-arbitrarily. The first district extends from the Hudson to the Potomac, and is characterized by an axial ridge with an interior trough and by broad estuaries nearly insulating it from the mainland; the second district, extending from the Potomac to the Neuse, is a low, eastward-sloping plain, characterized by canal-like arms of the sea reaching far within it, by broad terrace plains of loam, and by a high natural breakwater peninsulated by broad coastal sounds; the third district extends from the Neuse to the Suwanee as a seaward-sloping plain characterized by vast stretches of pine-clad sands, by a distinctive division into "high grounds" and "low grounds" near the coast, and by a lower natural breakwater alongshore which sometimes expands into "sea islands;" the fourth district, extending from Suwanee River to the bluff rampart overlooking the Mississippi from the east, is a peneplain whose larger undulations reflect geologic structure while the smaller express stream work, but which, nevertheless, generally inclines Gulfward, characterized by a low yet distinct concentric ridging that sometimes dominates the local configuration, by a blanket of loam at the lower levels, by a division into savannas and swamps in the subcoastal region, and by coastal keys sometimes outrun and drowned by the encroaching Gulf; the fifth region is the flood-plain of the lower Mississippi, and is characterized by the base-level attitude over a vast area, by a complex network of tributaries and distributaries, by natural levees flanking all waterways, by a swampy subcoastal zone, and by a feeble or drowned natural breakwater; the sixth district extends from Atchafalaya Bayou to the Rio Grande as a Gulfward-sloping plain, characterized by orthogonal and convergent drainage, by a weak interior configuration expressing feebly the local structure and more strongly the fluvial development, by a semitidal subcoastal zone of low and lower lands, and by a well marked bordering breakwater with extended sounds nearly parting it from the mainland, the eastern third of the breakwater being outrun and completely submerged by the waters of the growing Gulf.

This coastal lowland, stretching from New England to Mexico in a belt averaging 150 miles in width, is the land of the Lafayette formation.

THE GENERAL GEOLOGY OF THE COASTAL PLAIN.

THE METHOD OF CLASSIFICATION.

The coastal plain is classic ground for the geologist. Mitchell and McClure, joint founders of American geology, discriminated the province and recognized many of its characteristics. Conrad, Mather, the Rogers brothers, Tuomey and Holmes, Harper, and other representatives of the second generation of American geologists, made much of their fame in deciphering the records of ancient life in its strata; Lyell, the leading geologist of his times, aided in developing its structure; Hilgard, the prophet of southern geology, analyzed in masterly fashion the succession among its elements, doing for the Gulf States that which the magnificent corps of New York geologists did for the northern part of the country—for just as the New York classification and terminology gradually extended over the eastern Paleozoic province, and just as the principles of taxonomy and nomenclature developed there have guided later students, so Hilgard's classification and nomenclature are ineffaceably impressed on the southern province. Still later, Cook in New Jersey, and other geologists in different parts of the coastal plain, did much to develop the structure and elucidate the history of the region. The coastal plain was among the first of American geologic provinces to receive systematic study, and no province has been more ably investigated.

The researches in coastal-plain geology antedating the investigation on which this is a partial report were carried forward in accordance with the principles enunciated by William Smith and developed by Lyell, and largely by methods imported from Europe. In these researches it was postulated that the successive formations are characterized by distinctive faunas of world-wide extent; and the fossil remains of these faunas were deemed the most trustworthy if not the only criteria for classification of the formations. So the primary classification was biotic, either wholly or fundamentally.

The method pursued in the earlier researches was determined by the primary postulate, and thus was either wholly or largely paleontologic. Fossils were collected here and there, and by means of them not only the fossiliferous but the intervening non-fossiliferous strata were classified and correlated among themselves and with European deposits. The features employed in the classification were relatively minute, so minute that it is within limits to say that each square mile of terrane was classified by the characters of a square foot of surface. The method magnified a single feature and minified all other features of the formations.

The principal outcome of these early researches was the development of a chronology and an interpretation of the history of the province. The history was an epitome of the record found in the entombed fossils, and its episodes were episodes in the development of organic life upon the continent rather than in the development of the continent itself. This history was correlated with that of other parts of the world and with that of other periods in world-growth in accordance with the Lyellian scheme of chronology, which was based upon the numerical proportions of extinct forms to the existing fauna of the earth; and in elaborating this history little if any account was taken of those deposits (e. g., the Columbia and Lafayette formations) which happen to be devoid of fossils.

So the fundamental principle recognized in these researches was that of biotic classification and correlation. The method pursued led to the magnification of a minute and inconstant rock character and the minification of the immeasurably preponderant rock characters; and the history developed by the researches was a biotic chronology, semi-abstract in its nature and only remotely connected with the actual physical development of the continent. The early researches and their results were admirable, and represent an essential and important stage in the evolution of geologic science—a stage long considered the acme of scientific progress, and one in which even to-day half the geologists of the world are content to rest.

When the investigation now partially reported on was begun certain new principles were recognized, and as the work progressed certain new methods were developed. It was recognized that the formation per se represents a series of deposits laid down by a definitely limited set of agencies in a definitely limited area within a definitely limited period of time, and that each formation thus expresses tangibly certain conditions of a certain part of the continent during a certain period of geologic time; it was conceived that the formation discriminated at any point might be traced by stratigraphic continuity to other points and by identity or similarity of position to still more distant points; and it was also conceived that the conditions of genesis of the formations discriminated in different areas might be inferred so exactly that the formations might be identified or discriminated on the grounds of similarity or dissimilarity of genesis. Thus it was recognized that the formation may be traced and correlated from place to place, first, by actual stratigraphic continuity; second, by identity of materials; and third, by similarity in origin, or by homogeny;[1] and it was opined that the suc-

[1] Am. Jour. Sci., 3d series, vol. 40, 1890, p. 36.

cessive formations discriminated by these means would express not only qualitatively but quantitatively the growth of the continent, and in terms so definite as to be susceptible of graphic illustration. Thus the primary classification recognized in the work is physical.

The methods pursued were determined by the primary principles guiding the work, and led to study of each rock character, major as well as minor. Fossils were used as criteria in discriminating fossiliferous rock masses, but not in wide-reaching correlation; pebbles embedded in the masses were similarly used as criteria either in conjunction with or instead of the fossils, and it was found as the work progressed that pebble beds are sometimes the most eloquent of witnesses as to the relations among rocks; the finer materials of the rocks were similarly inspected as criteria for identification and classification, and these materials, whether at the surface or at depths, were carefully scrutinized. Thus the method led to the study of widespread rather than local characteristics, of assemblages of features rather than minute objects, of the square mile of terrane rather than the square foot of rock. Incidentally in logical statement, but in point of fact as a primary and important condition, it came about that the method led to a discrimination of soils and subsoils and to a classifiation of agricultural and horticultural resources growing out of the conditions of genesis of successive terranes—a basis of soil classification, and within certain limits of mineral classification, which is held to be more widely applicable and more serviceable than any other.

An outcome of the work is the determination of ancient physiographies with a high degree of exactitude. It was early foreseen and afterwards ascertained experimentally that the elucidation of the conditions of deposition of each formation in each of its parts gives an image of the local physiography; and so, as the elucidation progresses, the images grow and blend in such manner as to give clear conceptions of the relations of land and sea, of hill and valley, of river and bay during the period. The images and conceptions thus evolved become so definite and tangible as to be susceptible of graphic representation on maps approximating in refinement and accuracy the cartography of present conditions, and comparison of the physiographies of the successive periods gives a definite physical chronology of the entire province.

Thus the principles recognized in the coastal plain work are those of important physical relations and of correlation by conditions of genesis; the methods pursued involve appreciation of all criteria found in the rocks in proportion to their volume and their economic value; and the outcome of the work includes the determination of past conditions of the earth with a higher degree of exactitude than any other method even promises, and the determination of a definite physical chronology susceptible of extension over a considerable continental area.

It is of course recognized that direct correlation by homogeny is practicable only within single geologic provinces and that when this method fails recourse must be had to the biotic criteria found in entombed fossils, and for this reason the faunas and floras of the coastal plain formations receive attention. But in the progress of coastal plain work it was ascertained, as was synchronously or subsequently ascertained by half a dozen American and foreign geologists in other provinces, that geologic history may be read from configuration of the land as readily as from the contemporaneous rocks and fossils, and thus it has been found that the limits of a geologic province are no longer confined to the area of deposition, but include also the area of concurrent degradation; and the areas of degradation stretch inland and merge to such an extent that in many cases the correlation may be extended from the sea part of a province across the land area of the same province to the perhaps remote sea parts of other provinces. So the applicability of homogenic correlation has been greatly extended through the development of that branch of geologic science which relates to the interpretation of topographic forms.

It is of course recognized, too, that the physical chronology developed in a single geologic province can not be compared directly with the biotic chronology either for other provinces or for the world at large; but it is in this fact, in connection with the unique conditions of the coastal plain, that the plan of work in this province finds its principal strength. Although it has been well shown by H. S. Williams, by Calvin, by Renévier, and by other paleontologists, that the faunas of the earlier eons in earth history varied by reason of local variations in the conditions of sedimentation, it is in general a primary paleontologic postulate (albeit commonly implicit) that genera and species have always been continent-wide if not world-wide in distribution, and have remained alike throughout their wide habitats; and the strength and weakness of biotic correlation are substantially measured by the degrees of validity and falsity in this primary postulate. Now, it is known that the faunas and floras of the present are diverse, that this diversity is due largely to varying conditions of environment, and that one of the most potent factors in environment is climate; and it is a fair inference that the faunas and floras of the past reflected climatal conditions in like manner, though possibly or even probably in a degree diminishing with the remoteness of the period. There is thus an element of error in biotic correlation which can never be eliminated by comparison of faunas and floras of distinct but restricted deposits, however numerous or however widely distributed over the earth—an element of error which can be eliminated only in a single province of sufficient extent to express considerable climatal variation in its various parts. The coastal plain of southeastern United States is so conditioned more completely than any other thus far known: it stretches over 15° of latitude; there is a still wider range in longitude, so related to the continent as to involve a considerable climatal range; and in general the relation between land

and water during past times has been fairly uniform throughout the province. The coastal plain thus affords an incomparable opportunity for measuring the influence of climate on the faunas and floras of past ages, and thus forming a standard for future paleontologic correlation. But in order to eliminate the element of error inhering in paleontologic correlation, and in order to establish a standard for future work of that character, it is essential that the formations shall be classified and correlated, not by paleontology, but by some other method. Such a method is found in homogeny, and consequently the elucidation of the physical history of the province and the determination of the distribution of each genus and species during each period will not only permit the translation of the local chronology into a general one, but promises to afford an improved basis for general chronology.

In accordance with these considerations the coastal-plain work has been devoted primarily to the determination of physical relations, and for the present only secondarily to the discovery and determination of fossils; and in accordance with these considerations the definition of the formations is determined primarily by physical relation and only incidentally, if at all, by biotic relation. In accordance with the same considerations the work of earlier geologists in the province is adopted only in so far as the principles and methods agree with those now set forth; and so in epitomizing present knowledge concerning the structure of the coastal plain, special prominence is given to units defined by physical relation.

THE COLUMBIA FORMATION.[1]

Next to the Lafayette, this is the most extensive formation of the coastal plain; but unlike the Lafayette it varies widely in composition, structure, and thickness in different portions of its extent. It is the youngest considerable formation of the province, and in general may properly be regarded as a superficial deposit.

In the type locality—the District of Columbia—the most conspicuous phase of the formation is developed only along the Potomac River and its principal affluents, and consists of a sheet of brown loam passing down into a bed of pebbles and bowlders. These members, which intergrade through community of materials and through interstratification, and which are definitely connected in genesis, vary in thickness both relatively and absolutely; the loam ranges from 3 or 4 to 20 or 30 feet in thickness, while the coarser bed ranges from 12 to 15 feet downward. The distribution of the members, as well as of the deposit as a whole, is intimately related to the local physiography; the coarser member

[1] The Columbia formation was defined and briefly described in print in the Report of the Health Officer of the District of Columbia for 1884-'85, 1886, p. 20; it has been described either in general or in part in Am. Jour. Sci., 3d ser., vol. 31, 1886, p. 473; in Proceedings of Am. Ass. Adv. Sci., vol. 36, 1888, p. 221; in the Seventh Annual Report of the Director of the U. S. Geological Survey, 1888, pp. 594-612, and elsewhere; in Am. Jour. Sci., 3d ser., vol. 36, 1888, pp. 368-388, 448, and 466; in Am. Jour. Sci., 3d ser., vol. 40, 1890, pp. 16-18; and elsewhere.

is thickest and its bowlders largest and most sharply angular toward the gorge of crystalline rocks through which the Potomac embouches at Washington; the loam member culminates in thickness 3 or 4 miles from the mouth of the gorge; farther from the gorge the loam differentiates into sand and silt, while the lower member thins and nearly or quite disappears; and there is a parallel variation in the deposit going with variation in altitude, which need not be set forth in detail. In short, the various phenomena of the deposit indicate that its materials were collected in the Potomac valley and laid down in the estuary formed by the river when the land stood 150 feet or more lower than to-day, and when the climate was colder and river work more active than now. There is a less conspicuous phase of the formation, also developed in the District of Columbia, which consists of rearranged débris of several terranes, variously assorted and transported for short distances by the action of the waves rather than fluvial currents. There is a third phase of the formation, fairly well displayed in the southernmost angle of the District of Columbia and at low levels, consisting of loamy silt passing down into a silty loam which may in turn grade into a silty sand, the materials displaying more or less definite stratification. The composition, structure, and texture of this phase of the formation are such that on exposure to the weather in cliffs and scarps it assumes a peculiar and distinctive configuration; it is cleft into a labyrinth of gullies separating steep pinnacles, cusps, and spurs, so that the cliff is never smooth, but always dentate or serrate in a remarkable yet remarkably uniform fashion. The three phases have, in earlier publications, been designated respectively the *fluvial phase*, the *interfluvial phase*, and the *lowlevel phase*.

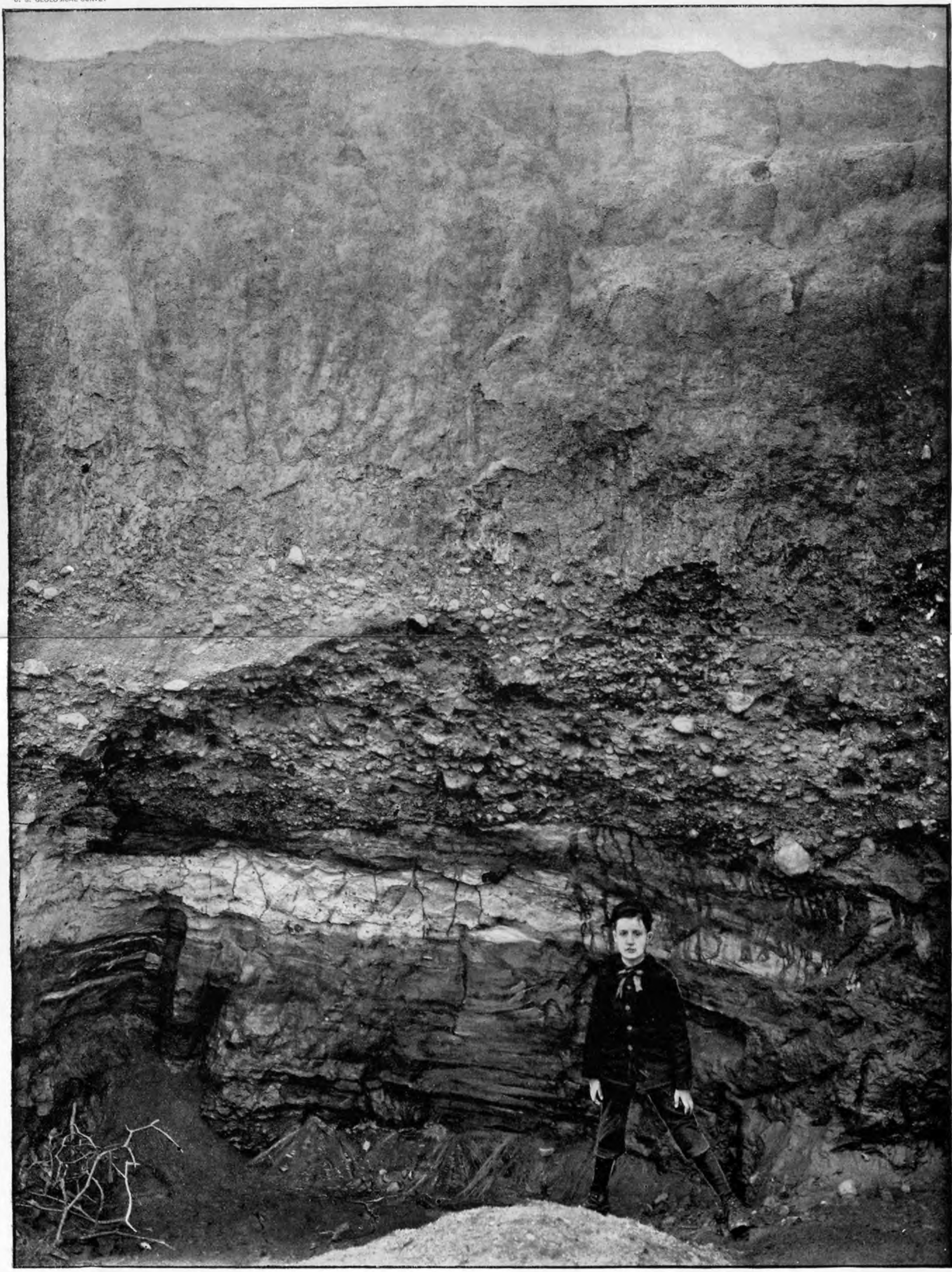
North of the type locality the characteristics of the formation are maintained so far as the typical physiography is retained. On Patapsco River at Baltimore the loam and gravel bed are developed as characteristically as in Washington[1]; at the mouth of the Susquehanna the development is equally characteristic and still more extensive; and far above the mouth of the river, even in the intermontane valleys of the Appalachians at Harrisburg, Northumberland and elsewhere, the formation may also be found; on the Schuylkill and Delaware at Philadelphia both the loamy and bowldery members are well developed, the former being extensively exposed in pits from which it is extracted for brickmaking; at Trenton it maintains related characteristics, as it does also farther up the Delaware nearly to the terminal moraine 10 miles above Easton. Over the interstream portions of the Piedmont plateau

[1] The accompanying Pl. XXXIII, illustrates a typical exposure of the Columbia formation reproduced mechanically from a photograph. The locality is the western side of Ensor street, between Preston and Biddle, Baltimore; altitude 130 feet. The loam is orange yellow, changing to brown in the lower portion, where it becomes coarser and forms a sandy matrix in which the pebbles are imbedded; the pebbles are chiefly quartzite, derived mainly from the Potomac formation, but in part from the neighboring crystalline terranes. Below the Columbia formation the Potomac arkose is exposed; the unconformity is accentuated in nature by a line of jet black cement composed of ferric oxide, cobalt, etc.

in northern New Jersey it passes into an ancient and discontinuous drift sheet running beneath the terminal moraine, as recently ascertained by Salisbury. The interfluvial phase is of wide distribution though limited thickness between the rivers; in the cliffs of the Chesapeake Bay the lowlevel phase is frequently displayed. The altitude reached by the formation steadily increases northward from the Potomac River nearly to the terminal moraine of the later ice invasion, so that the deposit overspreads the greater part of the northern lowland; the insulated knobs and buttes characterizing the topography of this region represent eminences rising above the Columbia waters, but whose sides and angle were swept smooth and round by the Columbia waves; and the deposits skirting the Susquehanna, the Schuylkill, the Lehigh, and the Delaware show that the waters rose even higher in the Appalachian valleys than along the fall line, thus indicating northwestward tilting of the land during the Columbia period.

The extension of the formation from the type locality northward may briefly be characterized as a sheet of loam generally grading into a basal pebble bed, best developed along the rivers, thinning out and running into local and sublocal débris over the divides, becoming silty at low levels and toward the coast, and grading into an ancient premorainal drift sheet toward the terminal moraine of northern New Jersey.

South of the type locality the characteristics of the formation gradually change. Along waterways, it is true, the fluvial phase retains the typical aspect, as on the Rappahannock, the James, the Appomattox, the Roanoke, and intermediate rivers, save that the bowlders of the basal bed progressively diminish in dimensions from the Potomac to the Roanoke, and save that the slight element of unoxidized rock débris, particularly noteworthy on the Susquehanna and Delaware, completely disappears from the loam; but as the relief of the coastal plain diminishes the estuarine deposits stretch farther over the interstream tracts, and the interfluvial phase increases correspondingly in extent and thickness, despite the diminution in altitude. Moreover, the component of sand in the loam increases and the clay component decreases southward from the Potomac until, between the Roanoke and the Neuse, the loam of the river sides and terraces is conspicuously sandy. The peculiar dentate cliffs marking the presence and recording the structure and texture of the lowlevel phase are prominent on the lower James and sometimes elsewhere toward the coast, yet not so conspicuous as in other portions of the province. This is the topographic area of smooth yet distinctly terraced lowlands, and the terraces represent the Columbia formation, which, albeit more and more sandy toward the south, yet retains so much of clay in the matrix as to maintain the smoothness of terrace surface and steepness of terrace scarp by which the area is characterized. The maximum altitude reached by the deposits and the terraces diminishes southward to the latitude of Cape Hatteras at about the same rate as that of increase northward from the Potomac; so that the best



COLUMBIA AND POTOMAC FORMATIONS ON ENSOR STREET, BETWEEN PRESTON AND BIDDLE STREETS, BALTIMORE.

developed estuarine phase of the formation on the Roanoke is only 40 or 50 feet above tide level instead of 80 to 150 feet as on the Potomac, 100 to 200 feet as on the Patapsco, and proportionately higher levels on the Susquehanna. Although the maximum altitude of the formation diminishes southward, it continues to mantle the divides and run up the waterways quite to the fall line; for the lowland inclines southward as strongly as the deposits or the old shore lines.

Still farther southward the differentiation of the deposits continues. In the north the fluvial phase is conspicuous and the interfluvial phase inconspicuous, but in the Carolinas and eastern Georgia the fluvial phase weakens while the phase developed between the rivers strengthens and expands until it gives character to the entire coastal plain; in the north the formation is predominantly loamy or perhaps gravelly at the higher and silty at the lower levels, while in the Carolinas and Georgia the loamy aspect shrinks and the sandy aspect stretches out until by far the greater part of the formation becomes a simple sand bed, limited in thickness but vast in area. This is the lowland district characterized by pine-clad sand plains; and the sand and the plains represent the interfluvial phase of the Columbia formation. In this smooth lowland the rivers have cut their channels but a little way below the general level, so that deep estuaries were not formed when the base-level was lower; and the fluvial belts of the deposit differ but little in composition from the general mass and extend but little farther inland. Toward the fall line the sands are commonly coarse, and along the rivers they contain sheets of pebbles with occasional bowlders of Piedmont rocks, chiefly of the vein quartz by which the gneisses are intersected; toward the coast the sands become finer and are interstratified with silts and finally grade into silts and peculiar muddy clays, of which the well known "pluff" mud of Charleston is an example. Still the exposures in the river banks are always more loamy than those of the divides, and river deposits partaking at the same time of the character of ancient alluvium and of typical Columbia loams lie along the Savannah at Augusta, along the Santee system at Columbia and other points, and along other large rivers about their intersection with the fall line. Sometimes here, as generally in another part of the coastal plain, these riparian accumulations are known as "second bottoms," but here they represent only the closing episodes of the Columbia period, not the period in entirety.

The source of the sands composing the Columbia formation in this district is easily traced. Here the Lafayette formation is magnificently developed and exceptionally sandy; and with the advent of the Columbia waters the Lafayette sands were broken up and assorted, the finer materials were carried farther away, and the coarser were dropped as a littoral deposit over the remnant of the older terrane; sometimes the waves were destructive agents alone, and the orange-tinted loams of the Lafayette were laid bare rather than buried; and sometimes the post-Columbia erosion invaded the later deposit so energetically that whole hillsides have been denuded. Thus there has been developed in the lowland a broad area in which some hills are of Columbia sand and some of older Lafayette loam, and these have been discriminated by the inhabitants and are colloquially known respectively as the "sand hills" and "red hills" of the Carolinas.

In this district the lowland margin of the formation increases in altitude and stretches toward the interior so far as to cover the entire coastal plan and overlap upon the Piedmont terrane, particularly in the region of the Santee and Savannah rivers. Over the divide between these rivers the "sand hill" phase of the formation is characteristically developed up to 650 feet above tide. This is the culminating area of the Columbia formation on the Atlantic coast. Northeastward it sinks to less than 75 feet above tide on the Cape Hatteras axis; southwestward its shore line inclines seaward until about Mobile and Pascagoula bays the highest deposits rise barely 25 feet above the Gulf. During this latest of important episodes in continental development, an episode so recent that since its close the rivers have done little more than clear out their immediate channels, the continental outline was modified to the extent that the southeastern angle of the United States disappeared and the common waters of the Gulf and ocean stretched in a nearly direct line from the head of Mobile Bay to the head of Pamlico Sound.

An imperfect illustration of the friable Columbia sands so extensively developed in the district appears in Pl. XXXVI, which is a mechanical reproduction from a photograph taken a mile east of the state house in Columbia, South Carolina. They overlie unconformably the Lafayette formation, which is here so thin that the unconformable contact with the Potomac below is also shown. The geography of the Columbia period is depicted in Pl. XLI.

The pine-clad sands of central Georgia extend beyond the limits of that commonwealth far into Florida, generally covering the northern portion of the latter state east of the Suwanee and stretching with scarcely broken continuity beyond the St. Augustine-Waccassassie isthmus over much of the surface of the peninsula proper. Here the fluvial phase of the formation fails utterly; for the rivers either flow in shallow canals bearing little mark of fluvial action, or are skirted by alluvial belts of coarse sand from which the finer materials have been washed seaward.

From New Jersey to central Georgia the natural districts into which the Columbia terrane falls coincide approximately with the natural topographic districts of the coastal plain; but farther westward the coincidence fails. The remaining districts of the formation are (1) that extending from central Georgia to eastern Mississippi; (2) the district of the Mississippi embayment, extending thence westward about to the Sabine River, northward beyond the mouth of the Ohio, and overlapping on the east and the west the ramparts and undulating plains overlooking the Mississippi flood plain; and (3) the district extending from the Sabine to the Rio Grande and thence to Vera Cruz in Mexico.

In the type area the formation is differentiated into fluvial, interfluvial, and lowlevel phases, the first being the most conspicuous. Passing southward there is a progressive change in the direction of unification and in the development of the interfluvial phase until it alone is conspicuous, which culminates about where the altitude of the formation culminates in South Carolina and Georgia. In the district extending from central Georgia to eastern Mississippi the differentiation recurs and the interfluvial and fluvial phases approach equality in prominence, though the latter assumes certain distinctive characteristics which are significant of genetic conditions.

In southwestern Georgia, extreme southern Alabama, and the panhandle of Florida, the pine-clad sand plains sink and flatten until the "red hills" rise far above their level and they become sand valleys rather than sand hills. The marginal sands continue to display the composition and texture and structure of the Carolina sands, i. e., remain commonly structureless above, faintly stratified medially, more distinctly bedded and sometimes cross-stratified or pebble-charged at the base, while at lower levels and greater distances from the margin the sands become silty and toward the coast pass into silts, muds, or clays with sand partings. Meantime the rivers are flanked by belts of loam with basal pebble beds more or less closely approaching the fluvial deposit of the type locality. Here, as in the north, the loam is more homogenous and more closely similar not only in its different parts on the same river but among various rivers than the phase developed on the divides; here, as in the north, the predominant element of the loam is clay (or finely comminuted rock débris commonly so designated) evidently derived largely from the residua of the Piedmont and Appalachian rocks, while the interfluvial phase is coarser and of local or sublocal origin; here, as in the north, the loam grades into a pebble bed, sometimes thin and inconspicuous, again thick and conspicuous; here, as in the north, the thickness and extent of the pebble bed are in at least a general way proportionate to the size of the rivers along which the deposits are accumulated; and here, as in the north, the pebbles represent two petrographic elements, one evidently derived from the older coastal-plain formations of the vicinity, and the other made up of the harder rocks in the terranes traversed by the river along which the gravel lies. But there is one essential difference between the fluvial component of the south and that of the north: In the north the fluvial phase of the deposit rises only to the level of the interfluvial sands and loams (except about the margin of the contemporaneous drift sheet), but in the south the fluvial deposits rise far above the level of the interfluvial deposits; indeed, throughout lowland Alabama these loamy or silty riverside lands (the "second bottoms" of the vernacular) stretch all the way from the coastal zone to and sometimes beyond the fall line.

Although the loam of the riversides is more uniform than the sands of the divides or the muds or silts of the coast, yet there are certain differences, of which some are local and significant of restricted conditions, while others are systemic and characteristic of the various loam belts of the district. The systemic diversity includes progressive increase in the element of sand from the inland limit of the belt to its coalescence with the general terrane and a concurrent increase in the silt element, so that the lower courses of the rivers frequently display the peculiar dentate cliffs characteristic of the lowlevel phase of the middle Atlantic slope, and this is true even above the maximum altitudes reached by the deposits over the interstream areas.

Typical exposures of the "second bottom" loam of this district occur on the Chattahoochee River about Columbus, Georgia, the best section being that on the western side of the river just above the mouth of Mill Creek, between the villages of Girard and Phœnix City (or Lively), Alabama. This section is illustrated in Fig. 28, which is a mechanical reproduction from a photograph. Here the deposit

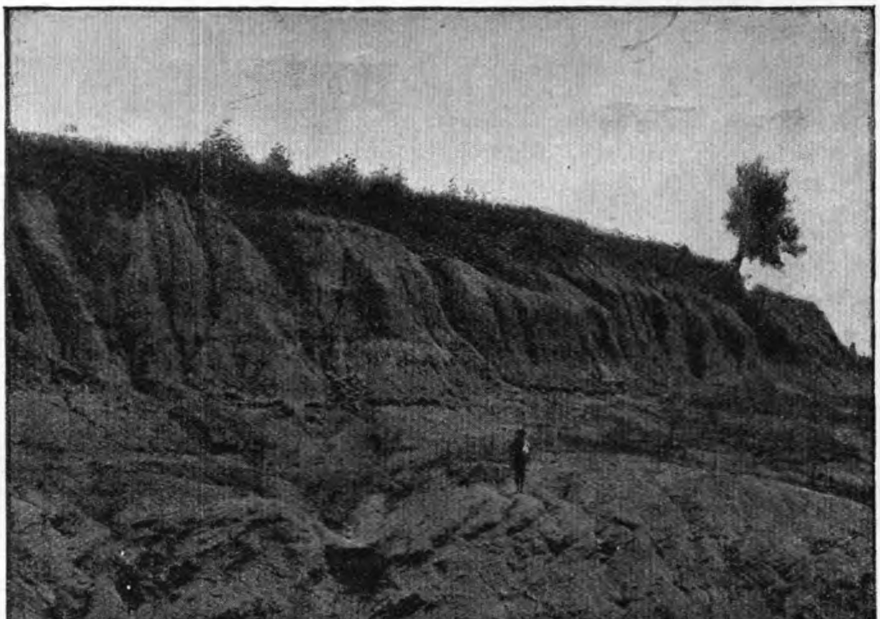


FIG. 28.—"Second bottom" phase of the Columbia formation, near Columbus. Ga.

forms a precipitous cliff face, of which two-thirds consists of red-brown loam hardly distinguishable in hand specimens from that displayed in the type locality or that of Ensor street, Baltimore, represented in Pl. XXXIII. The lower third of the exposure is made up of similar loam intermixed with pebbles and grading into a gravel bed, just as does the Baltimore deposit. The deposit rests directly on disintegrated gneiss.

The material of the gravel on the Chattahoochee, as on the Patapsco, is such as to indicate its source: the prevailing material is quartz, rounded or subangular in shape, the former unquestionably derived immediately from the Tuscaloosa and Lafayette formations of the vicinity, and the latter (as well as the former, more remotely) from the veins of quartz in the contiguous Piedmont terrane. Other materials represent the more obdurate crystalline rocks of the same terrane. As usual, the deposit here forms terraces, and the altitude of the higher terraces is approximately 260 feet above tide, while about the confluence of the Chattahoochee and Flint rivers (to form the Appalachicola) the altitude of the Columbia sands barely reaches 100 feet.

The "second bottom" phase of the Columbia formation is similarly displayed on the Tuscaloosa (or Black Warrior) River at Tuscaloosa in a mile-wide terrace rising 50 feet above the river and 100 feet above tide, while the "pine meadows" of southern Alabama, representing the interstream phase of the same formation, rise only 20 or 30 feet above the river carrying the Tuscaloosa waters into the head of Mobile Bay. Even at Tuscaloosa the loam is silty, and displays a tendency to weather into dentate forms; for this peculiar erosion habit everywhere reflects the composition of the loam and indicates the presence of a certain proportion of silt.

The conspicuous development of the "second bottoms" extends to the tributaries of the Pascagoula, as well as to those of the more easterly rivers. The Okatibbee, in the neighborhood of Meridian and Corinne, is flanked by broad loam plains, and near Meridian the upper division of the loam is worked as brick clay, while the lower portion consists of stratified sand with intercalated silt layers. The Tallahoma at Ellisville is flanked by a mile-wide terrace, so trenched by the river as to expose a 25-foot cliff of which the upper half is homogeneous loam, undistinguishable in general aspect from that on the Potomac (though minute examination shows certain difference in composition), grading downward into stratified sandy and silty loam with some heavy layers of light gray silt which assume the usual dentate form on erosion; and even as far southward as Hattiesburg, Leaf River is similarly flanked by loam plains of like aspect. Meridian, Ellisville, and Hattiesburg are, respectively, 330, 240, and 150 feet above tide, while the coastal phase of the Columbia formation at the mouth of Pascagoula River rises scant 40 feet above the Gulf waters.

In brief, throughout the district stretching from Suwanee River to the Pascagoula, the Columbia formation is differentiated more prominently than anywhere else in its vast terrane into fluvial and coastal (or interfluvial) phases; the coastal phase lies low, generally forming a continuous mantle of sand toward the interior and of silt toward the Gulf shore; while the fluvial phase stretches inland in long arms for a distance of 100 miles or more and rises to a height of several hundred feet. These remarkably extended belts of riparian loam record a slack-water condition more decided than simple lifting of the base-level could produce, a record of land-tilting which is fortunately corroborated in the most complete manner by the distribution of the contemporaneous interfluvial deposits along the Atlantic slope toward the east and along the Mississippi toward the west.

From the Delaware to the Pascagoula the local development of the Columbia formation varies with two factors, of which by far the more important is the volume of local drainage; and this variation extends to and includes the great river of the continent. The drainage basins of the Atlantic and Gulf slopes from the Delaware to the Pascagoula, as they existed when cut off above by ice and below by ocean during the Columbia period, aggregate about 200,000 square miles; the drainage basin of the Mississippi (now a million and a quarter square miles), when reduced by the northern ice and southern waters during the same period, was about 750,000 square miles; and it is accordingly not surprising to find in the Pleistocene estuary of the great river a volume and variety of deposit exceeding much the like qualities of the contemporaneous deposits toward the east and north.

In the Mississippi embayment the Columbia formation displays four phases which are commonly discriminated, and by some students have been considered to represent successive periods or episodes; but while these phases are not strictly contemporaneous, and while they commonly fall into certain stratigraphic sequences, they nevertheless represent local and temporary conditions of deposition during a single period rather than a definite time series covering several periods. Enumerated in the order of the age sometimes assigned from youngest to oldest, and also in the order of hypsographic distribution from highest to lowest, these phases are: (1) Brown (or yellow) loam; (2) Loess; (3) Orange Sand (of Safford); and (4) Port Hudson. The order of the first two members might be reversed with equal propriety in the southern portion of the embayment; for the loess is but a phase of the loam, and is frequently underlain as well as overlain by loamy deposits.

The loess of the lower Mississippi is a light buff homogeneous aggregation of finely divided particles, such as was discriminated first on the Rhine, then in this region, and afterward in various parts of the Mississippi valley and in other lands. As usual it displays the paradox of friability so perfect that it may be impressed by the fingers, combined with obduracy so great that it stands in vertical cliffs for a decade without even losing the marks of spade and pick; as usual in interior America it is calcareous, effervescing freely under acid; as usual it contains calcareous nodules (loess-kindchen) and dendritic tubules of carbonate of lime; and as usual it yields, from the mouth of the Ohio to the Louisiana line, shells of land snails sometimes associated (particularly at the lower levels) with shells of water snails and other fluviatile mollusca. Here as elsewhere, too, it forms one of the most individual and expressive of superficial deposits; the erosion forms developed within it are steep high hills and sharp slopes, divided by frequent ravines and valleys all of autogenetic type; it gives to the river bluffs gigantic dentate forms characteristic as the pygmy toothed forms of the Columbia silts on the Atlantic coast—huge cusps scores or hundreds of feet high separated by V-shaped notches cut down perhaps to the water's edge; it forms the most fertile of soils, particularly for the vine and the fruit tree, and so men congregate upon it and transform the face of nature; in the lower Mississippi region the roadways are beaten by hoofs, ground by wheels, and washed by storms until the way of the traveler is a dark defile bounded by vertical walls a score of feet high, often so narrow that two teams can not pass, with luxuriant canes and leafy branches intertwined above (Fig. 47).

In geographic distribution this phase of the Columbia formation skirts the higher river sides, crowning throughout the bluff rampart overlooking the Mississippi flood plain from the east, and similarly crowning the insulated parallel rampart of Arkansas, Crowley Ridge; but toward the south its zone widens to 10 miles at Yazoo, 15 miles at Vicksburg, and 20 miles on the Mississippi–Louisiana line; and thence toward the mouth of Pearl River it still further widens, but parts with its fossils and gradually loses its distinctive characters.

In hypsographic distribution the loess is specially noteworthy. Here, as frequently elsewhere, it forms the highest lands of its region; in the bluff rampart east of the modern Mississippi flood plain it overlooks not only the great river on the west but the undulating peneplain on the east; and it is by this deposit that the old erosion scarp is built up and carried half across the valleys to make this prominent boundary more prominent than of old—the highest summits in the Chickasaw bluffs and Choctaw bluffs alike, and the long marginal ridges so often traversed by modern roads, are built of this deposit.

In stratigraphic relation the loess usually forms the surface and rests upon the brown loam; but in some exposures the brown loam is divided, a part of it overlapping and another part underlying the loess, and in some cases the loess either rests upon or grades into coarse sand and gravel (the Orange Sand of Safford) or is similarly related to the Port Hudson clays. The loess and the loam are always conformable and always intergrade whether the latter lies only below or both above and below. The intercalation of the loess within the brown loam in lens-shaped sheets is well displayed in the numberless exposures between the Mississippi and the Big Black about the latitude of Vicksburg.

In brief, the loess of the lower Mississippi region may be characterized as a peculiar condition of the brown loam, or as an imperfectly demarked phase of the great formation into which both deposits fall. As shown by Hilgard, the loess condition or phase is strongly individualized in the central part of its area only, losing character peripherally; in local sections it may sometimes be seen to lie entirely within the loam in lens-shaped masses at high levels; and in like manner the entire deposit may be regarded as a distorted, elongated, and irregular lens rising to the surface centrally but feathering out within the loam toward the complex periphery.

The brown loam is a massive or obscurely bedded sheet of finely divided rock matter, made up chiefly of the argillaceous and heterogeneous materials commonly called clay, but partly of sand, silt, etc. Like the loess it is sometimes calareous, though commonly to a less extent than that deposit; like the loess, too, it frequently contains calcareous nodules, but these are commonly more or less ferruginous; it is eminently friable, yet its prevailing forms are steep slopes rather than vertical cliffs, and the erosion profiles are flatter than those of the loess; it is a fertile soil, and was luxuriantly wooded or cane-grown until man began to wrest its area from nature; and the roadways lie in gullies on the hillsides, but the gully walls are sloping.

In geographic distribution the brown loam extends inland from the rampart overlooking the Mississippi flood plain for 10 to 100 miles, commonly dying out in a veneer of sublocal débris, yet sometimes maintaining considerable thickness to the very bases of the rounded knobs which formed islands in the Columbia embayment of the Mississippi; for this deposit forms the terraces circumscribing Gordon and Lumpkins mountains and their homologues in northern Mississippi and Tennessee. On the Eocene hill land of northern Mississippi it extends well toward the headwaters of the Big Black and the Pearl, nearly to the Alabama and Pascagoula watershed; farther southward its margin withdraws westward to Pearl River, 20 miles below Jackson, where it divides, a narrow arm (in which the deposits simulate the "second bottoms" of the Alabama rivers) running down that river, and the main margin sweeping southwestward to cross the Mississippi–Louisiana boundary 25 or 30 miles from the great river. Thence the inland margin of the deposit bears east-southeastward to mid-length of Biloxi River, the deposit itself differentiating in this direction into clays and sands—the Biloxi sands and Pontchartrain clays of Johnson.[1] In general the western margin of the area and of this phase of the Columbia formation coincides with the Mississippi bluff rampart; but the brown loam reappears beyond the great river in Crowley Ridge and wherever else the loess is found and, in modified form, in the Calcasieu prairies.

In hypsographic distribution, this phase of the formation ranges from altitudes of over 600 feet to somewhat below tide level. Its maximum altitude is attained in northern Mississippi and western Tennessee, about Holly Springs and La Grange; thence its height diminishes slowly both northward and southward to some 450 feet at the mouth of the Ohio and about the same over the Grand Gulf ridge in southern Mississippi, and then much more rapidly southeastward to 50 feet or less where it passes into the Biloxi sands near Biloxi Bay.

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[1] Bull. Geol. Soc. Am., vol. 2, 1890, p. 24.

The complex stratigraphic relation of the brown loam to the loess has already been indicated. It lies unconformably on the Lafayette and all older formations of the region; in 90 or 95 per cent of the good exposures north of the thirty-first parallel it grades into sands and gravels (Safford's Orange Sand); at low levels in the north and generally south of the thirty-first parallel it grades either directly or through a sandy stratum into Port Hudson clays; while in localities of high relief, as about Vicksburg and Natchez, the exposures are sometimes complicated by landslips in such fashion that the loam rests with apparent unconformity upon both its own basal sands and the Port Hudson clays. The gradation into the Port Hudson is shown graphically in Figs. 29, 30,

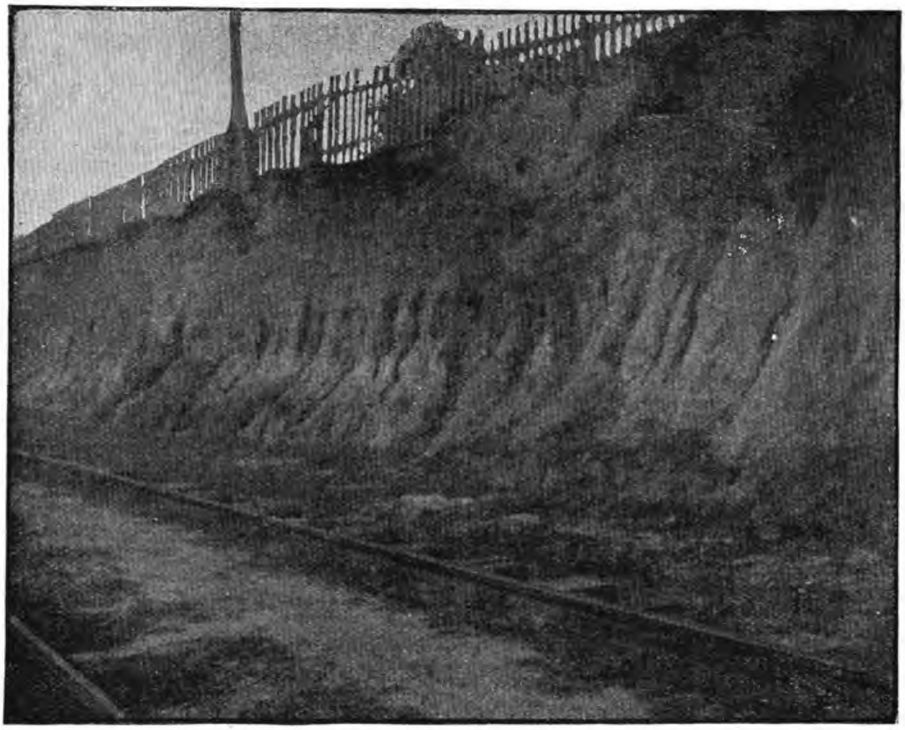


FIG. 29.—Brown loam with silt layer at base; Arsenal Cut, Baton Rouge, Louisiana. The buttressed bed mid-height of the exposure is the silt layer, or the "pinnacly clay." It contains at base fine gravel grains sparsely disseminated. Typical Port Hudson clays occur below the bottom of this cutting in the river bank. Exposure, 12 feet.

and 31, reproduced mechanically from photographs of the Arsenal cut at Baton Rouge, of the river bluff at Port Hickey, and of the principal bluff at Bayou Sara, all in Louisiana; and landslip unconformities between the loess (or loam) and the subjacent sands are illustrated in Figs. 32 and 33, reproduced mechanically from photographs taken a mile south of Natchez, Mississippi.

In brief, the brown loam is a sheet of the material indicated by its name, mantling 50,000 square miles of the nominally low yet actually high land overlooking the Mississippi flood-plain from the east; it lies on a distorted surface ranging from 600 feet above tide to below sea level; the loess is partly enfolded within and partly superimposed upon it while, with its basal gravel, it rests unconformably upon all other formations of the region; and it grades into the other phases of the formation which it represents, vertically downward into the Orange Sand (of Safford) at high levels and the Port Hudson at low levels, and horizontally into the Biloxi sands and Pontchartrain clays as well as into certain newer phases of the Port Hudson in the lower part of the Mississippi embayment.

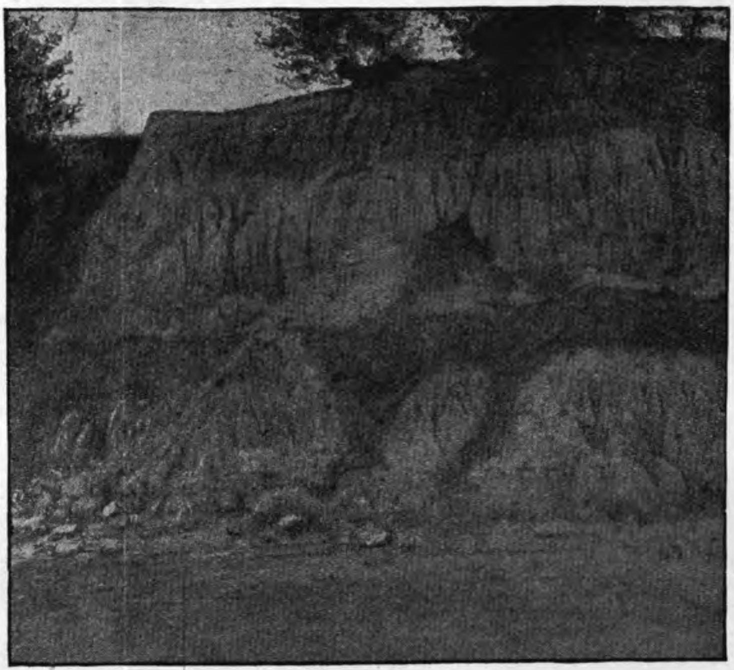


FIG. 30.—Relation of brown loam to silty beds and Port Hudson clays; Port Hickey, Louisiana. The "pinnacly clays" are greatly thickened, and a sandy bed at their base contains gravel up to $\frac{3}{16}$ inch. This bed grades by interleaving into typical Port Hudson clays. Exposure, 75 feet.

This difference goes with a related difference in the constitution of the formation: in the type locality the bowlder bed is the base of the formation as exposed above tide level; in the Mississippi embayment a heavy mass of clays underlying the gravel is exposed above tide level.

The coarse phase of the Columbia formation lying beneath the brown loam (Safford's Orange Sand) may be either gravel or sand, or both combined. The most conspicuous display of this bed is at Natchez, where the sands are stratified and cross-stratified, sometimes marked by lines or parted by beds of gravel and calcareous clays of the Port Hudson type, and fully 100 feet thick. The exposures at this locality are especially noteworthy, not only by reason of the exceptional volume of the sand and gravel, but also by reason of the occurrence of fossils, and perhaps still more by reason of the definite stratigraphic relations there displayed. The sequence observed in the bluffs overlooking the river for a mile above and two miles below Natchez is greatly complicated by landslips, but when clear is about as follows: loess containing abundant shells of pulmoniferous mollusca, 10 to 50 feet; brown loam, unfossiliferous, sometimes orange-tinted, becoming silty and sand-parted

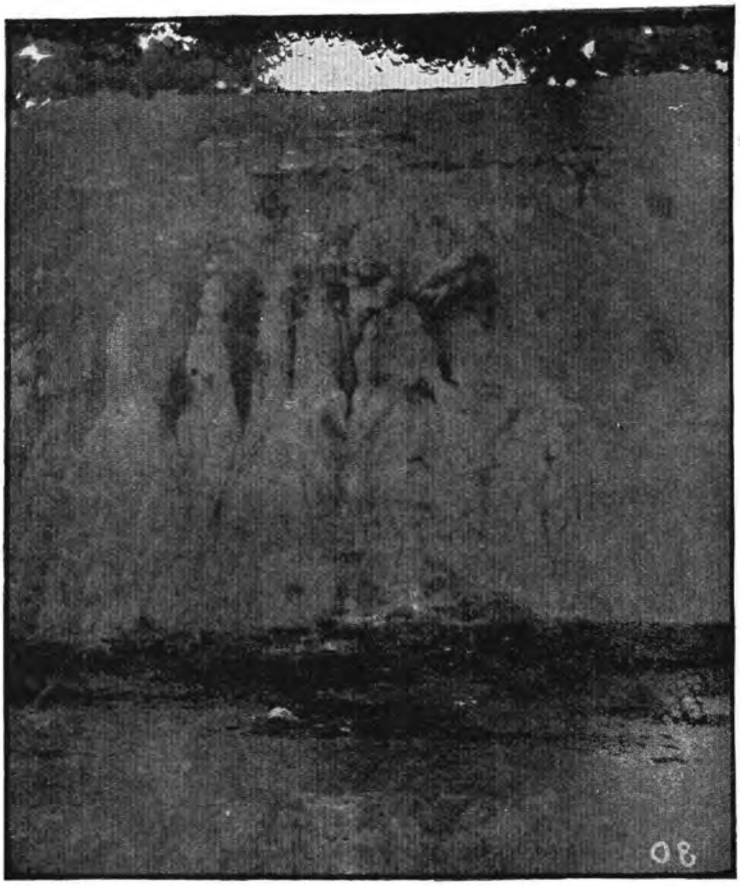


FIG. 31.—Brown loam with silt bed and gravel beds near base; Bayou Sara, Louisiana. The silt bed is thinner than at Port Hickey, but the basal sands and gravels are better developed, the pebbles reaching $\frac{1}{2}$ or $\frac{5}{8}$ inch. The Port Hudson clays form the lower part of the exposure, which is about 30 feet.

below, 10 to 40 feet; stratified loamy sand, generally fine, sometimes silty, 5 to 15 feet; tenacious blue, ashen, or gray clay with calcareous nodules (Port Hudson), 10 to 15 feet; cross-stratified sand with scattered pebbles and intercalated pebbly beds, becoming coarser below, 30 to 50 feet; stratified gravel, often cemented by iron, 5 to 15 feet; greenish and blue clays (Grand Gulf), 5 to 10 feet above low water. These divisions, be it noted (except the Port Hudson and Grand Gulf), are purely arbitrary; no definite line can be drawn between loess and loam, loam and fine sand, fine sand and coarse sand, or coarse sand and gravel; even the clays occur in lenticular beds of which one is fairly constant, though others appear at several lower horizons; the arbitrarily defined beds merge by intergrading of materials and by interstratification; lines of gravel sometimes occur in the lower part of the loam, and lenses of

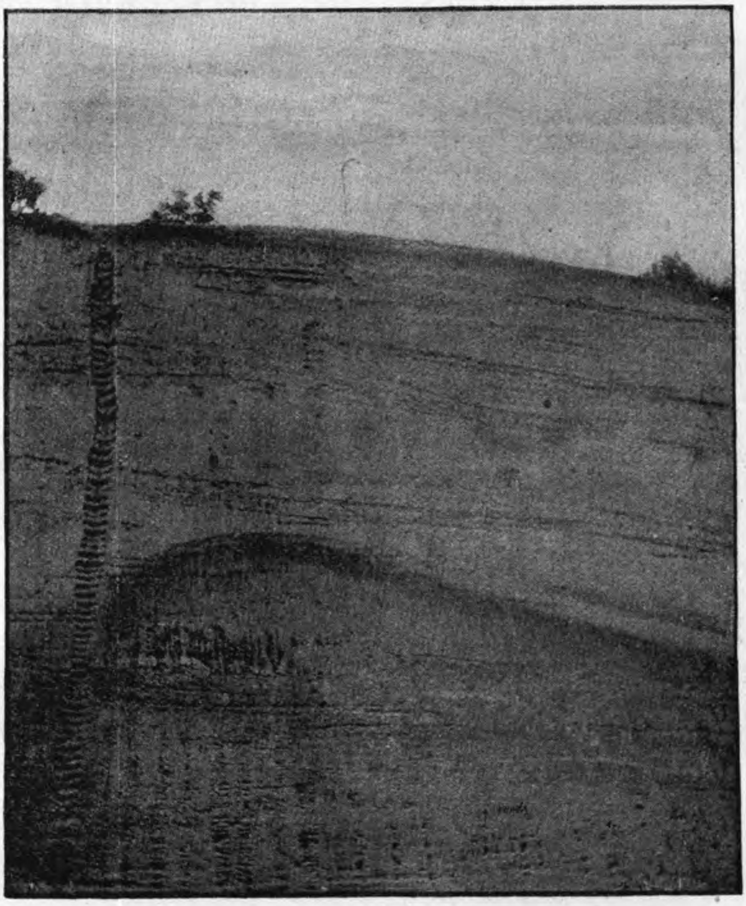


FIG. 32.—Loess resting on stratified sand, near Natchez, Mississippi. In a part of the section the loess grades into the sand; but in the part figured there is a slight unconformity of structure and coincident change in material from fine above to coarse below. Fossils are found in both loess and sand, and the Port Hudson clays crop out beneath in a neighboring cut. Exposure, 90 feet.

loam sometimes occur in the lower part of the coarse sand and also in the gravel; the arbitrarily defined beds of fine sand, coarse sand, and gravel, as well as of Port Hudson clays, are inconstant from exposure to exposure, even from place to place in the same exposure, and are interleaved in complex and ever-varying fashion, so that it can be said only that fine sand predominates above, coarse sand medially, and gravels below, and not at all that the materials designated are wholly confined to the respective beds; no break in deposition is indicated by unconformity, by old soil stuff, or in any other way; and although the coarser materials are locally ferruginated and sometimes firmly cemented, the general aspect of antiquity is alike from summit to base of the exposure. Only at the base of the gravel bed is there, toward the south-

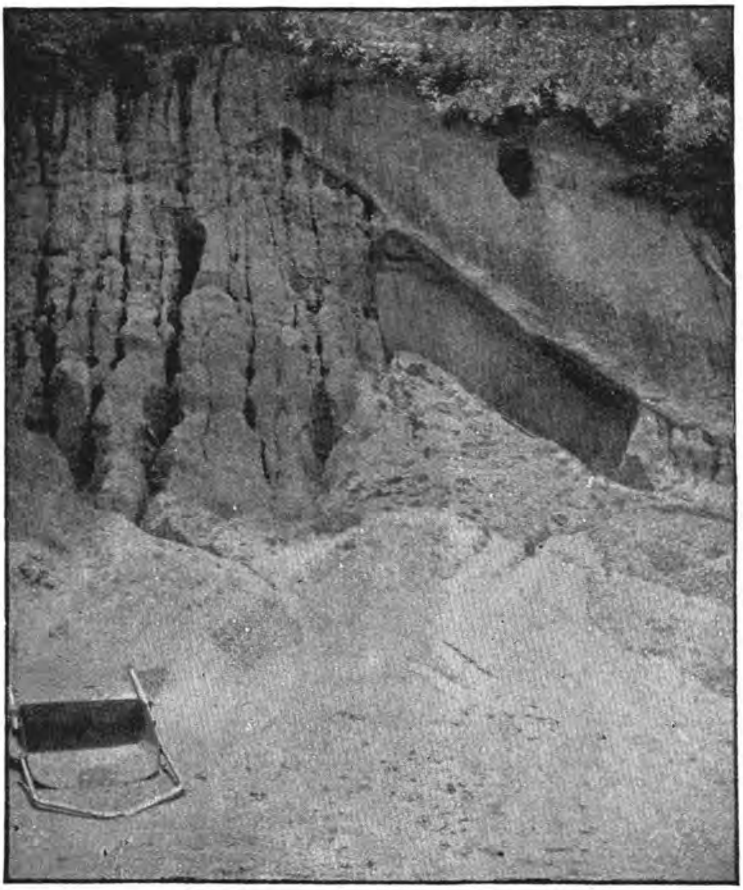


FIG. 33.—Landslip contact between loess and stratified sand; 1 mile south of Natchez, Mississippi. The loess is of the usual massive fossiliferous type; the stratified sand is coarse and sometimes gravelly, particularly toward base. In a neighboring cut the deposits intergrade. Exposure, 25 feet.

ern extremity of the exposure, any indication of discontinuity in deposition, in lieu of alternations in the character of the deposit from loess and fine clay to gravel in a clayey matrix; for here the gravels are unconformably underlain by dark clays or mudstones of Grand Gulf type. The loess is unusually rich in shells of land and swamp mollusca, together with a few aquatic species; the stratified fine sands about the base of the brown loam, and in some cases the gravelly beds well down toward the Port Hudson clays, have yielded elephantine bones and teeth, including several nearly perfect skulls of the mastodon and at least one of the American elephant, to which a matrix of coarse gravel adhered at the time of examination. The Port Hudson clays are, as usual, characterized by abundant and large nodules of carbonate of lime commonly arranged in strings and sheets. The sand is in general predominantly quartzose, but the pebbles of the gravel and many grains of the sand are chert, similar to that forming the pebbles of the Lafayette formation in the same region—indeed both the sands and the pebbles of the deposit are evidently derived in large measure immediately from that latest of ante-Pleistocene formations. It is noteworthy, however, that the basal gravel beds yield moderately abundant granite and greenstone pebbles, resembling the Lake Superior rocks in appearance, up to 6 inches in diameter.

In geographic distribution the sands and gravels of this phase of the Columbia formation are essentially conterminous with the brown loam, though they may be traced farther into the Port Hudson clays where the loam and the clays intergrade horizontally, as at Bayou Sara, Port Hickey, and Baton Rouge. In hypsographic distribution they follow the loam (and the loess, when no loam lies below), of which they are indeed but the basal portion, just as the bowlder bed at Washington forms the basal portion of the formation in its type locality. One difference alone appears: in the type locality the bowlder bed generally characterizes the lower levels; in the Mississippi embayment the Columbia gravel beds commonly characterize high altitudes or midheights. This difference goes with a related difference in the constitution of the formation in the type locality the bowlder bed is the base of the formation as exposed above tide level; in the Mississippi embayment a heavy mass of clays underlying a part of the gravel is exposed above tide level.

Most conspicuous and important of the four phases of the Columbia deposits in the Mississippi embayment, by reason both of extent and thickness, is the Port Hudson. It is a vast bed of blue, black, gray, or brown laminated clay, commonly clean, though sometimes parted with sand, silt, or fine gravel, and often charged with calcareous or ferruginous nodules. This tenacious clay floors the entire flood plain of the Mississippi from the mouth of the Ohio well toward the Gulf shore, sometimes beneath a veneer of modern alluvium; and the main and most of the minor channels of the great river, and the principal tributaries and distributaries as well, are carved within it. It is preeminently a lowlevel deposit, seldom rising far above the modern baselevel, and many of the corn, cotton, cane, and rice fields of the vast region represent it. These Port Hudson soils are most fertile when intermixed with modern alluvial sands; when not so intermixed the deposit gives rise to a tenacious and heavy soil which, when charged with small ferruginous or calcareo-ferruginous nodules, is colloquially known as "buckshot lands." This phase of the formation lines the broad ancient valley of the Mississippi from Cairo to the Gulf. It is well displayed in the area lifted by the New Madrid earthquake—an area complementary to and hard by the sunken tract of Reelfoot Lake, now forming Lake County, Tennessee. Its thickness reaches 400 feet at Greenville and over 600 feet at New Orleans, and it rests unconformably upon the Lafayette and all older deposits of the region.

The physical relations of the four phases of the Columbia formation as developed about the mouth of the great river have been set forth; the genetic relations are simple in the general view, though complex in certain details. Disregarding the details, they may be thus stated: With the initiation of the Columbia submergence, which was greater toward the interior than along the coast, the great river gradually silted up its lower valley, the sedimentation lagging somewhat behind the sinking so that after the first droppings the interior sediments were fine and homogeneous, the shore sediments coarser and heterogeneous; this continued until the embayment became wide and deposition became predominantly lateral and only subordinately central—the lateral materials, partly river-borne, partly wave-washed, remaining coarse, the central materials finer. When the waters spread over the peneplain lying east of the old embayment proper, the combined wave work and river work produced a basal sheet of coarse deposits, which, as the sinking continued, became finer, and at the greatest submergence, as during the earlier stages, there came from the north immense quantities of rock flour, the grist of the glacial mill, to form the loess or to combine with local débris and form the brown loam. The main current of the muddy stream from the north followed the line of the old erosion rampart, which rose nearly, sometimes quite, to the water level, and there the swollen Mississippi built, as it has done during other stages of its existence, a broad natural levee by which the rampart was strengthened. Then the northern floods diminished and the land lifted, but for a long time the lowland remained submerged, and sedimentation progressed in the embayment until it was filled to baselevel. So the first deposits are the sub-local gravels and sands (chiefly derived from the Lafayette formation) displayed by borings at New Orleans, at Greenville, and beneath the Calcasieu prairie; the next deposits are found in the lower part of the Port Hudson, and consist of the sediments of the great river and its lateral tributaries, together with some glacier-ground débris from the north; the mid-period deposits are the sub-local gravels mantling the peneplain east of the embayment proper and stretching into the marginal portion of the Port Hudson, formed mainly by the wash of waves and streams upon the Lafayette remnants, but mixed with some northern pebbles, much northern rock-flour; the next deposit is the vast mantle of brown loam, consisting partly of local and partly of sub-local material, but always containing an important and usually predominant element of glacier-ground sediment, and where the glacier-ground materials were not mixed with those from local sources the deposit is loess; but meantime, and long after as well, far-traveled and fine rock matter was dropped in the deep embayment.

Correlated genetically with the typical formation, the gravel bed at the base of the Port Hudson represents the beginning of Columbia deposition in the ancient valley, just as the bowlder bed in Washington represents the beginning of Columbia deposition in the Potomac estuary; the bed of gravel and sand (Safford's Orange Sand) at the base of the brown loam represents the beginning of deposition on the peneplain, but along the eastern rampart, at least, it was always washed a little way into the embayment, so that today it appears between the high-lying brown loam and the low-lying fine clays; the brown loam represents the greater part of the peneplain deposition; the loess represents peneplain deposition of exclusively glacier-ground materials, apparently in the form of broad natural levees during the culmination of the submergence; the Port Hudson represents deposition in the ancient valley from the beginning of the submergence up to the final retreat of the waters; and, just as on the Atlantic coast, the drowning of the land itself represents a submergence beginning about or shortly after the first ice invasion, culminating a little after the culmination of this invasion, and continuing some time after the retreat of the ice.

Correlating the several phases or members of the Columbia formation developed in the Mississippi embayment with the phases developed in the type locality, certain resemblances and certain differences appear: Most conspicuous among the resemblances is the similarity between the brick clay or loam of the type locality and the brown loam of the embayment. Only less conspicuous is the similar gradation of the loam into a coarse basal bed. A third notable resemblance is found in the character of the basal bed itself, which in both areas consists of local and sub-local materials, but is coarser in the typical area than in the embayment. The most conspicuous difference is found in the vast sheet of Port Hudson clay, which is, so far as known, without exact representative in the District of Columbia, though it is possible that this deposit may yet be found by borings in the submerged estuaries of the Atlantic slope, while it may be represented in a greater or less part by the silty low-level phase in the typical area. Another noteworthy difference is found in the important element of rock flour forming the loess and brown loam of the embayment, which is but feebly represented in the calcareous element of the loam on the Susquehanna and Delaware Rivers.

Correlating the phases or members of the formation in each of the natural districts from the Potomac to the Mississippi, all are found definitely connected by a complete chain of homology. In the type locality there is an estuarine or fluviatile deposit lining the comparatively deep canals cutting the coastal lowland, and a thin and inconspicuous interfluvial deposit between. As the estuarine canals diminish in depth southward the fluvial phase persists, though diminishing in absolute and relative volume, while the lower divides are more thickly veneered with the interfluvial phase. In the third great district the estuarine canals fail and the fluvial phase becomes feeble, while the interfluvial phase stretches over the lowland in a vast mantle. In the next district the fluvial phase again develops to a degree even more conspicuous than in the type area, and the interfluvial phase continues but withdraws nearly to the present coast line. In the fifth and most noteworthy of the natural districts of the formation the two phases can, perhaps, be discriminated only in arbitrary fashion, yet the series as a whole grades through the Biloxi sands and Pontchartrain clays into the low-lying Port Hudson, which is unquestionably estuarine or fluvial, and into a portion at least of the brown loam with its basal gravel bed, which are evidently wave-formed and thus interfluvial. So in tracing the deposits from district to district the principal phases are susceptible of direct correlation; and, moreover, the deposits are stratigraphically continuous, as proved by actual presence, through the successive river valleys and over the successive divides all the way from the Potomac to the Mississippi.

Correlating the continental oscillations represented by the different phases of the formation in the several districts, it is found that all represent movements similar in kind though varying in degree. In the type locality the deposits represent a depression of the land, contemporaneous with the first invasion of Pleistocene ice, reaching 300 feet or more in the North and diminishing to about 150 feet on the Potomac River; in the next district they represent submergence progressively diminishing to 50 feet or less about the Hatteras axis—an axis of interruption or change in epeirogenic movement during every geologic period since the Cretaceous; and in both districts the fluvial deposits record a colder climate than the present and decided flooding of the rivers, diminishing from north to south. In the third district the deposits represent submergence increasing to 600 feet or more and stretching far inland, and there are indications of enfeebled river work. In the district characterized by "second bottoms," lying between the Suwanee and the Pascagoula, the deposits represent slight submergence along the coast, increasing inland to such an extent that the rivers were clogged—they tell of that northward tilting of the land which is recorded even more decisively by the great incursion of the Columbia shores nearly to the headwaters of the Savannah, and by the great rise of the Columbia sediments in the embayment of the Mississippi near the deflection of the Tennessee. In the embayment district the deposits represent a submergence of 100 feet or less in the south, increasing to 600 feet or more under the thirty-fifth parallel, and then diminishing gradually northward, together with materially increased discharge, particularly of fine glacial materials, through the great river. So the formation in its various parts gives consistent records of the movement of land and sea.

Correlating the genetic conditions of the deposits in the different phases and several districts, it appears that the principal conditions are two, of which one was coincident throughout while the other varied locally. The primary genetic condition was submergence with concomitant wave work and dropping of sediments, and this was everywhere alike. The subordinate genetic condition grew out of the local work of the rivers, and this varied from river to river with the volume, with the changes in regimen growing out of the warping of the continent, and with the influence of northern ice upon some of the rivers; yet the local records are consistent, not only among each other but with the general record and with the records read from other phenomena in the interior of the continent. So the various parts of the formation may be correlated by homogeny as well as by intergrading of phases and by stratigraphic continuity.[1]

There is a sixth natural district of the Columbia formation lying beyond the Mississippi embayment, which is in a general way bounded on the east by Sabine River, on the southwest by the Rio Grande, and on the northwest by a line midway between the fall line and the coast. In the type district the Columbia formation comprises well defined fluvial and interfluvial phases and an ill defined low level phase, and is moreover commonly separable into distinct upper and lower members; in the districts extending thence to the Mississippi the typical phases and members may be traced with greater or less continuity; in the lower Mississippi district the entire formation is predominantly fluvial, but it is separated into four members, of which the first two correspond to the fine upper and the third to the coarse lower member of the type area, while the fourth, which is finest and lowest of all, is not represented above tide level in the type area; and in the southwestern district the formation is substantially represented by a single deposit corresponding to that lowest member of the lower Mississippi district which is not represented within reach of observation in the type district; i. e., aside from a relatively unimportant development, the Columbia formation of Texas is essentially an extension of the Port Hudson clays of Louisiana.

In central and southwestern Louisiana the Columbia formation is a vast sheet of laminated clays, commonly several hundred feet in thickness, which toward Atchafalaya Bayou are frequently blue or bluish gray and charged with carbonate of lime, often segregated in nodular form, while farther westward they become brownish or reddish in color, noncalcareous in composition, and arenaceous in texture; i. e., the portion of the deposit brought down chiefly by the great river contains an important element of fine rock flour, while the portion supplied by Red River contains a predominant element of red mud and sand derived from the southwestern red beds. Moreover, there is a fairly constant difference between the upper and lower portions of the deposit, the lower strata being coarser and the upper finer, while the uppermost materials

[1] Certain members and phases of the Columbia formation, particularly in the Mississippi embayment, have been referred to the Tertiary upon various grounds, and there may be reason for regarding the coarse basal bed as Neocene rather than Pleistocene; but the series is identical in the various districts, and division in one part will involve division throughout.

are finest of all, particularly within the many shallow interstream basins circumscribed by levee-flanked bayous. Toward and beyond the Sabine these conditions slowly change: In the first place the element of northern rock flour diminishes, and the calcareous nodules frequently fail; then the Red River sands diminish, and the materials become more tenacious; meantime an element of black mud, such as is carried down by the rivers flowing over the Cretaceous chalks of Texas, appears, and the deposit becomes the black tenacious clay characteristic of southeastern Texas. This aspect is maintained for 100 miles west of the Sabine, when the clay again becomes calcareous, and the element of lime increases until, about the mouth of San Antonio River, the texture and even the surface configuration are largely determined thereby. Here the clays are black, weathering drab, streaked with light gray and white, sufficiently tenacious not only to stand long in natural or artificial faces but to form the most strongly accented topography of the western Gulf coast. Corpus Christi Bay is semi-circled by a 40-foot scarp of this clay, which is sometimes carved into precipitous cliffs, and the city of Corpus Christi is built on steep-sloped bluffs forming part of the same scarp; yet within a few hundred yards of the scarp and of the ravines by which the Columbia plain is partially invaded, the surface is a flat, monotonous, ill drained expanse diversified only by curious natural crevices and narrow pits widening downward in such manner as to indicate subterranean drainage and solution combined, and to suggest the origin of the puzzling "hog wallow" lands of the Cretaceous "black prairies" of Texas, Arkansas, and Louisiana. Still farther southwestward the calcareous material again diminishes in quantity, and the deposit contains a larger element of silt and sand contributed by the Rio Grande and its neighbors.

In geographic distribution (as ascertained chiefly by Hill) the predominant phase of the formation in this district skirts the Gulf coast in a zone 75 to 125 miles wide; the town of Sabine approximately marks its inland extension; the city of Houston is well within it; the town of Beeville approximately, and the city of San Diego exactly, marks its margin; while still farther southwestward the feather edge of the formation extends farther inland, and doubtless grades into the light buff loess-like fossiliferous loam of the lower Rio Grande. In hypsographic distribution the formation extends from tide level to altitudes of 60 feet at Houston (which is not far from the middle of the zone) to about 90 feet at Sabine, 110 feet at Rosenberg, 185 feet at Victoria, about 200 feet at Beeville, and over 300 feet at San Diego. In addition to the principal body of the formation, corresponding approximately with the Port Hudson of the lower Mississippi region, there are in this district narrow ribbons of "second bottom" loam with basal gravels running up most of the rivers from 50 to 100, or even 200 miles beyond the inland margin of the clays. Thus, on Red River the well known red-tinted terrace from which the waterway received its name extends half way from the mouth to the mountains, a score or more miles above Denison and 725 feet above tide; on Trinity River corresponding terraces extend above Dallas, reaching 450 feet in altitude; on the Brazos River they are well developed at Waco, 425 feet above tide; on the Colorado similar terraces form the finest agricultural lands about Austin, rising 450 feet above the Gulf; at San Antonio there are similar but less extensive terraces skirting the San Antonio River, reaching 650 feet in altitude; and the lesser waterways are similarly skirted by "second bottoms" of loam grading into sub-local gravel. These river-haunting ribbons are analogous to those of the Alabama rivers, and they are equally significant as records of the attitude of a considerable part of the continent during the wide-spread Columbia submergence.

On generalizing this distribution, certain significant relations appear: In the first place, the zone is widest in the northeast, where the southwestern district passes into that of the lower Mississippi, and it is also lowest along this line; farther southwestward it gradually contracts in width and increases in height about to the Brazos; and still farther southwestward it again expands in width, and meantime continues to increase in altitude so far as the formation has been discriminated, perhaps 75 miles from the Rio Grande. This inequality in distribution tells of continent movements of the geologic past and of the geologic present, of the attitude and oscillations of the continent during the Columbia period, and also of the modern movement revealed in the keys and sounds of the present coast. The records overlap in part, and the characters of the one measurably obscure those of the other, yet both may be partially interpreted. The great inland extension of the littoral clays, and of the "second bottom" ribbons as well, in the northeast, corresponds with the inland extension of the formation in and beyond the Mississippi lowlands, and indicates that during the Columbia period the land not only stood low but tilted northward; the increase in altitude and partial increase in width of the low-level phase of the formation southwestward is consistent with the testimony of the keys and sounds, and indicates that the continent depression following the post-Columbia high-level is less decided toward the international boundary than toward the Louisiana line, and, indeed, progressively increases from near the Rio Grande to the delta of the great river.

In the second place, the distribution, viewed in connection with the waterways and the autogenetic sculpture of the southwestern district of the coastal plain, gives indication of the climatal conditions attending the Columbia submergence. Thus, everywhere southwest of the Guadalupe, the waterways traversing the coast prairies are few, small, and simple, while immediately inland from the coast prairie or Columbia belt they bifurcate again and again, and quickly multiply in number and in depth, albeit occupied to-day by only trifling and temporary threads of water, and still farther inland they terminate within 50 or 100 miles, and the drainage again becomes scant and simple.

Now, this multiplication of waterways tells of heavy precipitation along the Columbia coast and consequent rapid development of the stream-carved channels in the friable Lafayette sands; and their union or termination coastward indicates relative aridity in the same zone when the land subsequently rose and coast precipitation was transferred to a more obdurate terrane. The testimony of land sculpture thus coincides with that of the deposits and also with that of the starveling remnants of the coast flora now left far inland.

The greatly developed and differentiated Columbia formation of the lower Mississippi district is correlated with that of the type district by stratigraphic continuity as well as by homogeny; and the same correlation is extended into the southwestern district by direct stratigraphic continuity, by physiographic identity, and by homogeny even closer than that connecting any other two districts of the coastal plain. So, despite the simplicity of the record found in the deposit as developed in the southwest, the several districts may be combined, and the same Pleistocene formation, everywhere telling of similar episodes in continent growth, may be extended not only from the Hudson to the Mississippi but on to the Rio Grande.

The Columbia formation is significant in several ways in its bearing on the study of the Lafayette formation. In the first place, the two formations lie in physical contact. In the second place, the later formation is in part derived from the earlier, so that it is sometimes difficult if not impossible to discriminate them; and even when they are discriminable there is often a passage bed, made up of the earlier materials rearranged by the later agencies, which is differently classed by different geologists. Again, the unconformity between the formations can be interpreted only after a study of both, and since this unconformity is the erosion record of the Lafayette, it must be interpreted in order that the original condition of the earlier formation may be ascertained. Finally, and most important of all, the Columbia formation well illustrates the relative activity of geologic process about the great river and on the eastern Gulf and Atlantic slopes respectively, and thus gives a conception concerning general continental conditions which must serve as a basis for study, not alone of the Lafayette, but of all the lowland formations. The volume and diversity of the Columbia formation culminates in the Mississippi embayment; in like manner, the volume and diversity of the Lafayette formation culminates in the Mississippi embayment, and in a degree which would appear surprising, if not incredible, were not the earlier record corroborated in every detail by the later; so, too, the great pre-Lafayette formation which Hilgard called Grand Gulf culminates in volume and importance in the Mississippi embayment in a manner which would surely not be appreciated were it not for later records; and still farther back in geologic time the predominance of embayment deposition may be read in coincident terms.

THE GRAND GULF FORMATION.

Unconformably above the Lafayette formation throughout much of its extent lies the Columbia formation; unconformably below in the central Gulf region lies the Grand Gulf formation of Hilgard.

The prevailing materials of the Grand Gulf formation are peculiar, semi-indurated and more or less sandy clays or mudstones, sometimes definitely bedded with occasional indurated ledges, again massive, and elsewhere consisting of alternating harder and softer layers, each some feet or yards in thickness. In certain cases the sand, which is nearly always sharp, predominates, and the lithifaction is so complete that the rock becomes quartzitic, as in certain layers at the type locality—Grand Gulf, Mississippi. Elsewhere clayey materials prevail nearly or quite to the exclusion of the sand, as in the exposures on Leaf River, west of Hattiesburg, Mississippi. The color is generally gray, ranging from whitish or yellowish to blue and green, more rarely brown, and sometimes nearly black. The texture is commonly uniform throughout considerable thicknesses. The bedding planes are irregular and sometimes stylolitic, and the mass is usually so dense and tenacious as to simulate veritable stone in large masses and in cliffs, though the behavior in hand specimens and under the hammer is rather that of indurated clay or mud. The various features of structure, texture, color, etc., are combined in such manner as to give a facies so distinctive, that, despite the dearth of fossils, the formation is in general easily identified wherever seen.

The best known portion of the Grand Gulf terrane is a triangular area overlooking the Mississippi from near the mouth of Big Black River to the southwestern corner of Mississippi and narrowing thence eastward to about the confluence of the Alabama and Tombigbee rivers, where, so far as at present known, the formation either feathers out or passes into deposits of distinctive character. Throughout this area the formation is commonly overlain by the Lafayette, save where the latter formation has been trenched, or removed from larger areas, by erosion; but since the Lafayette, here as elsewhere, reflects with greater or less fidelity the characters of the subterrane, and is accordingly exceptionally obdurate, Grand Gulf exposures are rare. Widely separated exposures are, however, sufficiently numerous to indicate that the Grand Gulf surface beneath the Lafayette mantle is nearly or quite as rugose as the strongly undulating peneplain of to-day, and thus that this formation was deeply carved by streams before the next succeeding invasion of the Gulf waters. The exposures indicate, too, that the formation reaches its greatest northing along the Big Black rather than the Mississippi, since it extends nearly to the latitude of Jackson on the eastern side of the former stream.

The thickness of the formation has not been measured and can only be estimated roughly from the width of outcrop and the dip of strata. Assuming to be continuous the observed dips of about 10 feet per mile through the 75 miles of strata exposed along the Mississippi, the thickness might be put at 750 feet in this latitude; but unquestionably the deposit thins materially toward the sea.

The Grand Gulf formation attains a considerable development west of the Mississippi in Louisiana and perhaps in Texas, as shown by Hopkins and Johnson, but beyond the great river the land lies low, the exposures are less satisfactory than in the east, both the Lafayette and the Columbia mantles are thicker, and the data are so incomplete and indefinite that little can be said concerning this part of the terrane.

East of the Mississippi the Grand Gulf deposits appear to rest unconformably on the next older member of the coastal plain series, the Vicksburg limestone; for, as shown by Johnson,[1] not only is the dip of the later formation materially less than that of the earlier, but in the only contact thus far known (Brown's Bend in Chickasawhay River, 3 miles southeast of Waynesboro, Mississippi) the strata of the respective formations are discordant quite to the line of contact. The same section displays well the great unconformity between the Grand Gulf and the Lafayette formations.

The Grand Gulf is practically unfossiliferous; true, according to Hilgard, leaves, leaf impressions, and stumps and logs of dicotyledonous trees occur within it,[2] while Johnson[3] has found not only leaf impressions but fragmentary shells of *Unio;* yet the fossils are insufficient to determine the place of the formation in the biotic scale.

In southeastern Mississippi, particularly along the Pascagoula River, Johnson has brought to light a series of deposits resembling somewhat in material the typical Grand Gulf formation, though the bedding is more definite, and alternating layers of sand and clay partially replace the prevailing mudstones. The series appears to correspond in stratigraphic position either with the upper part or with the whole of the Grand Gulf, and carries a moderately abundant fauna of rather recent (apparently late Neocene) aspect, which has not yet been studied in detail. Pending the determination of precise relations, Johnson has designated this series of deposits the Pascagoula formation.

Still farther eastward the deposits characteristic of the Pascagoula basin disappear, but whether by feathering out or by gradual transition has not been ascertained; and in southeastern Alabama and the panhandle of Florida white marly limestones, with associated clayey and shaly beds, supervene in corresponding relation to the Lafayette sand beds and the Eocene limestones; but it is not yet possible to correlate the marly limestones (which are commonly classed as Miocene, though the fauna exhibits, as a whole, decided Pliocene characteristics) with the Mississippi mudstones.

In brief, the Grand Gulf formation is known to be one of the most important elements in the stratigraphy of the coastal plain within and

[1] Am. Jour. Sci., 3d series, vol. 38, 1889, pp. 213–216.

[2] Geology and Agriculture of Mississippi, 1860, p. 153.

[3] Am. Jour. Sci., vol. 38, 1889, p. 213

about the Mississippi embayment. Although its precise relations have not yet been definitely ascertained, it is certain that the formation is a vast delta-shaped deposit many hundred feet in thickness, now more than 100 miles in maximum width (including the subsurface portion) and originally much wider, and several hundred miles in lateral extent; certainly the locus of greatest development is near the line of the great river, and the deposits thin out laterally; certainly the materials are coarsest in the central part of the terrane and progressively finer toward the east if not toward the west; certainly the formation is homogeneous and apparently conformable throughout, and is demarked from contiguous formations by great unconformities; certainly the physical relations and mechanical condition of the deposit indicates that the materials were borne into an estuary or bay chiefly by the Mississippi River, and that they were distributed by the action of waves and currents; and certainly the deposit represents a well defined and important epoch in the physical history of the southern United States. It is practically certain, too, that the formation once extended so much farther northward within the Mississippi embayment as to sheet and long protect from erosion the limestone peneplain of middle Mississippi and perhaps even the Lignitic hill land; it is practically certain, moreover, that the original locus of maximum deposition lay somewhat east of the present line of the Mississippi, suggesting that the progenitor of Big Black River (then fed by the Tennessee and Cumberland drainage) contributed much of its material; and, finally, it is practically certain that this deltaform sheet of obdurate mudstones deflected the great river as the land lifted after the Grand Gulf drowning, and ultimately aided in deflecting the Tennessee-Cumberland drainage, and in this way gave origin to the rugose peneplain constituting eastern Mississippi.

The present indications are that the formation as a whole is the analogue of the Columbia and the Lafayette, and that it grades toward the east into the fossiliferous arenaceous clays of the Pascagoula and thence into the Neocene calcareous deposits of the Chattahoochee, perhaps forming the Chattahoochee limestone of Langdon[1]; and that it is thus connected with the thin, calcareous and glauconitic formation commonly assigned to the Miocene fringing the Atlantic coast from Florida to New Jersey; but this connection has not yet been established. Present indications are, also, that the formation extends westward to or a little way beyond the Sabine and then feathers out, the Fayette sands sometimes correlated with it more probably representing the Lafayette.

THE CHESAPEAKE FORMATION.

Certain of the fossiliferous deposits of the middle Atlantic slope commonly assigned to the Miocene in biotic taxonomy have recently been

[1] Bull. Geol. Soc. Am., vol. 2, 1890, p. 605.

differentiated on physical grounds and designated the Chesapeake formation by Darton.[1] He describes the formation as follows:

This formation occupies a belt comprising nearly the entire width of the coastal plain region in Virginia and a wide area in southeastern Maryland. All the water courses of the region cut more or less deeply into the formation, and it frequently constitutes high bluffs along the larger streams. In Maryland it lies east of the Potomac River, and on the "western shore" its northern termination is in a series of outliers midway on a line connecting Washington and Annapolis. Its northern limit on the "eastern shore" is * * * not yet determined.

The formation is diverse in composition, consisting of sands, clays, marls, diatomaceous beds, and shell fragments, in all several hundred feet in thickness. The lower beds consist mainly of dark colored clays and sands, with occasional local inclusions of blue marl. The upper beds are coarser grained, and consist chiefly of white beach sands containing shells and deposits of shell fragments, and occasional argillaceous members. These three series intergrade in zones, which vary somewhat in stratigraphic position and vertical extent, and all the members rapidly thicken seaward, apparently reaching a thickness of nearly 1,000 feet at Fort Monroe.

For the greater part of its area, the clays of the Chesapeake formation lie directly on the eroded surface of the Pamunkey greensands. Westward at some points it overlaps for short distances on the Potomac formation and crystalline rocks. On the James River below City Point the medial portion of the formation lies on Pamunkey greensands, indicating an island or local shore bluff in the early Chesapeake seas. Elsewhere the stratigraphic position of the base of the formation appears to be constant, and the basal plane is a smooth surface inclined eastward very uniformly at the rate of about 10 feet to the mile.

In the Washington section the base of the Chesapeake formation locally cuts across the thin edges of the Pamunkey and Severn formations, and lies directly on the Potomac formation. At Good Hope hill, in this region, occur the Eocene fossils mentioned by McGee,[2] but they are found to be casts mixed with casts of Cretaceous species, both imbedded in sands containing impressions of Miocene mollusca. This occurrence of pebbles, in part consisting of fossil casts, is quite common at the base of the Chesapeake formation, notably at Herring Bay and on the Pamunkey River. In Maryland, especially near Nottingham, and on Pope Creek, the base of the formation consists locally of a thin, hard, silicified stratum filled with Miocene molluscan impressions.

The Chesapeake formation is unconformably overlain by the Lafayette deposits, and along the shores of Chesapeake Bay and the Potomac River, as well as the lower divide, by the Columbia formation.

In the southern Atlantic slope Dall has defined, partly on paleontologic and partly on stratigraphic grounds, a coincident series of deposits containing an early Neocene fauna changing in facies from the lower to the upper portion in such manner as to suggest climatal change; the faunal change agreeing in general with that already recognized by Heilprin and made the basis of a separation of the Atlantic coast Miocene into a "Marylandian" and "Virginian" series. Darton, however, finds it inexpedient to divide the formation on this basis, and regards it as a physical unit.

In brief, the Chesapeake formation is a series of marine sediments, glauconitic in the north, calcareous in the south, and apparently con-

[1] Bull. Geol. Soc. Am. vol. 2, 1890, pp. 431-451.

[2] Three formations of the Middle Atlantic Slope: Am. Jour. Sci., 3d ser., vol. 35, p. 136.

tinuous, at least from Delaware to Virginia, resting unconformably on the Eocene formations, and overlain unconformably at least by the Columbia and Lafayette formations—a series representing a definite episode in the physical history of the continent, and standing toward the Grand Gulf formation of the embayment just as the Atlantic districts of the Columbia stand toward the embayment district of that formation; but definite connection has not yet been established, and the series may be found interrupted over the Hatteras axis, somewhere about the Chattahoochee River, or possibly elsewhere.

THE VICKSBURG-JACKSON LIMESTONE.

The lower portion of the rampart overlooking the Mississippi flood plain, between the Chickasaw bluffs in the north and the Choctaw bluffs in the south, represents a broad calcareous terrane which, during the Neocene erosion periods, yielded more readily to degradation than the Lignitic and Grand Gulf formations. In Mississippi the terrane has been divided, its principal elements being the Vicksburg limestone and Jackson limestone of Hilgard,[1] together with the more restricted Red Bluff and Salt Mountain calcareous deposits. The same terrane has been traced eastward, across Mississippi by Hilgard, and across Alabama by Tuomey, Smith, Johnson, and others, and for some distance into Georgia; but according to most students the series is essentially a unit, being indivisible either on physical or biotic grounds throughout nearly or quite all of its extent in Alabama and Georgia.[2]

In western Mississippi the prevailing rocks of the terrane are regularly bedded argillaceous limestones, calcareous silty shales, and beds of calcareous clay, all frequently fossiliferous; in central Mississippi the argillaceous element is much less conspicuous, and the prevailing deposits are chalky or slightly argillaceous limestones with shaly partings and intercalated beds of calcareous shale. Still farther eastward the calcareous element becomes more decidedly predominant until in central and eastern Alabama almost the entire mass of the formation consists of limestone, sometimes nearly pure, though commonly chalky, including only occasional shaly layers. The abundant fauna by which the formation is characterized is distinctively Eocene.

On the Mississippi the terrane extends beneath the Columbia and Lafayette deposits from the Tennessee line to about the mouth of the Big Black, or fully 250 miles; but by reason of the facility with which its materials have yielded to erosion, and by reason of the heavy mantling beneath newer deposits, outcrops are rare, and neither the precise limits nor the continuity of the formation have been established by direct observation. The thickness of the mass can be only roughly estimated. The observed dips average 20 to 30 feet per mile, which would give for the entire deposit a thickness of several thousand feet; but it is probable

[1] Geology and Agriculture of Mississippi, 1860, pp. 128–147.
[2] Bulletin 43, U. S. Geological Survey, 1887, pp. 15, 16.

that this formation (like all formations in some degree) comprises in cross section a series of imbricated lenses so disposed that the aggregate thickness of the several lenses far exceeds the actual thickness of the formation at any point. The maximum thickness may accordingly fall short of a thousand feet, though recent developments indicate that it materially exceeds the 212 feet estimated by Hilgard in 1871.[1] Traced eastward the terrane rapidly contracts to less than 50 miles at the Alabama line, while the thickness diminishes (probably) to between 300 and 400 feet. In eastern Alabama and Georgia the thickness is still further reduced (to 280 feet on the Chattahoochee River according to Langdon),[2] but by reason of the flatter attitude of the coastal plain strata generally in this longitude, the terrane maintains its width or even expands.

West of the Mississippi there are many exposures of the same calcareous series, and near the river (e. g., in the southern portion of Crowley Ridge) the argillaceous element is even more pronounced than in the Mississippi rampart; but the formation has not been definitely delimited either structurally or geographically.

The structural relations of the deposits east of the Mississippi are fairly well known. As already indicated, the series is separated from the Grand Gulf by discordance in dip, by dissimilarity in material, and by erosion uncomformity; it is separated from the subjacent deposits in Mississippi and Alabama by the same discordance in dip, by complete (though probably gradual) change in the character of the sediments, and by a faunal break indicating, even more decisively than does the change in sediments, a revolution in the physical conditions of genesis.

Briefly interpreted, this calcareous series records an eon of continent growth during which the land stood low and the seas ran high, although the extent of the tract thus conditioned is not yet definitely known. The Mississippi flowed near its present course, for there the precipitates are abundantly mixed with mechanical detritus; yet the detritus entering into the composition of the rocks is so fine, so uniform, so widely distributed, as to indicate either that the waters drowned a much larger area than the present embayment or (more probably) that the land tilted northward as it sank until the rivers ran sluggishly, corraded but feebly, and dropped the weightier part of their burden in their upper courses.

THE CLAIBORNE-MERIDIAN.

Beneath the conspicuous calcareous member of the Mississippi embayment there lies a series of heteromorphic deposits, calcareous above (the Calcareous Claiborne of Hilgard), siliceous below (including the Siliceous Claiborne and Buhrstone of Hilgard). In a general way this series corresponds with the middle Eocene of Alabama, as defined by Smith and Johnson.[3] The thickness assigned to the series in Mississippi

[1] Proceedings Am. Ass. Adv. Sci., vol. 20, 1872, p. 222, map.

[2] Bull. Geol. Soc. Am., vol. 2, 1890, p. 605.

[3] Bulletin 43, U. S. Geol. Survey, 1891, p. 18.

by Hilgard is 210 feet;[1] but in western Alabama Smith and Johnson found the probably coincident series no less than 440 feet thick, while on the Alabama-Georgia line Langdon records a thickness of 250 feet.[2]

The terrane is a crescentic zone, approaching the Mississippi in southwestern Tennessee and northwestern Mississippi, curving thence southeastward across Mississippi and east-southeastward across Alabama, with a width of from 10 to 50 miles. It is doubtfully recognized still farther eastward in Georgia; and it is known to have a considerable development in Arkansas and northwestern Louisiana, though its limits there are not clearly defined.

The upper portion of the series comprises argillaceous marls, sometimes chalky and sometimes siliceous, and now and then distinctly glauconitic. Below, the marls appear to pass into argillaceous and sometimes siliceous mudstones simulating in some degree the predominant material of the Grand Gulf, though commonly more definitely bedded and finely laminated. The basal portion of the series comprises the most distinctive rockmass of the Mississippi embayment, i. e., the "buhrstone," first of the pioneer squatter who ground his grain in primitive fashion, then of the more opulent planter, and finally of the geologist. The rock is as characteristic and distinctive as limestone, sandstone, shale, or marble; but by reason of its confinement to a comparatively restricted region it has never received the coordinate appellation it deserves; and unfortunately the designation of the vernacular is a misnomer, first in that it fails to express the rock character, and second, in that it connotes a diverse material—the French "buhrstone" of commerce, derived from a probably newer siliceous formation of the Paris Basin. This basal member of the series is typically displayed in the vicinity of Meridian; from these exposures it seems appropriate to designate the deposit the *Meridian formation*, or, if the general though unsatisfactory lithologic term be retained, the *Meridian buhrstone*. Here it comprises hard siliceous ledges, with intercalated beds of imperfectly indurated siliceous clay or marl, the mass displaying moderately regular bedding; yet, despite a high degree of uniformity in composition and in structure, there is a wide diversity in texture, owing to the variable degree of lithifaction. There is commonly a rude nodulation or segregation of the materials in plates and lenses, variously disposed in attitude; the nodules, plates, and lenses are generally hard, brittle, refractory under the hammer, clinking sharply, and breaking with conchoidal or splinterly fracture; while the intervening mass is less perfectly lithified, and sometimes indeed quite friable. This differentiation within the rockmass varies widely in magnitude; sometimes the nodules (which are seldom if ever sharply defined) are but an inch or less in diameter, the plates and lenses but hand specimens; again the harder segregations are measurable in feet or yards, the nodules running into lenses, the lenses expanding into ledges; and elsewhere the

[2] Proc. Am. Ass. Adv. Sci., vol. 20, 1872, p. 222, map. [3] Bull. Geol. Soc. Am., vol. 2, 1890, p. 605.

exceptionally obdurate phase forms whole outcrops, rods or furlongs in extent, affecting many strata, determining the drainage, and forming hills; yet the body of the deposit remains unchanged—it is a fine, mealy aggregation of angular siliceous particles, with a subordinate argillaceous element sometimes disseminated and again gathered into sheets. The appearance of the irregular segregation and lithifaction suggests that the harder spots or phases have undergone exceptional solidification, determined by weathering and infiltration during the eons throughout which the formation has lain exposed to sun, storm, and air.

The sediments extending from the summit of the calcareous Claiborne to the base of the Meridian buhrstone are not known to be definitely delimited either above or below, and indeed probably constitute only a series of links in the continuous chain of deposits and events running from the beginning of the Eocene to the Vicksburg-Jackson epoch; yet by reason of the glauconitic element, which promises to connect it with distant deposits, and by reason of the distinctive rockmass forming its basal member, the deposit is important. Standing by itself, it is a puzzling phenomenon; but its unique materials are in some respects analogous with the quartzites of the Grand Gulf, and still more closely with the siliceous clays of the lower Lafayette, and these analogies aid in interpreting the obscure record of the buhrstone, and thus in elucidating the conditions of genesis of the entire series.

In brief, the Claiborne-Meridian deposits stand for a definite episode in continent growth, during which the land lay low, yet not so low as during the next later epoch, and during which the waters rose high, yet not so high as later; thus the rivers were fairly active and swept into the embayment fine detritus, of which an important element was siliceous débris derived from the decomposition of Paleozoic cherts weathered out of the Appalachian and Cumberland rocks. This episode can be separated from that marked by the Lignitic only in the Mississippi embayment and eastern Gulf States.

THE LIGNITIC.

Most significant of the embayment deposits through its elucidation of continent history is the Columbia formation; most extensive of the lowland deposits is the Lafayette; most impressive of the embayment deposits through its testimony as to the activity of the great river in later geologic time is the Grand Gulf formation; but most important of these deposits in extent, in thickness, in topographic expression, is the vast deposit, combined by some though divided by others, which Hilgard styled the "Lignitic" or "Northern Lignitic."

In Kentucky the deposits extend from the Tennessee to the Mississippi, including the Lignitic and probably the Hickman of Loughridge.[1] Here the predominant materials are dark clays and mudstones, which toward the deeper part of the old embayment are finer, more definitely

[1] Geol. Survey of Kentucky, Report on Jackson purchase region, 1888, pp. 17, 18, and geologic map.

bedded, and sometimes calcareous, or siliceous, e. g., at Hickman, where the deposits are so distinctive as to have been set apart by Loughridge under the name of "Hickman group."[1] In Tennessee the claystones of this deposit crop from beneath the Lafayette formation within a dozen or two miles of the Tennessee River, appear in some of the deeper drainage ways thence westward, and are again exposed at the base of the rampart overlooking Reelfoot Lake and in Randolph Bluff. In 1869 Safford designated the deposit as developed toward the Tennessee River the "Porter's Creek group" and, as developed on the Mississippi, the "Bluff Lignite."[2]

In Tennessee and Kentucky the prevailing material is massive clay or semimetamorphic mudstone; but toward the center of the embayment the materials are even finer and more regularly disposed than at the sides, and in the exposures on the shores of Reelfoot Lake, about Idlewild, there are occasional regular ledges of semilithified calcareous claystone of deeper water facies than is displayed in the northernmost outcrops at Hickman.

In Mississippi the deposit is occasionally exposed at the base of the Lafayette over a broad lunoid zone stretching from the Mississippi to the headwaters of Wolf River on the thirty-fifth parallel, and sweeping thence south-southeastward to the Alabama line about latitude 32° 30′, the width of the outcrop diminishing from over 75 miles to not more than 25 to 30. Throughout most of the region from the Ohio River to the Tombigbee the local variations in the deposit are so irregular and the outcrops from beneath the exceptionally heavy mantle of the Lafayette sands so rare and imperfect that the series has not been definitely divided save by Loughridge; but in Alabama the Lafayette mantle thins, exposures are more frequent, and the variations in the deposit become more orderly, and Smith and Johnson have separated the mass into six or seven well defined members.[3] The terrane stretches quite across Alabama, with certain changes in composition, crossing the Chattahoochee River in a 40-mile zone, separated by Langdon into five members with an aggregate thickness of 670 feet.[4]

The six or seven members discriminated in Alabama by Smith and Johnson combine to form a single homogenetic formation comprising three well marked divisions, defined by color, which is here an index of constitution. The upper fourth consists of irregularly bedded dark siliceous and lignitic clays and heterogeneous sands, interstratified with discontinuous beds of lignite and continuous layers of clay and sand containing marine fossils. The medial three-fifths of the formation is made up of rather more regularly stratified clays and sands of light color, frequently cross-bedded, containing occasional beds of lignite and of marine sands, one of which is 50 or 60 feet thick and yields

[1] Ibid., p. 37.
[2] Geology of Tennessee, 1869, p. 422.
[3] Bull. 43, U. S. Geol. Survey, p. 18.
[4] Bull. Geol. Soc. Am., vol 2, 1890, p. 605.

littoral fossils The basal deposits are irregularly bedded or even black calcareous shaly or silty clays with few fossils or definite beds of lignite, though considerable quantities of carbonaceous matter are disseminated throughout its mass.

On the Chattahoochee River the series comprises the Hatchetigbee brown, purple, and gray laminated sandy clays and cross-bedded sands, only 10 feet thick, and the Bashi lignitiferous clays and marls, 45 feet thick; the Tuscahoma sands and sandy clays, the Nanafalia limestones and calcareous claystones with conspicuous siliceous layers, in all 350 feet thick; and the Midway argillaceous and sandy limestones and calcareous sands, with a well defined marine fauna, reaching 218 feet in thickness. The whole series here is only 670 feet thick, although on the Alabama River the thickness is over 850 feet.

West of the Mississippi embayment the corresponding series of deposits has been recognized with greater or less certainty, notably by Hilgard[1] in Louisiana, and by Johnson[2] in western Louisiana and Texas. The Camden series discriminated by Hill[3] in Arkansas, and the Timber Belt or Sabine beds discriminated by Penrose[4] in Texas, have also been provisionally correlated with Hilgard's Lignitic on the ground of general lithologic similarity. This provisional correlation is greatly strengthened by homogeny: The eastern and western deposits are similarly related to a common Cretaceous floor; they record a similar continental configuration; they represent similar conditions of deposition with respect both to source of materials and to the attitudes of land and Gulf bottom; and in all other ways they appear to stand for a stage in continent development so closely similar as to argue identity. But beyond this general geologic correlation inference may not safely be carried, though there is a strong suggestion of at least partial equivalence between the western Lignitic and the easternmost extension of the wonderfully widespread Laramie formation of the western plains and the eastern Rockies.

Collectively, Hilgard's old Lignitic group of strata is pregnant with records of the past. The deposits occupy an extended area and tell of wide transformation of land and sea. By their change in lithologic character from the depths of the embayment along its eastern side they indicate gradual transition from estuarine to oceanic deposition; by their volume and comparative coarseness they tell of active rivers, and so either of a high level in the interior or of some equivalent genetic condition. They also prove that the great river of to-day was the great river of the olden time and, at the beginning of the Eocene as at the end of the Pleistocene, dominated the entire interior basin and so far outstripped other rivers of the eastern continent that the several records may not yet be correlated. Viewed collectively and

[1] Supplementary and final report of a geological reconnaissance of Louisiana, 1873, pp. 20-23.
[2] Report on iron regions of northern Louisiana and eastern Texas, 1887.
[3] Annual report geological survey of Arkansas for 1888, vol. 2, pp. 59-65.
[4] Report of the geological survey of Texas for 1889, p. 22 *et seq*.

appreciatively, the deposits are found to record approximately not only the areas of land and sea during the early Eocene, but the character of the shores, the volumes of the rivers, and the altitude of the land; and they suggest means of correlating their entire mass not only with the more easterly deposits of the Atlantic, but also with the formations of the interior of the continent long corraded by the western tributaries of the greatest of American rivers.

THE PAMUNKEY FORMATION.

Quite recently a well defined early Tertiary formation has been discriminated on both physical and biotic grounds on the Atlantic slope by Darton, and from the river along which typical exposures occur, has been named the "Pamunkey." Mr. Darton's description is as follows:

This formation occupies a belt of considerable width extending through Maryland and Virginia above tide level, with a length of about 200 miles. The greater part of its area is buried beneath younger formations, but it is exposed extensively in each of the larger depressions, where it is a conspicuous member of the coastal plain series.

The formation consists of a homogeneous sheet of fine-grained materials, glauconitic sands mainly, usually profusely fossiliferous. Excepting a few local beds of clay, secondary limestones and some gravels at its base, the formation does not comprise stratigraphic components. Wherever the formation has been bared of overlying formations its glauconitic constituent is either weathered out, leaving fine light-colored sands, or decomposed and the iron redeposited as a red or brown stain, and in crusts and concretions. This weathered phase is general in the northern part of the region beyond the edge of the overlying Chesapeake formation, along the western margin in Virginia, and in all old outcrops.[1]

The characteristic fauna of this formation is well known throughout the southern Atlantic slope and in the Gulf lowland, and biotic correlations have already been made; but the physical delimitation of the deposits has not been carried much beyond the James River, in Virginia, while the definite physical delimitation of the approximately contemporaneous deposits of the Gulf slope terminates on the Chattahoochee River. At present it is impossible to bridge this break of nearly 800 miles. Moreover, while certain petrographic elements of the Pamunkey formation have been interpreted, and while the relations of the deposit as a whole indicate certain geographic conditions during the period of its formation, too little is known concerning the genesis of the glauconitic deposits to warrant definite statement concerning the origin of the materials. Accordingly, correlation of the early Tertiary deposits of the Atlantic slope with the much more extensive deposits of the same era on the Gulf slope and in the Mississippi embayment, is at present quite out of the question. Only this much is certainly known: During the early Tertiary the land sank and the sea rose along the Atlantic seaboard, and during the early Tertiary the land sank and the sea rose in the Gulf region; but in the one case the record is simple and tells only

[1] Bull. Geol. Soc. Am., vol. 2, 1890, p. 439.

of sea work, while in the other the record is complex and tells much of river work with less of sea work; and whether the continent changes in the two regions were wholly or even partly contemporaneous may not be said with confidence.

THE UPPER CRETACEOUS.

The Eocene and Neocene deposits of the Gulf lowland give remarkably consistent records concerning a particularly significant point: the record of the inland extremity of the embayment is preeminently simple, while that of the widely separated embayment sides is more complex; and this peculiarity in the record repeats a like peculiarity in the record of the Cretaceous.

In western Kentucky Loughridge recognizes a single Cretaceous deposit, consisting of laminated black clay with sand partings and beds of white and yellow micaceous sand,[1] 200 feet or more in thickness. He points out that in lithologic features the Kentucky beds can scarcely be distinguished from the oldest of the upper Cretaceous series of Mississippi and Alabama (Eutaw), though he refers them to the next newer member (the Ripley), partly on personal grounds and partly by reason of the entire absence of fossils.

In Tennessee Safford finds a more complex series, which he differentiates into the Ripley sandy and glauconitic clays; the "Green Sand or Shell Bed," consisting of glauconitic sands and clays; and the Coffee Sand, made up of stratified micaceous sands with thin leaves of dark clay and occasionally thicker clay beds; the whole 800 or 1,000 feet thick.[2]

In Mississippi the series was differentiated by Hilgard into the Ripley micaceous sandy marls, sandy limestones, and hard crystalline limestone with a distinctive fauna; the Rotten limestone (now called the Tombigbee chalk by Smith), made up of "a soft chalky rock of a white or pale bluish tint, with very little sand;[3]" the Tombigbee sand, comprising fine grained micaceous and calcareous sands; and the Eutaw group, made up of sands with some gravel and layers of laminated clay.[4] The thickness assigned to the series in 1871 was nearly 2,000 feet.[5]

According to Smith and Johnson the succession of deposits in western Alabama falls into three systemic members, viz, the Ripley, the Rotten limestone, and the Eutaw (the Tombigbee sands failing or else merging either with the Rotten limestone or, more probably, with the Eutaw), the aggregate thickness approaching 1,600 feet.[6] In crossing Alabama the upper Cretaceous series changes rapidly, perhaps more rapidly than in any other equal length of its zone, the principal change being the dis-

[1] Geol. Survey of Ky., Report Jackson Purchase, 1888, pp. 18-32.
[2] Geol. of Tennessee, 1869, pp. 410, 421.
[3] Geol. and Agriculture of Miss., 1860, p. 76.
[4] Ibid., pp. 60 to 106.
[5] Proc. Am. Ass. Adv. Sci., vol. 20, p. 222, plate.
[6] Bull. 43, U. S. Geol. Survey, 1887, p. 18.

appearance of the predominant calcareous member, colloquially known as the Rotten limestone. On the Chattahoochee River, according to Langdon, the upper Cretaceous is represented only by the Ripley and the Eutaw, with an aggregate thickness of 1,376 feet.[1]

The well known upper Cretaceous of the cis-Mississippi terranes is a slender crescent semicircling the Cumberland anl Appalachian provinces; its northern horn lies just beyond the Tennessee River and is exposed to the daily sun and the eyes of man only in erosion valleys; at its broadest bulge, in eastern Mississippi and western Alabama, it forms the prevailing surface over a 40-mile zone; while the eastern horn is in the little known tract of central Georgia.

Beyond the Mississippi a corresponding series has been made out and has been correlated by the contained fossils with that of the nearer area; but physical continuity is interrupted by the vast bottom lands of the Mississippi, and physical correlation is thereby embarrassed. Moreover, in this direction the deposits grade in unknown fashion into the wide stretching sands and shales of the plains and mountains, and these sands and shales were formed and accumulated under conditions so different from those obtaining in the cis-Mississippi region as to discourage physical correlation.

Later Cretaceous formations are also known, but chiefly from their fossils, in the southern Atlantic slope, particularly in the Carolinas; but the mass relation of these to the well defined series of the cis-Mississippi crescent has not been ascertained.

The continent history recorded in the clays and sands and limestones laid down in the Cretaceous sea about the flank of the Cumberland and southern Appalachian and Piedmont provinces is wonderfully clear and decisive. The sands and clays of the northern limb tell of active river work, and, through poverty in fossils, of brackish, muddy waters and shifting currents, and prove that even thus early in the building of the land the principal source of mechanical sediments lay in the north and northwest; the prevailing limestones of the swelling crescent tell of deeper waters and of sluggish, yet persistent, rivers charged with precipitates gathered among the limestone hills of the plateau and washed from the corrugated strata of the mountains, and indicate that thus early in continental history the cis-Mississippi region had become moderately stable and quiescent; while the disappearance of the limestone about the junction of the Appalachian and southern Piedmont provinces tell of the dependence of sea work on river work, and prove that the early partition of the drainage was much the same as to-day, though suggesting that the Atlantic rivers have, during later eons, stretched farther inland than of yore and robbed their westerly neighbors of a part of their legitimate territory and tribute.

[1] Bull. Geol. Soc. Am., 1890, vol. 2, p. 605.

THE SEVERN FORMATION.

In the middle Atlantic slope Darton has discriminated a later Cretaceous formation named, from the river of typical exposure, the Severn.[1] He describes it as consisting throughout almost entirely of fine black sand more or less flecked with scales of mica, sparingly but irregularly glauconitic, and usually containing considerable carbonacous material. It outcrops in a narrow belt beginning in a feather edge a few miles south of Washington and extending northward to the Delaware. It rests unconformably on the early Cretaceous Potomac formation, and is in turn unconformably overlain by the Pamunkey formation, from which it is widely distinct, both structurally and faunally. Mr. Darton adds:

> The Severn formation is the continuous southern extension of the New Jersey Cretaceous greensand series, but whether it represents all or part of these members is not as yet determined. In Maryland it is a stratigraphic unit, distinctly separable from the New Jersey series as a whole by its homogeneity of constitution, and it is with this restriction that the term "Severn" is applied.

The interpretation of the Severn record is far from complete. It indeed tells clearly of sinking of the land and encroachment of the sea to the extent of many hundred feet and many scores of miles respectively, measured from the present shore; it is known from collateral evidence that the Potomac, the Susquehanna, and other main rivers of the middle Atlantic slope flowed along their present lines, and Davis has recently shown that the present drainage of northern New Jersey and New England was outlined during the base-level period preceding Cretaceous deposition;[2] yet the sources of the Severn sediments have never been clearly ascertained, and their character is so different from that which might be expected of the detritus derived from the contiguous land area that Cook thought it necessary to postulate a Mesozoic Atlantis to explain them. It is known that the sinking of the land and the encroachment of the waters diminished southward progressively, and perhaps ended somewhat north of the Hatteras axis; and by reason of this known attenuation or disappearance of the formation, as well as by reason of the vast intermediate expanse not yet fully investigated, it is inexpedient to correlate physically this formation, either with the entire southern series or with any of the members of that series.

THE POTOMAC AND TUSCALOOSA FORMATIONS.

It is well known that the progress of geologic investigation has followed the inverse rather than the direct order of the proximity and accessibility of the phenomena investigated, and this is as true of the physical study of the coastal plain deposits as of geology in general. The clastic series of the coastal lowland comprises a widespread super-

[1] Bull. Geol. Soc. Am., vol. 2, 1890, p. 438.
[2] Bull., Geol. Soc. Am., vol. 2, 1890, p. 549 et seq.

ficial deposit of Pleistocene age; an uncomformably subjacent deposit of vast extent and of prime importance as an element in physical history; several fossiliferous deposits whose biotic contents have been under investigation for over half a century; and finally a basal bed standing for the beginning of later Mesozoic deposition, the initial link in the long chain of episodes in continent development recorded in the coastal plain—the datum-plane alike of coastal structure and coastal history; yet this imperfectly exposed basal bed was the first to be studied by the physical method. In its northern extension this is the Potomac formation;[1] in its southern extension it is the Tuscaloosa formation of Smith and Johnson.[2]

In its type locality (on the Potomac River at Washington) the formation consists of two vaguely differentiated members, of which the upper is an inconstantly bedded and protean clay of variegated colors, either clean or sandy and pebbly, and the lower a generally friable sandstone, arkose or gravel of irregular and inconstant structure.[3] In its type locality (on the Tuscaloosa) the Tuscaloosa formation is composed largely of purple and motley clays, interstratified with white, yellowish white, pink, and light purple micaceous sands, and near the base of the formation of dark gray, nearly black, thinly laminated clays, with sandy partings.[4] On the Chattahoochee River the formation is made up of irregularly and inconstantly bedded, sometimes massive, and in general heteromorphic white-red mottled and sometimes bluish gray clays and sands, frequently micaceous, together with beds and lenses of arkose and lines or beds of predominantly quartzose gravel. The formation has not yet been traced across Georgia, though it has been recognized at Macon and at Augusta; and it has been definitely discriminated in South Carolina, where it is made up chiefly of arkose of inconstant structure, and where it is overlain by the Lafayette, as illustrated in Pl. XXXVI, which is mechanically reproduced from a photograph. It has been discriminated by Holmes elsewhere in South Carolina and in North Carolina at a large number of localities. In Virginia it has been under study for a decade by Fontaine, who has monographed its wonderfully rich and distinctive flora.[5] Farther westward the typical Tuscaloosa deposits have been traced by Johnson in northwestern Alabama and northeastern Mississippi well toward the Tennessee line; and there are good grounds for considering the basal portion, at least, of Safford's Coffee sands to be physically equivalent to the well defined series discriminated from the later Cretaceous formations elsewhere about the inland margin of the coastal plain.

Although important structurally, the Potomac-Tuscaloosa terrane

[1] Seventh Annual Report U. S. Geol. Survey, 1888, p. 546.

[2] Bull. 43, U. S. Geol. Survey, 1887, p. 16, footnote. (All but the first three lines of this footnote are evidently misplaced from body of text.)

[3] Am. Jour. Sci., 3d ser., vol. 35, 1888, p. 133.

[4] Bull. 43, U. S. Geol. Survey, 1887, p. 95.

[5] Monograph, U. S. Geol. Survey, vol. 15, 1889.

is unimportant geographically. Even where best developed its outcrops form but a narrow zone, seldom 10 miles wide and commonly appearing only in the erosion valleys by which it is traversed; and there are long stretches of the Piedmont margin in which the deposits are completely overlapped by the newer formations. Moreover, the outcrop is still farther complicated by later geologic process, in that marginal outliers are frequently cut off by erosion so as now to form completely insulated remnants from rods to miles in extent and perhaps miles inland from the general coastal border. Beyond the Mississippi the break in the terrane by reason of erosion and subsequent deposition is so broad that the basal Cretaceous deposits of Arkansas, Indian Territory, and Texas (the Trinity formation of Hill) may not yet be correlated physically with the cis-Mississippi formation, despite the many indications of homogeny, and despite the approximate identity in flora recently made out by Ward.

Viewed as a whole the deposits are diverse in composition. In the northern type locality, clays predominate, sand is abundant, arkose is common, and quartzite pebbles and cobbles constitute a considerable portion of the formation; farther southward, where the Piedmont plateau is wider and the rivers do not reach the easternmost quartzite ridges of the Appalachian province, the predominant material is clay, with a nearly equal element of sand and an important share of arkose, while the coarser element is sandy or made up of quartz pebbles; toward the southern extremity of the Piedmont province arkose is perhaps predominant, sands and clays are nearly as abundant, and the pebbles are scant and small and chiefly quartzose; about the type locality of the characteristic southern phase (Tuscaloosa) clays predominate, sands are abundant, the pebbles are small and rather scant and made up of quartzite, chert, etc., while the arkose completely fails; and in northwestern Alabama and northeastern Mississippi the composition remains much the same, save that sand becomes predominant. This diversity in composition expresses diversity only in local conditions of genesis and not in the general condition; the deposit as a whole records the first of the land depressions and sea incursions which have combined to build the coastal plain, and the local characteristics merely reflect the local features of the shores, of contiguous terranes, and of tributary rivers.

The leading features in the history recorded in the Potomac and Tuscaloosa formations have been set forth in detail elsewhere, and also have been recapitulated with some fullness; and the recapitulation may be repeated:

At an undetermined epoch in the Mesozoic, the southern extremity of the Appalachians, together with the Piedmont region on the east and the Cumberland plateau on the west, was submerged, and the uneven surface, sculptured by subaerial erosion, formed an irregular shore line diversified by a multitude of estuaries and a highly inclined and unequal sea bottom. Within the estuaries and upon the uneven sea bottom the strong currents, high tides, and violent waves of a deep seacoast washed here and there, assorted rudely, and finally deposited the coarse detritus brought down by numerous streams of high declivity—the upper reaches of the river courses shortened by submergence and steepened by tilting; the strong currents, the constant shifting of littoral deposits, and the variable salinity of the estuarine and shoreward waters (depending upon the seasonal and nonperiodic variability in stage of the affluents) were inimical to organic existence; but leaves, logs, and other vegetable matters were occasionally swept into the sea by the rivers. The downward movement during this epoch was interrupted, and about the middle of the epoch perhaps reversed; but in general it went on progressively. With continued deposition a submarine terrace analogous to those now fringing the Atlantic and Gulf coasts was apparently developed; and, with the growth of the terrace and consequent shallowing of the offshore waters, there was evidently a diminution in strength of currents and violence of waves, accompanied by a diminution in heterogeneity and coarseness of sediments. The deposits produced by these agencies are those of the Tuscaloosa formation.[1]

There is a great hiatus in the geologic history of the Atlantic slope. The history is fairly legible up to the termination of the Paleozoic deposition, and it is even more clearly legible from mid-Cretaceous time to the present; but the hiatus includes the most interesting period in the evolution of the eastern portion of the continent. The transfer of sea and land, the elevation and corrugation of the Appalachians, and the profound displacement and metamorphism of the Piedmont rocks; the degradation of thousands of feet if not miles of strata and the transportation of materials whither no man knows; the deposition of the Triassic and Rhetic rocks under conditions which no geologist has ever clearly pictured in imagination, at least to the satisfaction of his fellow geologists; the Triassic displacement and diking; the post-Triassic degradation of thousands of feet of strata and the removal of the débris to other regions—these and many other remarkable episodes have been completely blotted out of the geologic record as commonly interpreted. But the Potomac formation narrows the hiatus. The formation itself carries the record back from mid-Cretaceous time to the earliest dawn of the Cretaceous or the closing episodes of the Jurassic, and the post-Rhetic and pre-Potomac degradation will tell the story of the Jurassic as eloquently, when men have come to read geologic history in erosion as well as in deposition, as if the deposits of the period were exposed to observation instead of lying beneath the thousands of feet of newer strata forming the Atlantic bottom. So while the hiatus is not yet closed it is reduced by a fifth, a fourth, or perhaps a third of its length.[2]

RÉSUMÉ.

In physiography the coastal plain is a fringe of lowland stretching from the Hudson to the Rio Grande, with a pronounced inland expansion about the Mississippi, and with a pronounced oceanward extension at the southeastern extremity. Structurally the coastal plain consists of a series of successive formations laid one upon the other in leaves of varying continuity and varying inland extent, and each of the formations, so far as they have been correlated, greatly thickens and expands in the inland extension about the great river.

The latest of the formations is the Columbia, which overlies half the coastal lowland as a mantle of sand and loam with a basal bed of coarse materials, save in the Mississippi embayment where it thickens so far as to include a vast sheet of clay; and this deposit is demarked by a decided unconformity, representing erosion of perhaps half the volume of the immediately subjacent formation. Then comes the Lafayette

[1] Bull. 43, U. S. Geol. Survey, 1887, pp. 136-137.

[2] Am. Jour. Sci., 3d ser., vol. 35, 1888, pp. 142, 143.

loam, sand, and gravel, once occupying practically the whole coastal plain; it is thickened and diversified greatly in the Mississippi embayment, and is separated by a strong unconformity from the subjacent beds. Next in order of the deposits thus far discriminated on physical grounds lies the Grand Gulf formation, well known only in the Mississippi embayment, though probably merging in the east with fossiliferous deposits, which is sometimes called Miocene on biotic grounds; and beneath it are indications of an unconformity. Still lower lies the most extensive calcareous deposit of the coastal plain, the Vicksburg-Jackson or the White limestone overspreading the area between the Mississippi and the Atlantic Ocean, which is abundantly charged with mechanical detritus in the Mississippi embayment and is unknown in the north. Beneath lie the silico-argillaceous deposits forming the Claiborne and Meridian, well developed only in the Mississippi embayment and apparently representing an earlier stage in deposition of the period during which the calcareous beds were laid down. Next lower lie the Lignitic beds, constituting, like the Grand Gulf, a typical embayment deposit; and eastward toward the Atlantic basin the last three imperfectly demarked members, calcareous, silicoargillaceous and argillaceous, appear to blend so completely that if represented at all in the north it is by a single homogenous deposit. Below this great series of early Tertiary deposits, there is probably an unconformity. The next series comprises the upper Cretaceous deposits, thickest of all the successive leaves in the coastal structure, which almost exactly homologizes, phase for phase and stage for stage, the early Tertiary series; and, as is the case in the early Tertiary, the members blend eastward so that if represented at all in the North it is by a single homogenous member. Whether or not an unconformity separates the upper Cretaceous from the subjacent division has not been definitely determined; but certain it is that the coastal formations begin with a sheet of coarse débris made up of the discharge of the nearest rivers; and this sheet is now dissected by erosion and often buried beneath the newer leaves in coastal structure.

The sequence of events recorded in the coastal plain deposits is one of changes in the relation of land and water resulting from rise and fall of the continent; with each continental fall the shores advanced upon the land, and the lower hills and plains and river valleys were sheeted with sediments; with each continental rise the shores retreated and the rains and rivers attacked the successive sheets of sediments and carved channels, sometimes entirely through more than one formation, and sometimes far seaward of the present shore line; and the continental rise and fall varied from place to place in the coastal plain, and from time to time in the course of its history.

The history of development of the eastern land is recorded in nature in characters so grand that but a small part of a single one may be seen at once, so that the direct reading is difficult; but intelligent men of modern days annihilate space and time by the aid of memory

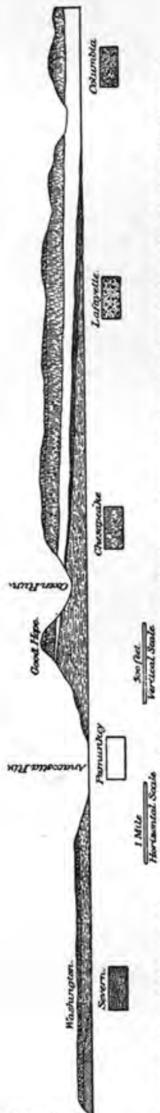


FIG. 34.—General section through inner portion of the coastal plain in the middle Atlantic slope. (Redrawn from a section constructed by Mr. Nelson H. Darton.)

and imagination, and thus combine the parts of characters and the characters themselves, and easily read aright the rhythmic runes of terrestrial rise and fall. So may the geologic history of the province be read.

There are two languages in which history may be interpreted: The first is the verbal language, which sufficed for primitive purposes and which suffices to-day for many simple purposes; the second is the graphic language required for the expression of highly differentiated conceptions and for a wide variety of special purposes. These two languages are of unlike order: It is the strength of the first that it subserves a wide range of uses, and permits unlimited qualifications of statement; it is the weakness of this language that it expresses conceptions of quantity only by unnatural and inadequate devices, and that its complex machinery conceals all but the central part of a conception—the elaborate conception requires so many pages for its presentation that the first part fades before the last part comes into view. It is the merit of the graphic language that it expresses quantity and relation, and juxtaposes in natural order the various elements in a complex conception; it is the demerit of this language that it admits of no qualification, and that thus far in the differentiation of intellectual methods it is susceptible of limited application only, since there are conceptions which, albeit definite and tangible, can not be intelligibly depicted. The verbal language is qualitative and diffuse, yet of higher order than pantomime; the graphic language is quantitative and condensed, and of higher order than the verbal language. There are stages in the development of knowledge in which it becomes possible to pass from the verbal language to the graphic language, either for purposes of study or for purposes of presentation, and when such a stage is reached it is invariably found that the use of graphic language renders conception far more definite and tangible than before, and at the same time enlarges the grasp of the student so that he easily leaps where before he laboriously crept; and there are many cases in which graphic presentation conveys in a moment complex conceptions which by the verbal method could be conveyed only in hours or not at all.

The brief presentation of leading structural features and historical episodes of the coastal plain has been made in verbal language. Let the same conceptions be still more briefly presented in graphic language.

The accompanying diagram, Fig. 34, is a generalized section through the coastal plain in the middle Atlantic slope. It shows approximately the relative position and configuration of the Piedmont plain and the coastal lowland, and the relative positions and thicknesses of each of the coastal plain formations.

The diagram forming Fig. 35 similarly expresses the structure found in the Santee River basin in South Carolina. Since the graphic language does not admit of qualification in expression, it is desirable to point out that this diagram can be regarded only as an approximation to the truth.

FIG. 35.—General section through the coastal plain in the southern Atlantic slope. (Redrawn and reduced from a section constructed by Dr. R. H. Loughridge).

FIG. 36.—General section through the coastal plain in the eastern Gulf slope (Chattahoochee River). (Generalized from sections constructed and described by Mr. Lawrence C. Johnson, Dr. Eugene A. Smith, Mr. Daniel W. Langdon, Jr., and Dr. J. W. Spencer).

FIG. 37.—General section through the coastal plain in the eastern Gulf slope (western Alabama). (Generalized in part from sections constructed and described by Dr. Eugene A. Smith and Mr. Lawrence C. Johnson.)

FIG. 38.—General section through the coastal plain in the Mississippi embayment. (Generalized in part from sections constructed and described by Dr. E. W. Hilgard and Mr. Lawrence C. Johnson.)

The diagram represented in Fig. 36 represents with approximate accuracy the structural conditions displayed in the banks and bluffs of the Chattahoochee River, and thus conveys a fairly accurate conception of the relations of the physiographic units in that portion of the lowland province.

The diagram forming Fig. 37 expresses the quantitative relation of parts found to obtain on the Tuscaloosa and Tombigbee and Mobile rivers in western Alabama.

The diagram shown in Fig. 38 illustrates in roughly approximate fashion the relations and dimensions of the units in the coastal plain along the northeast-southwest diagonal of the State of Mississippi, projected some miles in either direction.

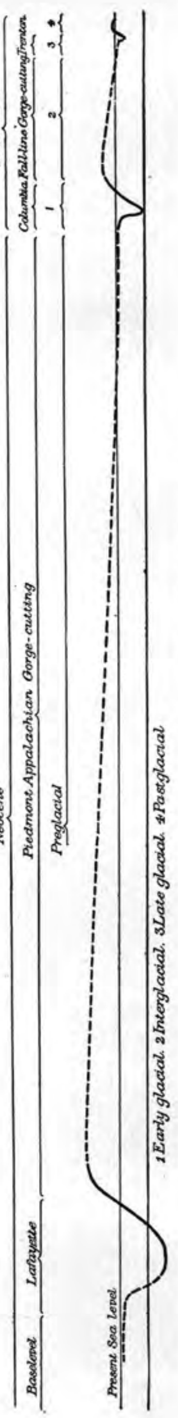


FIG. 39.—Later continental oscillations of the middle Atlantic slope.

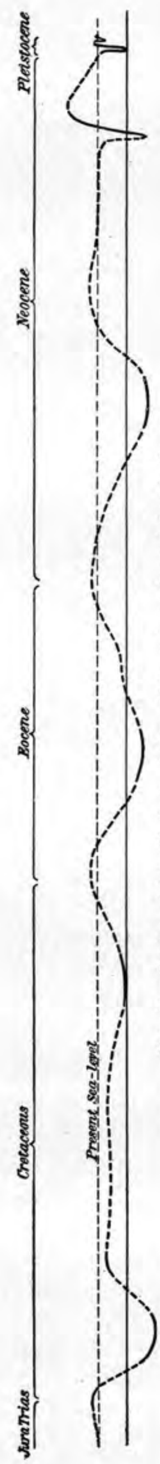


FIG. 40.—Continental oscillations of the middle and southern Atlantic slopes.

These five diagrams may easily be connected in imagination, when they will combine to express the principal structural features of the entire coastal plain; yet it is to be remembered not only that the second and fifth of the series, as well as all in some degree, are only approximately true to nature, but that the continuity of many of the units depicted has not yet finally been established either by direct examination or by homogenic correlation. It is to be remembered too, that the nomenclature of coastal plain formations is in inchoate condition, and consequently that while the current names are synonymous they are not precisely isonomous.

From each of the structure diagrams, conditions and processes may be inferred so definitely and tangibly that the relation of land and sea during different episodes may also be represented graphically. The diagrams forming Figs. 39 to 43 are constructed with this view, and express a series of episodes in continental development, of course with a degree of accuracy less closely approximate than the physical representation in the structure diagrams. Be it observed, too, that the time limits are introduced in accordance with careful estimates from trustworthy data in only the first two of these diagrams, and that the last three give little indication of the relative duration of the episodes except through the inference of equality growing out of homogenic correlation.

There is a certain uniformity in the structure diagrams indicating homology among the various members represented in each; there is a certain uniformity among the genesis diagrams suggesting homogeny among all; but while the uniformity in structure and in genesis is suggestive, it must be borne in mind that the area is vast, that systematic observation has been extended over only a relatively small

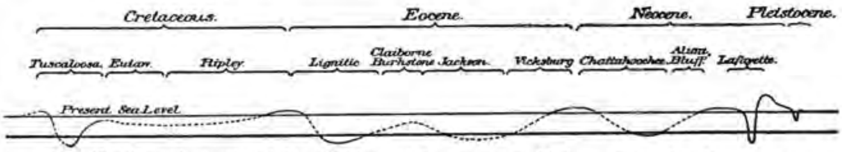


FIG. 41.—Neozoic continental oscillations of the eastern Gulf slope (Chattahoochee River).

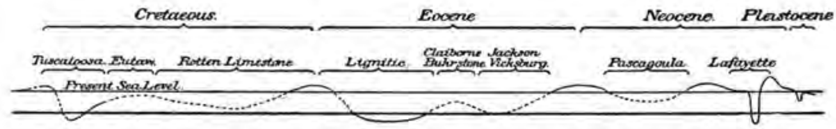


FIG. 42.—Neozoic continental oscillations of the eastern Gulf slope (western Alabama).

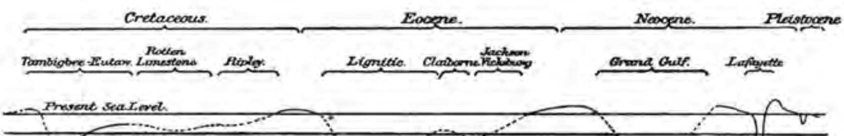


FIG. 43.—Neozoic continental oscillations of the Mississippi embayment.

portion of that area, that the lower members of each series are revealed only locally and rarely, and hence that in the earlier part of the series the conclusion to which the mind intuitively leaps is no more than tentative; only in the uppermost two members of the structure series, in the latest two episodes of the genesis series, are observations sufficiently definite and extended to render the intuitive conclusion final.

CHAPTER II.

THE FEATURES OF THE FORMATION.

THE FEATURES IN DETAIL.

Although the proximity of the formation is indicated by the presence of its pebbles in the basal part of the Columbia farther southward, the southernmost exposure of the undisturbed Lafayette formation near the Mississippi is 7 or 8 miles south-southeast of Bayou Sara, a mile west of Thompson Bayou, and midway between Fairview and Star Hill plantations. The road cutting here displays five or six feet of rather sandy but otherwise characteristic Columbia loam, becoming pebbly at the base and resting unconformably on the Lafayette deposits. These consist of orange-red sandy loam, containing scattered pebbles, becoming mottled with pink and gray and faintly stratified at 3 feet below the summit. The upper and more massive 3-foot layer is flecked with minute spots of white, gray, yellow, and cream-tint; and the flecks are found on examination to consist of fine pulverulent material, apparently siliceous. The upper portion of the orange-red loam is more obdurate than either the superjacent Columbia loam or the subjacent semibedded material, and thus forms an outcropping ledge or cornice; and this ledge, as well as the subjacent mass to a less degree, is characterized by a smooth (almost semiglazed) surface, and a massive and rock-like aspect, such as has been found diagnostic of the formation elsewhere.[1] The pebbles are subangular and rounded fragments of chert up to an inch and a half in diameter, sparsely disseminated in the massive summital ledge, and both disseminated and arranged in lines in the lower portion. The exposed thickness of the Lafayette deposits is about 10 feet.

Near Bayou Sara there are several less noteworthy exposures of Lafayette loam, which is sometimes sharply demarked from the subjacent brown loam of the Columbia, though elsewhere the two deposits intergrade in such manner that they may not be demarked save by an arbitrary line. In general the exposures of the Lafayette are definitely related to the configuration. Hereabouts the prevailing surface is a plane of Columbia loam slightly inclined seaward and partially invaded by dendritic drainage ways in such manner as to give a nascent autogenetic configuration of wonderfully youthful aspect; the prevailing profile is a horizontal or slightly inclined line broken by sharp-cut V-shaped depressions; the roads traversing the country pass from

[1] Am. Jour. Sci., 3d series, 1890, vol. 40, p. 22.

plane to ravine and from ravine to plane through cuts, sometimes originally designed to flatten the grade but always deepened by stormwash and the work of wheels and hoofs, so that the best exposures are in the crenulate scarps of the plane; and in these narrow road gorges the Lafayette is displayed, with a rounded contour rather than the angular one of surface deposits, in such manner as to indicate that the Columbia mantle thins over the ill drained divides and thickens toward the intervening waterways. So the exposures indicate that the Lafayette surface is a strongly undulating one, though characterized by rounded contours, and that the post-Pleistocene drainage lines generally follow the courses of their ante-Pleistocene progenitors. Thus, the Columbia configuration is indicative of topographic youth, the Lafayette configuration of topographic maturity. These relations of the deposit to the configuration are significant, and explain the dearth of exposures of the Lafayette in the bluffs overlooking the great river as well as in the lesser bluffs of the minor waterways.

From Baton Rouge northward the river bluffs constitute the scarp of the inclined Columbia plain, and gradually rise toward Bayou Sara. About Bayou Sara the rise becomes more rapid and the configuration more complex, and both the lifting and the complexity of surface culminate in Loftus Heights, overlooking the village of Fort Adams. With the modification in configuration from Bayou Sara northward the Columbia deposits thin and the Lafayette exposures multiply. Half a mile north of Bayou Sara-on-the-Hill (or St. Francisville) a 12-foot road cut is excavated to half its depth in unmistakable Lafayette loam, massive, rock-like and semiglazed in aspect as usual, generally orange red but flecked with white, pink, and cream as usual, structureless above, faintly bedded below, with partially disseminated chert pebbles as usual—in short, a typical example of the most strongly individualized formation of Cenozoic time.

Farther northward and eastward from Bayou Sara the riverward ravines diminish in depth and number and the surface flattens, and so, despite the gradual attenuation of the Columbia deposits, exposures of Lafayette are uncommon, particularly over the uplands; but toward Laurel Hill (on the Woodville and Bayou Sara Railway, near the Mississippi-Louisiana line and 18 miles east of the river bluffs) the brown loam thins and the ante-Pleistocene orange-red loam appears with increasing frequency until it crops in every 3-foot road cutting or stream gully, while its characteristic autogenetic configuration, inferred with difficulty south of Bayou Sara, constitutes the face of the country. Only a few miles east of here, indeed, the Columbia shore line ran; and the Columbia deposit is but a meager mantle composed largely of rearranged Lafayette sands and gravels, and this mantle is erosion-tattered to such an extent that the characters of the older formation are but half concealed. Here, accordingly, the distinctive features of the Lafayette are revealed alike in the rugose topography and in the numberless channels and gullies and road cuts to which the steep slopes give rise.

Three-fourths of a mile northeast of Laurel Hill on the Woodville road the Lafayette stands in the vertical walls of a road cut 12 to 15 feet deep, with but a veneer of brown loam above. As usual, its upper portion is massive, rock-like, orange-red but flecked with white, and dotted with pebbles; and it is noteworthy that this upper portion here is fully 10 feet thick, grading imperceptibly into mottled sandy clays. It is noteworthy, too, that the pebbles are materially larger and more abundant than toward Bayou Sara, though the material remains the same. All the pebbles, from 2-inch subangular masses down to coarse grains, are of white, yellow, gray, or bluish chert, sometimes stained externally and cemented into beds of pudding stone by ferruginous infiltrations. Two miles northwest of Laurel Hill the gravel is exceptionally coarse and abundant, and the bed is worked for road metal. Midway between gravel bed and road cut, the western prong of Thompsons Bayou cleaves the Lafayette to its base, exposing Grand Gulf mudstones below; and in a neighboring ravine the lower portion of the Lafayette formation is well displayed. Here it consists of stratified brown, red and yellow sands, with intercalated pebble beds, the pebble beds generally and the sand sheets sometimes cemented into ferruginous conglomerates and sandstones.

Hereabouts there is displayed a relation between the Lafayette formation and the surface configuration different from that partly observed and partly inferred about Bayou Sara. The prevailing land surface is indeed that inferred to exist beneath the Columbia nearer the great river and at a lower level; but here the characteristic Lafayette deposits generally fail in the banks and immediate bluffs of the larger water ways which are usually cut down to the Grand Gulf mudstones, so that the orange-tinted deposit commonly crops out only in minor ravines; from which it appears that the Lafayette mantle was of limited thickness (probably not more than 75 feet), and that it was completely cut away by the ante-Pleistocene streams to be replaced by Columbia deposits largely derived from its own upland remnants; near the lowland the Lafayette hills are buried beneath a mantle of northern origin; in the upland the hills are Grand Gulf and buried partly beneath the Lafayette and partly beneath a mantle derived from it.

Laurel Hill takes its name from a slight elevation on the general southerly slope from the crest of the Grand Gulf ridge toward the Louisiana lowland; but in this region the bedding and surface planes of the Columbia formation incline southward at about the same rate as the general antecedent surface, so that the Pleistocene deposits thin eastward more rapidly than northward despite the greater elevation in the latter direction. So, as ascertained by Johnson, the Columbia mantle soon disappears toward the Pearl River, and the Lafayette becomes the prevailing surface terrane to and for some distance beyond that river. In this direction the features of the formation displayed in northern Louisiana and southwestern Mississippi are maintained, save that the pebbles grow smaller, the sand element of the loam finer and the clay element more abundant, while the deposit attenuates to such an extent that Pearl River and its main tributaries and even the minor waterways frequently cut through it.

North of Laurel Hill the materials of the deposit gradually grow coarser; the pebbles are larger, the sand is more abundant, and the color is ruddier than ever. In this direction it remains partly concealed by the brown loam mantle; but in the gullies of abandoned fields, as well as in road cuttings and storm runnels, the newer loam has been washed away and the gaudy colors of the Lafayette glare from the sloping surfaces, yards or rods in extent and scores in number within each hour's journey. In this part of Mississippi the lands are invaded by modern erosion, due primarily to deforesting and secondarily to the abandonment of the fields; and in every "old field" the relations between the attenuated Columbia mantle and the subjacent orange-red loam are well revealed. A typical illustration of this relation is shown in Fig. 44, which is a mechanical reproduction of a photograph.

From numberless exposures of the contact between the Lafayette and Columbia formations displayed in the fields and road cuts, it is seen that the relations of the deposits vary from place to place. Commonly there is a rather abrupt transition in material and structure within a zone of a foot or less; less commonly the transition is sharp, and the formation may be demarked by a definite line; but not infrequently the two deposits intergrade in such manner that it is impossible to separate them save in some arbitrary fashion—the zone of transition may be a yard or more in thickness, and may partake of the features of both deposits throughout. Yet, however vague the common boundary, however largely the materials of the older formation are incorporated in the newer, the two formations may be clearly discriminated wherever typically exposed; the Columbia loam is always argillaceous and silty, soft in tint as well as in texture, smooth to the touch, loess-like, made up exclusively of finely comminuted materials, and brown or buff in color; while the Lafayette is sandy, harsh in tint and texture, friable, commonly pebbly, and orange red or red in color, particularly in its upper portion. The deposits are contrasted also in habit of weathering: the Columbia loam in this region stands in smooth vertical faces or breaks down in steep slopes, and all the minor forms of weathering suggest youth and weakness; the Lafayette, on the other hand, displays the usual massive, semiglazed, rock-like aspect in its upper portion, while below it breaks up irregularly, and the combination of characters in weathered exposures gives an aspect of age and obduracy to the entire formation. The two deposits, indeed, possess certain points of similarity, yet they are discriminated by agriculturists and geologists alike, as readily and reliably as any shale from any sandstone, or any marble from any granite.

Over the crest of the Grand Gulf upland from Woodville westward to the Mississippi bluffs, the Columbia loam thickens and exposures of the Lafayette loam become less and less frequent; yet, owing to the high relief and consequent rapidity of degradation, exposures occur here and there, even to the very verge of the bluffs. In the interior, where the later loam is thin and where it contains an element of Lafayette sand without the Lafayette cementation, the newer mantle is the weaker and yields the more rapidly to erosion, as illustrated in Fig. 44; but toward the river the newer mantle is the more tenacious and is invaded chiefly by sapping along the ravines, particularly at the heads

FIG. 44.—Denudation of the Lafayette sands by modern erosion; near Laurel Hill, Lousiana.

of the minor drainage ways. So in the region between Loftus Heights and Woodville the ordinary topographic forms—hill and valley, divide and waterway, salient and reentrant, cusp and amphitheater—are supplemented by "breaks," "gulfs," and "guts" of the local vernacular. The "break" is the head of a small retrogressive ravine, a minor water course gradually eating its way back into the upland; the "gulf" is a magnified "break" with precipitous walls, so deep and broad that man may not stay its progress but stands appalled by its depth and the rapidity with which it is carried into the highlands by successive storms. Inadequate illustrations of the "gulfs" of the region are given in Figs. 45 and 46, both mechanically reproduced from photographs. As suggested by these illustrations, the gulfs may be 50, 100, or even 150 feet in depth, with vertical walls; as suggested also by the cuts, they represent the usual manner of invasion and destruction of divides in this region. Originally the roads meandered through the valley here, followed the upland crest there; but with the growth of the "gulfs" the upland crests are narrowed until the traveler might easily toss a pebble from either hand which would fall 100 feet before striking the bottom of the gulf; and during each great storm some such narrow pass crumbles away, and the road must be changed, perhaps for miles. The "gut" is simply a deep road cut, started sometimes purposely to reduce the grade, sometimes by designless travel, but deepened by storm-wash, by the smoothing of gullies in mending the way, and by wheels and hoofs: for the storm

FIG. 45.—Typical "gulf" exposing the Columbia and Lafayette formations; near Fort Adams, Mississippi. Exposure, 90 feet.

carries detritus from the upper part to the lower; as the rain-cut gullies are filled, either by plow or spade, the material always moves down the slope; and the trampling of hoofs and the crushing of wheels similarly displace material, and always in the direction of the slope. In most deposits the precipitous walls would break down as the gorge deepened; but in the loess or loess-like loam of the Columbia, with which the Grand Gulf upland is mantled, the walls remain vertical until the "guts" are 10, 20, 30, even 40 feet deep, and until leafy branches meet overhead, transforming the way of the traveler into gloomy caverns. One of the "guts" of the Loftus Heights region, 3 miles east of Fort Adams, appears in Fig. 47, which is reproduced from a photograph, retouched in the foreground.

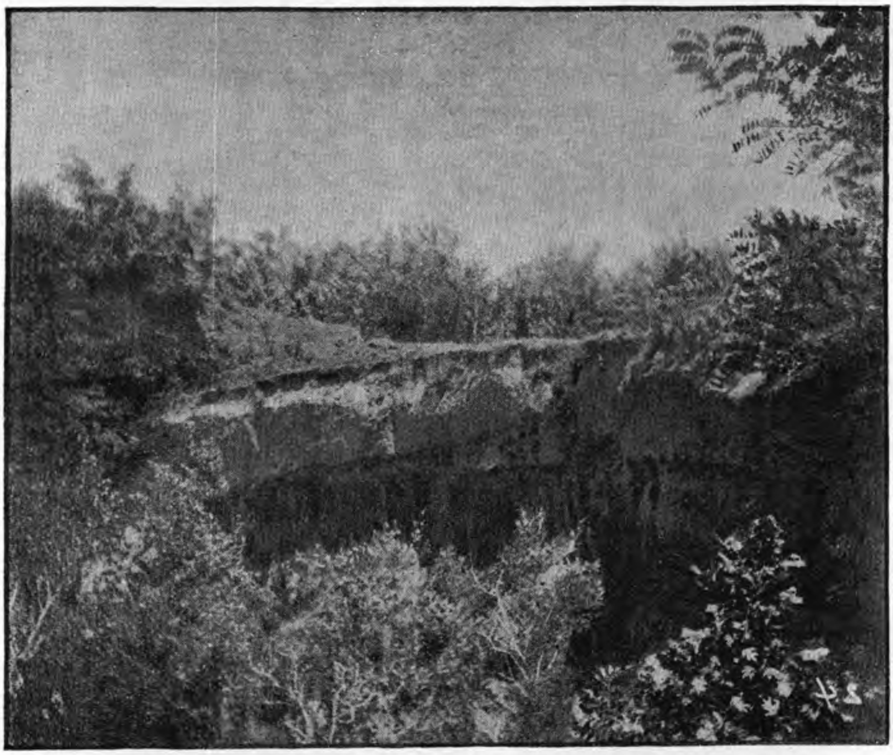


FIG. 46.—Typical contact between Columbia and Lafayette formations; near Fort Adams, Mississippi. Exposure, 65 feet; depth, not shown in photograph, 70 feet; total depth of "gulf," about 135 feet.

Now, in most "breaks," in all "gulfs," in many "guts," the Lafayette crops out beneath the Columbia loam and the exposures are sufficiently numerous to show that the formation overlies the whole of the upland except where the valleys are deepest, and, moreover, that its materials increase in coarseness and the entire deposit in thickness toward the great river. In the "gulfs" illustrated in Figs. 45 and 46 the Columbia loam is 20 to 25 feet in thickness, somewhat pebbly at the base, and rather sharply demarked from the Lafayette formation, which extends thence to the bottoms of the exposures, 70 and 110 feet lower. In the "gut" illustrated in Fig. 47 the newer loam is just cut through, and the semi-indurated sands of the Lafayette appear in wheel ruts. It is noteworthy that as the formation thickens it differentiates in a definite way: The upper part maintains the massive rock-like aspect, the peculiar case-hardening of weathered surfaces, and the orange-red color; while the lower part becomes stratified, the sands and the clays are separated in alternating layers, the case-hardening fails, and the color changes to grays, buffs, and browns, banded with the stratification.

The physical relations of the Lafayette are illustrated in Fig. 48, reproduced from a field sketch representing a cliff in Loftus Heights overlooking Stricker's landing (a mile south of Fort Adams, Mississippi). Here it is a firm sandy loam or loamy sand containing subangular and rounded

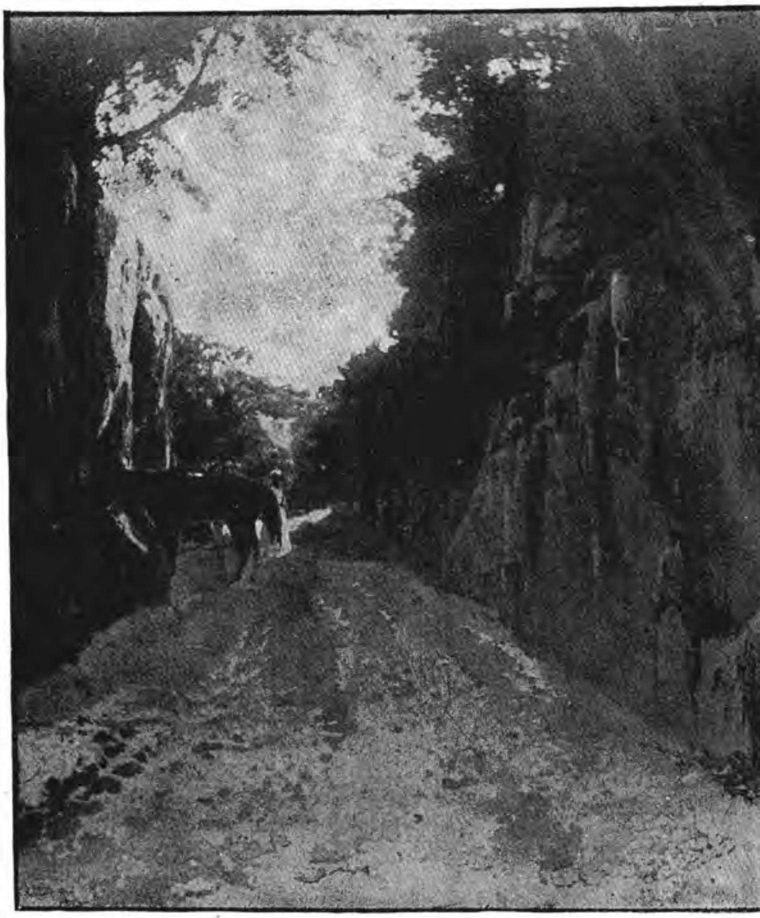


FIG. 47.—Typical "gut," 3 miles east of Fort Adams, Mississippi. Depth, 5 to 35 feet.

pebbles, mainly brown chert, up to 2 inches in diameter, both arranged in lines and disseminated; it is brick-red, pinkish gray, and orange in color, rarely flecked with white. As shown in the diagram, it rests unconformably on the Grand Gulf strata and is in turn uncomformably overlain by the Columbia loam, which is here a richly fossiliferous loess. The physical relation thus illustrated in the small way is that indicated by a wide range of phenomena over a wide area to hold in the large way in the southwestern counties of Mississippi and the contiguous parishes of Louisiana.

In brief, the Lafayette formation, as displayed over and south of the Grand Gulf hill land in southern Mississippi and northern cis-Mississippi Louisiana, is a sheet of sandy and somewhat pebbly loam, generally orange-red in color, perhaps 50 feet in average thickness but thicker as well as coarser in material toward the river, massive and homogeneous above but stratified in its lower portion; it rests uncomformably on a rugose surface of Grand Gulf mudstones, and is trenched to its base and sometimes cut away over considerable belts along the larger waterways, and fashioned into a strongly undulating autogenetic configuration; and it is uncomformably overlain by a mantle of Columbia loam or loess with basal pebble beds or sand sheets, deeply in the south and toward the great river, and less deeply inland until the later mantle feathers out or lies only in the valleys.

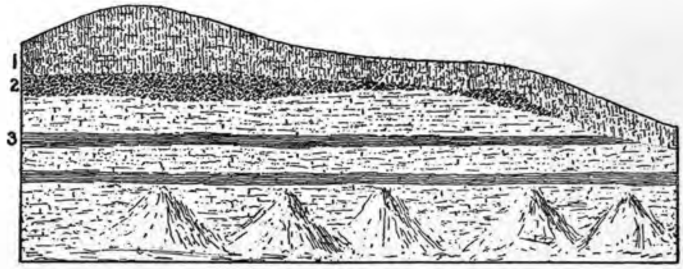


FIG. 48.—Relations of Columbia, Lafayette, and Grand Gulf formations; near Fort Adams, Miss. 1. Loess, fossiliferous above, sandy below, with scattered pebbles derived from the Lafayette toward base. 2. Massive brick-red loam with chert gravel. 3. Grand Gulf mudstones, with two partly lithified semi-quartzite ledges. Exposure, 175 feet.

Passing from the Mississippi marshland toward the higher portion of the coastal plain along a more easterly line, the characteristics of the Lafayette formation are again displayed. The New Orleans and Northeastern Railway traverses the marshland from the natural levee upon which New Orleans is built, crossing on trestles the part lying so low as to be submerged (Lake Pontchartrain) and then gradually rising toward the scarp of an undulating pine-clad plain about the eastern extremity of the Grand Gulf ridge. At Nicholson, 3 or 4 miles from Pearl River, the flat marshland configuration ends and the undulating surface of autogenetic sculpture begins. This scarp differs from the simple one of Baton Rouge in that it is deeply crenulate, each divide forming a salient, each minor waterway marking a deep reentrant. The upland surface also differs from the autogenetically incised plane of Baton Rouge in that it is completely invaded by drainage and transformed into labyrinthine crests, valleys, spurs, and amphitheaters, the whole undulating gently in soft contoured profiles in which convex curves prevail. The contrast between the marshland and the more elevated lowland is strong; and the configuration of the scarp and the interior forms alike indicate that the higher surface is but partly mantled by, and that its culminating points rise above, the sheet of Columbia loam—the older formation rises above the newer one, which merely overlaps its flanks.

The older formation is a predominantly orange loam, commonly massive above, but frequently stratified and sometimes cross-bedded with intercalations of clay below. In general the deposit is more argillaceous than its homologue near the Mississippi, and in general it is more distinctly stratified, while its pebbles are smaller and rarer. Moreover, its color is softer, orange prevailing rather than orange red.

North and east of Nicholson the orange loam is displayed in every roadway cutting, roadside gully, and storm runnel, just as it is displayed in the region about Laurel Hill; and as usual its upper portion is homogeneous, massive, semiglazed, and flecked with white and cream. The pebbles remain rare and small to Highland, where rounded and subangular fragments of chert rather suddenly become abundant, the matrix remaining practically unchanged. Here, indeed, the gravel is so abundant that it is largely used for railway ballasting.

About Nicholson the relations of the orange loam to the later Columbia loam are well displayed. On Leaf River and its tributaries, notably about Hattiesburg, the relations of the orange loam to the "second bottom" loams of the riversides, and also to the older Grand Gulf mudstones are well illustrated. Leaf River meanders through a flood-plain built of stratified sand and silt rising 20 or 25 feet above low-water level; then follows the "second bottom" terrace, rising 20 or 30 feet higher, half a mile to a mile in width, built of homogeneous drab loam grading down into stratified silt and sand with occasional pebbles; there is then a third terrace, 40 or 50 feet higher than the second and built of identical materials; and above this rises the general upland, 100 to 175 feet above the river level. Now, the modern flood-plain deposits rest sometimes on the "second bottom" loams and again on the Grand Gulf mudstones, and rarely at higher levels on the Lafayette, while the uplands overlooking the waterways are commonly sheeted with the orange-tinted loams of the Lafayette, save on the steeper slopes and along some ravines.

An interesting contact between the "second bottom" deposit and the orange-tinted loam is found at Mineral Springs, 6 miles west of Hattiesburg, on a tributary of the Leaf River. Here the later deposit consists chiefly of stratified sand with layers of clay and silt in its lower portion, the whole continuous with the broader "second bottoms" developed along Leaf River, although, as is usual along the smaller streams, the material is exceptionally sandy. In and near the stream channel these stratified sands contain large numbers of leaf impressions and more or less perfectly preserved leaves, together with twigs and larger fragments of wood, reaching 6 or 8 inches in diameter. The leaves are of the species now growing in the same vicinity; the condition of preservation of the wood is much like that of the forest bed found in glaciated regions; the spring evidently gathers its water from this stratum, and derives its chalybeate character from ferrugination effected through the acids set free in the slowly decomposing vegetal matter. These sands and silts rest on sandy loam of the prevailing white-flecked orange tint and case-hardening habit, except, in and near the stream channel, w re they rest on characteristic Grand Gulf mudstones, and it is evident that the vegetal matter is generally decomposed above the permeable Lafayette loam, but was largely preserved over the impermeable mudstones until invaded by the rapid modern erosion extending over all of eastern Mississippi.

On generalizing the various exposures in this vicinity it appears that the Grand Gulf terrane was long ago sculptured into a strongly undulating plain; that upon this rugose surface the Lafayette was laid down mantle-wise, thickest in depressions, thinnest over the eminences; that the mantle was in turn invaded by erosion, nearly along old lines, which continued until half or two-thirds of its mass was carried away, until every major and most of the minor waterways cut through into the Grand Gulf mudstones, and until this subterrane was exposed on many slopes; and that finally the deeper valleys were lined by "second bottom" loams rising scant halfway up the slopes and covering but a tithe of the area.

North of the Grand Gulf ridge in western Mississippi the relief diminishes and the mantle of Columbia loam thickens, and accordingly the exposures of the Lafayette occur rarely; yet, in all the deeper "gulfs" toward the divides, the orange-tinted sandy loam may be seen, sometimes sharply uncomformable with, but generally separable with difficulty from, the basal pebble bed of the Columbia. From the scattered exposures the deposit is found to maintain the characteristics displayed over the Grand Gulf terrane well toward the divide north of Homochitto River, save that its pebbles are notably larger and more abundant. From the composition of the Columbia pebble bed, too, gradual change in composition of the older deposit may be inferred; this pebble bed thickens, its constituent nodules and fragments of chert become larger, the element of sand in the lower portion becomes more abundant, until at Natchez the basal bed of the Columbia attains a thickness of 100 feet, of which one-fifth or one-fourth consists of gravel. It is noteworthy that in the Percus, Buffalo, and Homochitto basins the Lafayette appears to be trenched quite to its base, occasionally exposing Grand Gulf mudstones in the channels.

Over the divide between the Homochitto and Bayou Pierre the brown. loams of the Columbia continue to prevail, but in so attenuated condition that exposures of the Lafayette are moderately abundant, and of such character as to illustrate the stratigraphic relations to Columbia above and Grand Gulf below. Thus, in "rocky hill," 2 miles north of Washington, a road-cutting displays fossiliferous loess 10 or 12 feet thick, grading into argillaceous loam, pebbly below, 4 or 5 feet thick; beneath these a bed of stratified chert gravel in a matrix of orange red sandy loam with white flecks, 5 feet thick, resting unconformably on semilithified greenish gray mudstones of the Grand Gulf. Another cutting a mile farther northward displays typical Lafayette loam of the usual massive, semiglazed aspect, pinkish brown in color, with disseminated pebbles, overlain by loess with gravel bed at base. Again, half a mile north of Fayette, there are good exposures displaying 5 to 15 feet of rather sandy and friable loess, pebbly at the base, and resting with local as well as general unconformity upon orange-red and brown loam of the usual aspect, containing disseminated pebbles and sometimes stratified in its lower portion; in turn this lies with decided unconformity on Grand Gulf mudstones. Four miles north of Fayette there is yet more instructive exposure, in which the unconformity between the Lafayette and the Grand Gulf is strongly marked, and in which, moreover, the former deposit is stratified, one of its beds (2 feet in thickness) consisting of impalpably fine comminuted silica or siliceous clay, smooth, massive, structureless, and snow-white in color. This is the southernmost exposure of an element which is of increasing importance northward.

The last two sections illustrate in detail what the dozens of exposures over this divide illustrate in more general fashion with respect to the relations of the three formations displayed. The Grand Gulf surface was deeply sculptured and rugose, abounding in rocky ridges and cliffs, formed by reason of high relief and general obduracy combined with heterogeneity in materials; this highly rugose surface was mantled with the Lafayette to a thickness unknown, yet apparently exceeding that displayed farther southward; next, as on Leaf River, half the volume of the Lafayette was carried away—it was trenched to its base by every river, every considerable streamlet, and frequently cut through over the old ridges and cliff scarps; then the Columbia loam was spread mantle-wise over the doubly complex surface, but has in its turn been so deeply invaded by erosion lines that its base is frequently displayed.

Bayou Pierre is a sluggish stream beginning and ending within the Columbia terrane, and always charged with fine mud derived from the Columbia loam; and so it has not cut through its parent formation, and throughout its immediate valley the Lafayette is completely concealed; but within a few miles northward the orange loams reappear in increased thickness, and are conspicuous in numberless exposures over the elevated and rather narrow divide between the sluggish stream on the south and the active and potent Big Black on the north.

Within 3 miles north of Port Gibson on the Rocky Springs road the local relief reaches 150 feet, and appalling "gulfs," such as those of the Fort Adams region, invade the uplands; and, just as about Fort Adams, these chasms display the structure to depths of 50 and even 100 feet. A typical gulf is represented in Fig. 49, which is a mechanical reproduction of a photograph. Here the Columbia brown loam is 12 to 15 feet thick, becoming sandy and more pebbly below; its basal portion changes completely within a few inches, passing into massive orange red sandy loam with disseminated pebbles, structureless for 5 feet, then gradually becoming stratified. As indicated by the illustration, the amphitheater pushes back into the divide chiefly by sapping, for the basal part of the Lafayette is friable; where the sapping is rapid, the massive summital portion of the Lafayette and the subjacent Pleistocene loam cleave off together and vertical walls are formed, as in the center of the cut; while, if the sapping is slower, the partially cemented summital ledge of the Lafayette endures, and the softer loam melts away under the contact with the raindrops, as indicated in the left of the cut.

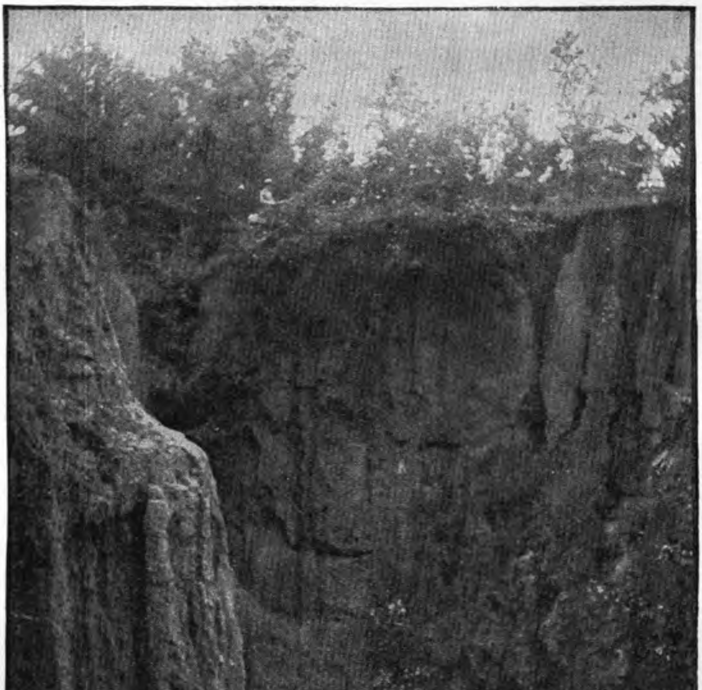


FIG. 49.—Columbia and Lafayette formations, as exposed in a typical "gulf;" near Port Gibson, Mississippi. Exposure, 50 feet.

It frequently happens in this region that the minor drainage line outlined on the Columbia loam cut down in their lower reaches to the friable basal portion of the Lafayette, when sapping begins and a gulf runs up the water way, exposing the Lafayette, with a bare veneer of Columbia above; when the soft contoured configuration is replaced by a sharp contoured one, in which the water way is reshaped and bounded by precipitous cliffs. A gulf at the head of a ravine thus conditioned is illustrated in Fig. 50, which is also a mechanical reproduction of a photograph, the locality being 5 miles north of Port Gibson on the Rocky Springs road. The peculiar erosion forms displayed in this cut illustrate well the obduracy of the summital ledge of the Lafayette; it is without lines of weakness, either vertical or horizontal, and the raindrops and running streams gradually carve it into miniature pinnacles, crests, and spurs which sun and wind do not affect and which storms invade but slowly, so that they stand long unless undermined

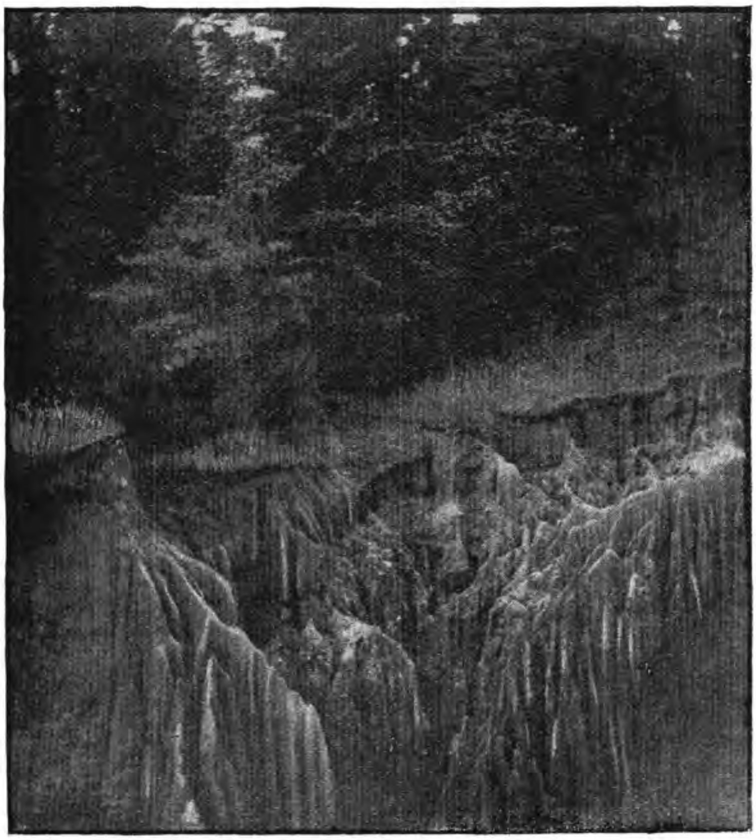


FIG. 50.—Erosion forms of the Lafayette formation; 5 miles north of Port Gibson, Mississippi. Exposure, 12 feet.

and carried away by sapping; and as the material stands its iron goes into new combinations, and the slender pinnacles and cusps, like the broad surfaces, become semiglazed or case-hardened, whereby they are strengthened still more and preserved still longer.

In the "old fields" on this divide, as on the greater Grand Gulf ridge, the loam may wash away, leaving a surface of obdurate Lafayette sandy loam to form an intractable and infertile soil. The configuration of the surface often left over acres as the fertile loams melt away under successive storms is illustrated in a direct reproduction, forming Fig. 51, of a photograph taken 5 miles south of Rocky Springs. Here, as in many other cases, the Columbia and Lafayette may be demarked only with difficulty; there is a zone of a foot or more through which the materials intergrade, though beyond the bounds of this zone the deposits may be distinct as marble and granite or as shale and limestone; but the obscure contact plane is sought out and laid bare by the agencies of erosion.

Although the north fork of Bayou Pierre is the longer its valley is much the narrower, and it is properly a tributary of the southern and

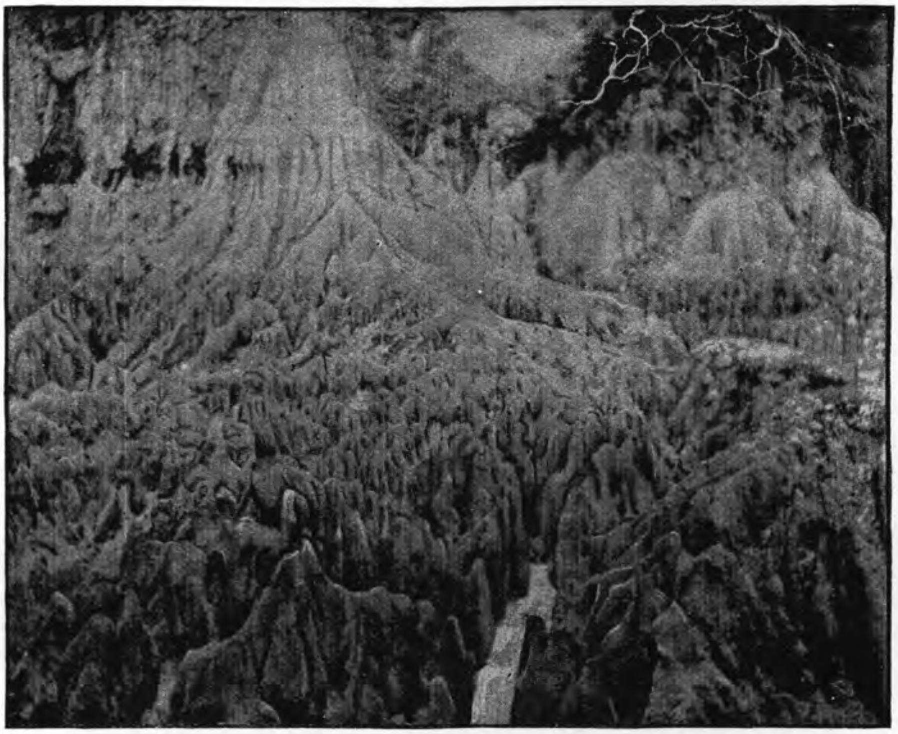


FIG. 51.—Lafayette erosion forms; 5 miles south of Rocky Springs, Mississippi.

middle forks, cleaving the main divide between the bayou drainage and that of the Big Black. Partly by reason of its greater length and partly because it lies half way up the general divide and thus has high declivity, it has carved its valley quite through the Lafayette deposits, revealing the Grand Gulf rocks in its own channel and in the channels of its minor spring-fed tributaries. North of it the land lies high and the friable basal beds of the Lafayette are less perfectly protected by the Columbia mantle than toward the south, and in consequence the surface is more broken than ever by a rapidly growing autogenetic sculpture running back into the divides in appalling "gulfs" and "breaks;" the roads are the most serpentine imaginable, meandering in labyrinthine valleys and following sinuous divides, and the modern erosion supplanting the old is literally taking the country; the road is encroached upon from both sides, and the "old fields" are denuded by the acre, leaving mazes of pinnacles divided by a complex network of runnels glaring red toward the sun and sky in strong contrast to the rich verdure of the hillsides never deforested; the plantation mansions and "quarters" are

FIG. 52—Lafayette erosion forms; Rocky Springs, Mississippi.

undermined, and whole villages, once the home of wealth and luxury, are being swept away at the rate of acres for each year. The once flourishing village of Rocky Springs, together with the stratigraphic succession beneath its site, are fairly illustrated in Figs. 52 and 53, which are mechanical reproductions from photographs. In the thousands of exposures of which these are types, the features of the Lafayette formation and its relations to the Columbia mantle are well displayed.

It is noteworthy that throughout this region of high local relief the usual massive summital member of the Lafayette fails. Commonly the entire thickness of the formation displayed in the "gulfs" and gorges consists of stratified sand and gravel with intercalated sheets of clay and loam; the stratified sands and even the coarse gravel merge to an exceptional extent with the Columbia deposits; and the grouped exposures indicate that while the ante-Pleistocene surface was rugose the contours were rounded rather than broken by angles, as in those regions in which an obdurate upper ledge protects the more friable lower members. It is noteworthy, too, that the pebbles hereabout while of the same material as in the south, are much larger and much less worn, the dimensions reaching 5 or 6 inches and the angles sometimes being barely rounded. It is noteworthy also that while the actual thickness of the formation may not be determined, there is every indication of increase in volume despite the extensive erosion to which it has been subjected.

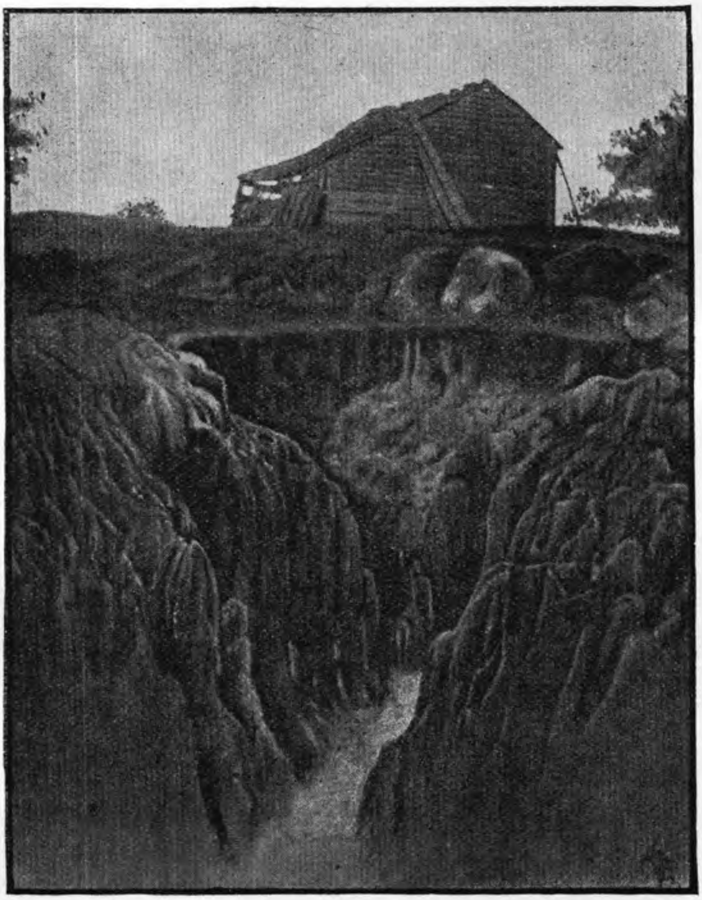


FIG. 53.—Lafayette erosion forms; Rocky Springs, Mississippi.

One and a half miles north of and fully 175 feet above the northern branch of Bayou Pierre there is a series of "gulfs" and gorges of exceptional magnitude displaying the following succession: (1) stratified silty loam, buff in color, weathering into blunt pinnacles, 5 to 12 feet; (2) silty sand, light buff or whitish, containing few pebbles, 2 to 4 feet; (3) loess unusually firm in texture, richly fossiliferous, 3 to 6 feet; (4)

clayey loess with loess-kindchen of irregular and fantastic forms, containing a few small pebbles, 2 to 4 feet; (5) great beds of gravel and cross-stratified sand, commonly brick-red, the pebbles being mainly of broken chert nodules with larger coralline cherty masses and fragments of Grand Gulf mudstone and quartzite, 20 to 30 feet; (6) Grand Gulf mudstones. The only distinct unconformity observed in this section is that between the pebbly sands of the Lafayette and the Grand Gulf; for at this altitude the Columbia consists partly of rearranged Lafayette materials, and thus the two formations intergrade. Between this point and the Big Black, no exposures of the Grand Gulf are known except at the very bottom of a railway cut at Ingleside, where it is directly overlain by the basal sands and gravels of the Columbia.

If the numberless exposures over the Bayou Pierre-Big Black divide be summarized, several significant features appear: The composition differs materially from that prevailing farther southward in the greater abundance and size of the contained pebbles; the structure differs in that the massive phase so generally prevalent at the summit of the formation is seldom seen, and in that the greater part of the deposit exposed is bedded, discontinuously but none the less distinctly; the color differs in that the prevailing orange or orange red of the south is replaced by browns, brick-reds, grays, and drabs, with some pinks and whites laid in lines indicating the stratification; the volume appears to differ in possessing greater thickness; the formation surface differs in that it gives indication of more pronounced erosion; and the structural relation differs in that the deposit commonly grades into superincumbent Pleistocene loam of the Columbia epoch. Generalization of these resemblances and differences and careful consideration of the bearing of each suggest that only a part of the differences are antecedent, and that the others are consequent upon them. The episodes suggested by the physical relations are, first, prolonged erosion of a Grand Gult terrane whereby the rugose surface was developed; submergence and mantling of this surface; emergence and tattering of this Lafayette mantle, including the cutting of trenches entirely through it, and also the nearly or complete removal of its surface; and then the Columbia submergence, with the deposition of the Columbia loam mantle-wise upon the greatly eroded surface of the Lafayette sands. In this view of the succession of episodes it would appear that the absence of the summital ledge of the Lafayette is due to exceptional ante-Pleistocene erosion, and that the merging of the Lafayette and Columbia deposits is due to the absence of the prevailing obdurate stratum to protect the friable basal sands as the advancing waves of the Columbia episode beat upon the sinking shores. The exceptional thickness (particularly of the lower portion) and the exceptional size and number of pebbles are undoubtedly, however, antecedent features to be explained as the multifarious phenomena of the widespread formation fall into order, but even at this stage these features may safely be connected with the proximity of the Big Black, which is the weakling progeny of a potent progenitor once reaching far into the Appalachians through the basins of the modern Tennessee and Cumberland.

In central Mississippi there is a considerable area in which the Big Black and the Pearl approach, and in which, by reason of the propinquity of two considerable rivers (originally brought into propinquity by weakness of the Eocene rocks), exposures are frequent despite the fact that this is the bottom of the trough bounded by the Grand Gulf ridge on the south and the Lignitic triangular ridge on the north. These exposures are, however, chiefly interesting in that they indicate attenuation of the Lafayette deposits without conspicuous change in their general character. The massive upper member which fails over the divide south of the lower stretch of the Big Black reappears, and the stratified lower portion thins and sometimes disappears; the characteristic texture and the massive, rock-like aspect recur and the disseminated small chert pebbles and the flecking with spots of pink and white are as distinctive as on the southerly slope of the Grand Gulf ridge or on Leaf

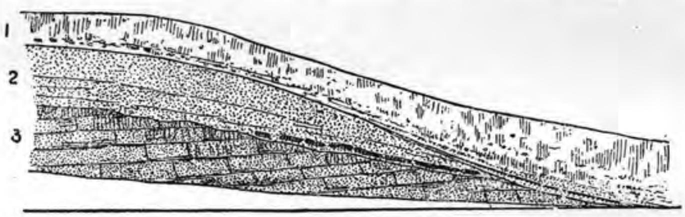


FIG. 54.—Relations of Columbia and Lafayette formations, near Jackson, Mississippi. 1. Columbia brown loam, sandy and pebbly at base. 2. Lafayette sands. 3. Vicksburg-Jackson limestone.

River. The only noteworthy difference aside from the attenuation (particularly of the lower member) is a redder color (brick-red being common) and more frequent cementation by iron.

At the sanitarium of Coopers Wells (near Raymond) a prominent ridge is crowned by red gravelly loam and sand, frequently cemented into a firm ferruginous conglomerate; and midway between Raymond and Jackson there are frequent exposures in which limonite nodules occur in such abundance as to stimulate, albeit fruitlessly, the prospector. The ferrugination is evidently related to the subterrane: thus, in a section displayed in a deep gully 4 miles southwest of Jackson the ferrugination is found to culminate at the contact of the Lafayette and the subjacent argillaceous limestone, particularly toward the feather edge of the former deposit, as indicated in Fig. 54. This section is of further interest in that it illustrates the relation of the prevailing mantle of Columbia loam and the discontinuity of the Lafayette, which appears in this region to be trenched along all major and most minor waterways and also along some lines not now occupied by drainage.

On both banks of Pearl River at Jackson, and along the banks of the Big Black, the Columbia loam conceals or replaces the Lafayette, but within 2 miles north of Jackson the brick-red sandy loam reappears in its usual aspect in road cuts and gullies; and toward the crest of the divide thence for 50 miles northeastward there is no mile without exposures of the deposit, though happily without the scores and hundreds of the Rocky Hill region. Yet the exposures are exceedingly monotonous: there is a mantle of Columbia loam a few feet thick, generally demarked sharply but containing lines of sand and Lafayette gravel at its base; then follows brick-red, orange red, or red brown loam, flecked with white and dotted with scattered pebbles, massive and rocklike above, often becoming mottled below, and displaying obscure stratification in deeper exposures; and only rarely is its base exposed, for all the larger streams are flanked with belts of brown loam so deep and so broad that the weaker terrane below is not revealed.

North of the Big Black River the Lafayette formation increases in thickness and in continuity, and gradually differentiates in such manner that the region extending from central Mississippi on the south to the Ohio River on the north, and from the Mississippi bluffs on the west to the Tennessee River on the east, may be regarded as the typical terrane of the formation. True, it is here, as elsewhere, profoundly eroded; it is nearly or quite cut away all along the bluff rampart overlooking the Mississippi, and trenched nearly or quite to its base by many secondary streams; and it is mantled for two-thirds of its area by the Columbia deposits; yet, partly by reason of the appalling modern erosion due to deforesting and abandonment of fields, it is displayed in hundreds of thousands of exposures, abundantly over the uplands and more rarely along the rivers, whereby its features may easily be ascertained.

The first known exposure in the bluff rampart above the Big Black is near Yazoo, where brick-red pebbly loam, markedly distinct from the prevailing Columbia mantle, crops out near the bases of the bluffs. It reappears, midway between the rampart and the Big Black, near Lexington, in bipartite condition, comprising the usual brick-red, white-flecked loam above and interstratified brick-red sand and gray or white siliceous clay below, the upper member ranging from 5 to 10 feet in thickness and the lower exceeding 20 feet, and resting uncomformably on calcareous clays of the Claiborne. These exposures are noteworthy as indicating more clearly than those south of the Big Black River the beginning of that bipartition which becomes pronounced in northern Mississippi and Tennessee. Orange, red and brown pebbly loams, unquestionably representing the upper member of the formation, appear occasionally in the rampart thence northward to Malmaison; and within 5 miles inland, notably about Carrollton, the Columbia mantle is so thin that the brick-red sands crop out in every gully, while the stratified lower member appears in every deeper cutting.

In the upland overlooking the Big Black the exposures are much more frequent—indeed no mile is without its display of features of this and associated formations. An instructive section is revealed in a great gully 5 miles south of Durant, as illustrated in Fig. 55, drawn from a field sketch. Here the Lafayette conforms to a hill made up of calcareous and sandy claystones, probably Claiborne, and exhibits the usual semiglazed aspect in its upper portion with definite bedding below; while the Columbia loam in like manner conforms to the Lafayette surface and is evidently made up in part of Lafayette materials, principally on the lower slope, where it is diversified by bands of red sand running out into it a few yards and then disappearing—the relation here being exactly similar to that displayed by the Columbia and Potomac formations on the eastern side of Chesapeake Bay.[1]

Thence northward, as the general surface rises toward the Lignitic ridge, the Columbia mantle thins and the exposures multiply; and at McGee and West stations, as well as about Beatty, on the Illinois Central Railroad, and still more frequently along the circuitous and hilly ways followed by wagon roads, the exposures revealing the bipartition are innumerable. Two miles northwest of Durant a 20-foot cut displays 10 feet of brick-red sandy loam, with interstratified sand and siliceous clay below, some of the latter being snow-white; a mile farther northward the massive upper member contains a silicified tree trunk; over the divide south of Peachavalla Creek the peculiar

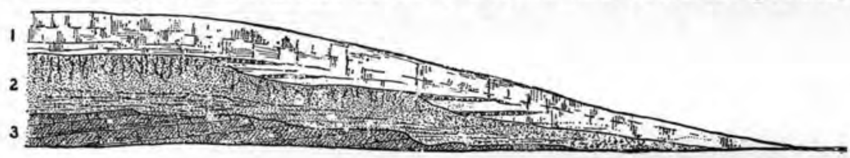


FIG. 55.—Relations between Columbia and Lafayette formations, near Durant, Mississippi.. 1. Brown loam of the Columbia, rather sandy, containing chert pebbles evidently derived from the Lafayette toward base, where also it is interleaved with layers of rearranged Lafayette sand evidently formed by the Columbia waves in advancing over sea cliffs of the older formations. 2. Lafayette sand, massive and brick-red above, interstratified with white and gray below. 3. Ferruginous claystones of the Claiborne.

quartzites of Hilgard's Siliceous Claiborne form rugged knolls and ridges, and these are half mantled, first by the Lafayette and again by the Columbia, both mantles being tattered in such manner that sometimes one, sometimes the other, and more rarely both together, half conceal the harder rocks; but wherever the Lafayette is well displayed the bipartition appears, and here and there snow-white bands of siliceous clay, perhaps only an inch but sometimes a foot in thickness, gleam out to dazzle the eyes of the traveler. About Vaiden the hills are brick-red beneath the stunted second-growth forests, and the obdurate upper member of the Lafayette, which forms their crests, is hard and smooth as a brick pavement; yet in every deeper gully the variegated banding, with occasional snow-white lines, is revealed. This is a region of strong relief; the autogenetic streams bifurcate again and again, and each branch sends out scores of minor arms, so that the drainage is perfect; and between the frequent ravines the narrow labyrinthine divides rise

[1] 7th Annual Report U. S. Geol. Survey, 1888, Pls. XLIII and XLIV.

50 to 100 and even 150 feet. Over all there was once a thin mantle of Pleistocene loam, but this is mainly gone save toward the Big Black River, which is here flanked by a deposit of brown loam with sandy base, evidently a hybrid partaking at once of the characters of the western Mississippi Columbia, and the eastern Mississippi "second bottoms." And the features characterizing the vicinity of Vaiden are represented in every mile northward nearly or quite to the Yalabusha.

The history recorded in the Columbia, the Lafayette, and the subterrane remains essentially the same as in the south: There is a deeply sculptured subterrane, Neocene mudstones in the south, here the silico-lignitic clays of the Eocene; then follows the Lafayette, spread mantlewise here as there, but here consisting of two divisions, the lower stratified member varying in thickness and continuity according to the subjacent configuration, and the upper massive member more uniform in thickness and more extensive in area; and this older mantle was erosion-rent in all directions before the later and final mantle of the Columbia was spread over the land. Now here, as in the south, the drainage ways first outlined on the Eocene surface, and afterward modified by interaction between autogenetic conditions and structural conditions, were generally chosen again after the Lafayette mantling, and the waterways thus resurrected were frequently chosen once more after the recession of the Pleistocene waters; so that in general the present drainage is twice resurrected, yet coincides fairly with the early prototype. Here and there, however, indications of modification in the drainage systems appear; here and there the Eocene strata are deeply trenched by a modern stream in such manner as to indicate that the modern stream is either larger than or differently placed from its prototype; here and there the Lafayette is displayed in stream cliffs in such manner as to give like indication with respect to the relations between the post-Lafayette and the post-Columbia drainage; while again the Lafayette deposits are absent from considerable belts not now traversed by modern streams, and these examples give a similar indication. One of these examples is found about Winona, which is located on the head waters of a small stream near the common water-parting of the Big Black toward the south, the Tallahatchie toward the west, and the Yalabusha toward the north; yet there is here a broad zone in which the deeper gullies and artificial excavations penetrating the Columbia loam expose only the brown and often ferruginous sandy clays of the Eocene.

Two miles northwest of Winona the Lafayette again appears in typical character, the brick-red sand or sandy loam, jointed obliquely, semiglazed, rocklike, massive, forms nearly vertical walls in all hilltop cuts, notably at the parting of the Carrollton and Duck Hill roads; while in the lower portions of these cuttings and in the lower exposures stratified red and gray sands with occasional snow-white bands extend to the bases of exposures. In these cuttings and in others toward Eskridge and Duck Hill, it is noteworthy that the white flecks and streaks characteristic of the upper member of the deposit in other regions appear in increasing number; and all the way to Duck Hill the Lafayette prevails over the uplands, save on a very few of the summits in which the ferruginous Eocene clays appear, and the snow-white bands ever increase in number and thickness.

Certain other subordinate features of the formation also characterize this region. Thus, from the Big Black to the Yalabusha the pebbles diminish in number and size until they become always inconspicuous and entirely disappear from some exposures. At the same time the color of the upper member deepens to dark brick-red and red brown. Moreover, the ferrugination progressively increases; the massive upper member is frequently cemented by ferruginous matter to such an extent as to clink under the hammer and when carried into waterways by sapping to form pebbles and bowlders that long resist stream wear; the stratified basal portion is often marked with plates and pipes of sandironstone, sometimes so abundant and so obdurate as partially to protect the mass from modern erosion; and the contacts of the two members as well as those between both and the subjacent Eocene or the superjacent Columbia mantle are sometimes marked with limonite nodules of such size and abundance as to attract the prospector. Many of the higher summits over the Big Black-Yalabusha divide are rounded knolls rising above the highest level of the Columbia mantle, and almost without exception hese knolls are crowned with ferruginated masses of the Lafayette sand.

The Yalabusha basin is the product of autogenetic carving of the western slope of the Lignitic ridge stretching through northern Mississippi; the Eocene strata are generally obdurate but heterogenous, and give a rugose yet somewhat erratic configuration; the surface was mantled and its contours softened by the Lafayette, but as this deposit in turn yielded to erosion it underwent local ferrugination in such manner as sometimes to accentuate the antecedent erratic relief; and although almost the entire basin was afterward overspread by the Columbia loam, this mantle was thin and, partaking of the sandy character of the substrata, yielding with exceptional readiness to post-Columbia erosion. Thus the present configuration is strongly individualized; the valleys of the main stream and its scores of tributaries are broad and deep; the divides are crenulate in plan and strongly undulating, even bluntly serrate in profile, frequently rising in conspicuous cusps, which are commonly near main water-partings, but sometimes rise near the main waterways, so that the general effect gives the impression of a miniature ancient water-carved mountain system, with the peaks and crests blunted and the valleys and gorges half drowned; but so nearly did the level of the Columbia waters coincide with the highest surface that only the culminating spurs formed islands, and these are sharpened by wave work about their bases, while their slightly lower neighbors were wave-swept and still further blunted. So when the basin is viewed from a commanding summit on either the southern or northern rim, it is found to be a labyrinth of broad valleys and a maze of steep-sloped hills, with here and there a rounded knob rising from the apex of a broad dome to 50 or 100 feet above the general upper level. One of the most conspicuous of these culminating knobs is Duck Hill, but there are a score of others of nearly equal note.

In traversing the Yalabusha basin, exposures of the Lafayette may be found in hundreds, chiefly, as usual, in the gullies and gorges of modern erosion; and in these hundreds of exposures the local features of the formation may readily be seen. The bipartition persists; the upper member remains massive and rocklike, brick-red, flecked with white, yet its materials are more sandy and its mass even more deeply ferruginated than south of the divide; the lower member remains stratified, with some bedding planes ferruginated, yet the snow-white layers are thicker and more numerous than before (3 miles northwest of Eskridge, 2 miles south of Duck Hill, and 3 miles east of Grenada, snow-white beds of siliceous clay 5 to 10 feet thick have been prospected for pottery material); the pebbles are still further diminished in number and size and frequently fail, while the thickness of the formation evidently increases to such an extent that, despite the increasing relief, exposures of the obdurate Eocene strata are not common. From the hundreds of exposures, too, the relations of the three visible terranes may be perceived. Before the Lafayette was deposited, the surface was even more rugose than to-day; before the Columbia loam was deposited, one-half or two-thirds of the Lafayette mantle was carried away; before white settlement, one-tenth or one-third of the Columbia was removed; since the abandonment of the "old fields," half as much more has gone.

Toward its western extremity the water-parting between the Yalabusha and Yocona basins is cleft by the Tillatoba, along the main stem and minor branches of which there are numberless exposures of the Lafayette. These are noteworthy chiefly in that the ferrugination is less than toward the interior, in that the pebbles are more abundant and larger, and in that stratification is more characteristic, apparently for the reason that the upper massive member was more frequently carried away before the Columbia mantling. There is an exposure of pebbly brick-red loam, undoubtedly representing the Lafayette, at the base of the rampart overlooking the Tallahatchie delta, a mile south of the Tillatoba at Charleston; there are half a dozen similar exposures along the rampart between this stream and the Yocona; over the main Yalabusha-Yocona divide farther eastward there are a dozen or score of good exposures of the Lafayette for every mile; and the characteristics displayed throughout the Yalabusha basin are maintained, save that the deposit (chiefly the lower member) attenuates over the higher lands and save that the ferrugination is even more complete—great masses of sandironstone, often many tons in weight, lie along the higher crests and crown culminating knobs. In short, in configuration, in number of exposures, and in features exposed, the Yocona basin essentially duplicates that of the Yalabusha. The only noteworthy changes in character of the Lafayette comprise thickening of the lower member and increase in the number of intercalated layers of white siliceous clay. Sometimes these snow-white beds are several feet or even yards in thickness; but commonly, as in the numberless typical exposures about Water Valley, they are thin bands marking the sides of the immense gullies which have undermined half the town and completely ruined scores of farms, diverting the roads until the way of the traveler is so devious that no citizen can direct his course to the next town.

In this vicinity the "gulfs," "breaks," and "guts" of the Fort Adams region are replaced on the face of the country and in local vernacular by "gullies." Here the Columbia mantle is thin and friable, for it consists chiefly of rearranged Lafayette sands, mixed with a generally less abundant foreign loam; the massive upper member of the Lafayette is sandy, and, except where ferruginated, friable; and in consequence the autogenetic ravines advance into the divides in V-shaped gashes rather than amphitheaters, and the fairly homogeneous materials are carried away by the erosion of steep slopes rather than by sapping. These gullies are enormous; they have taken a fifth of the land within a quarter of a century, and are growing with ever-increasing rapidity; already they have gone beyond the abandoned fields in which they started, and are invading the woodlands.

A typical exposure of the Yalabusha-Yocona divide is that mechanically reproduced from a photograph in Fig. 56, illustrating a 20-foot roadside gully 3 miles northwest of Water Valley. The massive superior member of the formation is shown at the right; the stratified inferior member extends from the surface to the bottom of the gully at the left. Unhappily photographic art does not reproduce the brilliant and distinctive colors characterizing this strongly individualized formation. The upper member is deep brick-red; most of the heavier layers below are orange-red, sometimes brownish, and rarely gray; while the finer lines are white as fresh-fallen snow and dazzle the eyes of the beholder.

The divides bounding the basin of the Yalabusha are lines and congeries of blunted crests and peaks, and the profiles are convex upward, save over the higher crests; but the divide between the Yocona and the Tallahatchie is of different character. Half way from Taylor to Oxford, and again half way from Oxford to Abbeville, the roads run on a broad, sensibly level plain, incised here and there by sharp cut ravines, and now and then by rounded knobs, though in general bearing the impression of topographic youth rather than the deep maturity displayed farther southward. The primary reason for this configuration is to be sought in the conditions effecting the original distribution of drainage on the Eocene surface; a secondary reason is to be found in the consequent (at least in part) greater uniformity of the Lafayette mantle, and in its exceptional preservation by the superior obdurate member; and a tertiary reason is to be found in the Pleistocene wave action, by which some irregularities were planed down while others were filled up.

In consequence of the exceptionally smooth configuration, exposures are less common over this divide than over the neighboring water partings toward the north and toward the south; yet there is no mile without one or more gullies revealing the substructure to depths of 10 to 50 feet. These exposures, too, show that the bipartition beginning 150 miles southward is continuous and is more trenchant than ever. The

FIG. 56.—Structure of the Lafayette formation, near Water Valley, Miss. Exposure, 20 feet.

upper member remains massive and rock-like, though consisting chiefly of sand and commonly devoid of pebbles, retains the brick-red color, and is frequently flecked with white; the lower member is more definitely stratified than ever, though frequently cross-bedded, and the snow-white sheets are numerous, as at Water Valley, and frequently thick, as at Duck Hill or Grenada; while the junction between the members is frequently marked by apparent unconformity, sometimes by a zone of pellets and pebbles of white siliceous clay, or here and there by a zone of pseudo-breccia consisting of angular fragments of laminated white clay and associated sands imbedded in a matrix of brick-red sand running into the upper member. A typical pseudo-unconformity is imperfectly represented in Fig. 57, which is a mechanical reproduction of a photograph, showing a gully 4 miles southeast of Oxford. This section measurably illustrates the misleading character of the pseudo-unconformity; true, the superior member is generally distinct in texture and structure from the inferior one, but toward the left the basal portion of the superior member grades in the usual manner into obscurely stratified sand marked by snow-white lines, while the line of apparent unconformity soon dies out. In this, as in many other cases, it is evident from careful examination of the section that the pseudo-unconformity marks, not the end of one episode and the beginning of another, but simply a local shifting in the currents, and consequently a local change

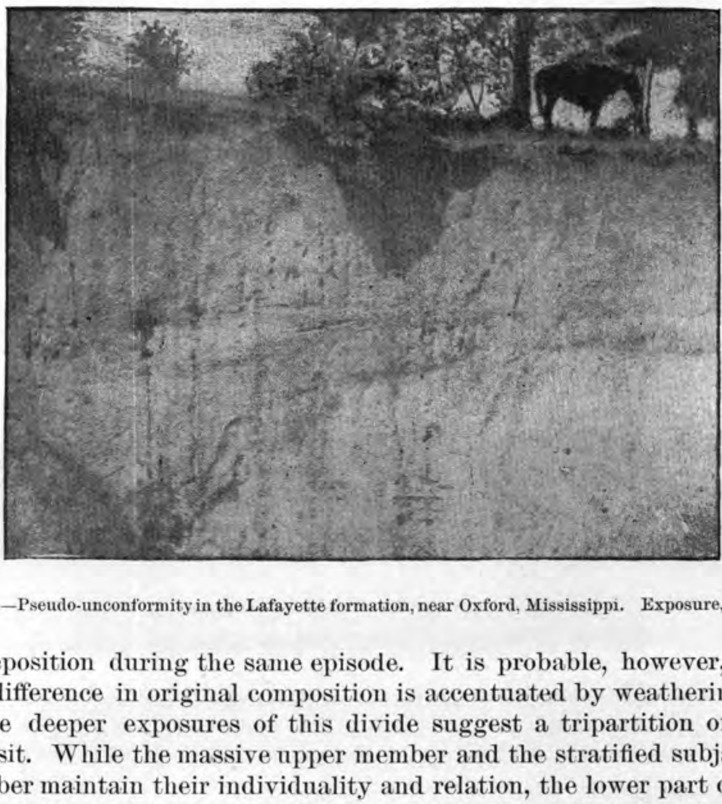


FIG. 57.—Pseudo-unconformity in the Lafayette formation, near Oxford, Mississippi. Exposure, 20 feet.

in deposition during the same episode. It is probable, however, that the difference in original composition is accentuated by weathering.

The deeper exposures of this divide suggest a tripartition of the deposit. While the massive upper member and the stratified subjacent member maintain their individuality and relation, the lower part of the latter is frequently cross-bedded, somewhat silty, and distinct in color from the overlying phase—there is an upper massive, brick-red member, a middle stratified member consisting of alternating layers of snow-white clay and orange-red sand, and the basal stratified and cross stratified bed of brown, drab, and gray sands, silts, and clays; but this division of the basal member is largely arbitrary. Going with the differentiation of the lower part of the deposit there is evidently increased thickness;

for although some of the valleys are deep, the subjacent Eocene rocks are rarely exposed. Moreover, the formation has a measured thickness of 200 feet at Oxford according to Hilgard,[1] who illustrates also the relation between the semi-arbitrarily delimited second and third members of the deposit as displayed in the railway cut at Oxford. His section[2] is reproduced in Fig. 58.

This is par excellence the type area of the formation; as shown elsewhere it was discriminated and named after the county lying largely between the Yocona and Tallahatchee in central Mississippi by Hilgard more than a third of a century ago; and, moreover, it comprises here the massive upper member of which alone the formation consists throughout much of its extent, and in addition the lower member or members characterizing the formation in the depositing ground of the great river of the continent—as well as the peculiar siliceous clays supplied by the Cumberland and Tennessee.

It is noteworthy that the increasing elevation of the land northward coincides almost exactly with the rise in the Columbia shore line, so that the Columbia mantle continues over the whole of the Yocona-Talla-

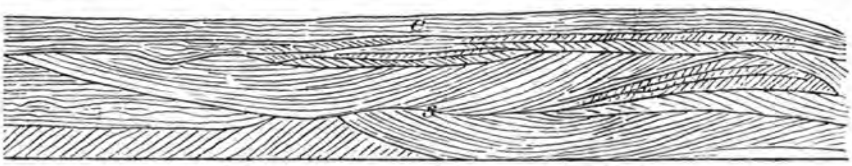


FIG. 58.—Structure of Lafayette formation at Oxford, Mississippi. After Hilgard.

hatchie divide save a few knobs crowned with clinking sandironstone of the Lafayette, which rise 50 feet or more above the general wave-washed upland plain as they rose above the Pleistocene waters. Toward Abbeville this upland plain breaks down into a labyrinth of valleys and a maze of steep-sloped, round topped hills, such as characterize the Yalabusha basin; for the Tallahatchie has long been an active river: During pre-Lafayette times it deeply sculptured the Eocene ridge; later it trenched completely through the massive Lafayette mantle, despite its thickness of over 200 feet, and carried away probably half the volume of that formation throughout its whole basin; and since the Columbia mantling it has cut through the latest sheet and renewed its work upon both the Lafayette and Eocene strata along scores of lines. So the Lafayette exposures again increase in number to dozen and scores to the mile, and the traveler is seldom out of sight of deep storm gashes in which the substructure is laid open. A typical gully 40 feet in depth is illustrated in Fig. 59, which is reproduced from a photograph taken near Waterford, Mississippi; and half the depth of a more appalling one midway between Waterford and Holly Springs (near Lump-

[1] Geology and Agriculture of Mississippi, 1860, p. 6. [2] Op. cit., Pl. 2, Fig. 3.

kins Mill) is shown in Fig. 60. Both illustrations represent the stratified member only, the superior massive layer being locally absent, as frequently happens north of Tallahatchie. In Fig. 59 the Lafayette forms the surface; in Fig. 60 there is a mantle of sandy Columbia loam 10 feet thick, definitely demarked at the base.

Certain features of the Tallahatchie Lafayette are noteworthy. First in importance, the tripartition beginning about the southern boundary of the basin becomes more definite, though the middle and lower members may be separated only arbitrarily; second in importance, the middle and lower members contain intercalated sheets of clay in which well preserved leaf impressions and other vegetal fossils are included;

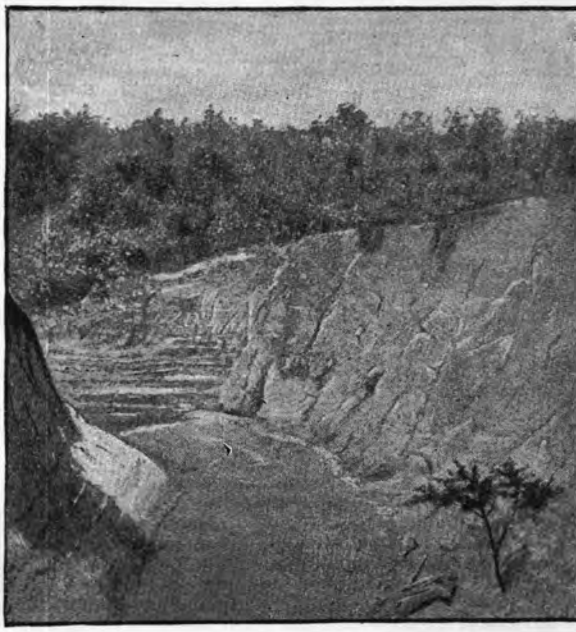


FIG. 59.—Structure of the Lafayette formation near Waterford, Mississippi. Exposure, 40 feet.

third, the sheets of snow-white siliceous clay thicken and become of considerable economic worth for pottery material, as at Holly Springs and elsewhere; and fourth, the entire deposit continues to thicken, a boring at Holly Springs revealing 200 feet, according to Johnson, despite the many indications that the subterrane here lies exceptionally high.

The plant remains found in the clays interbedded with sands in the Tallahatchie basin and on Wolf River have not been fully identified. It should be observed that while certain of the genera (if not of the species) are living in the lower Mississippi region to-day, the material as a whole displays, or at least suggests, a Laramie facies; and also that several competent geologists familiar with the Lignitic in Mississippi, Alabama, Tennessee and Arkansas are disposed to refer the leaf-bearing clays to that formation on the ground of lithologic resemblance. If this reference be just, then the thickness of the formation may be less than that assigned by Hilgard at Oxford and Johnson at Holly Springs, and even the exposed thickness at Lagrange may include an unknown amount of the protean Lignitic deposits, though no demarcation has ever been found. The testimony of the plant fossils is of course only suggestive; for not only is the identification incomplete, but there are thus far no means of comparing the stages in evolution of plant life in the upper Missouri and Rocky Mountain re-

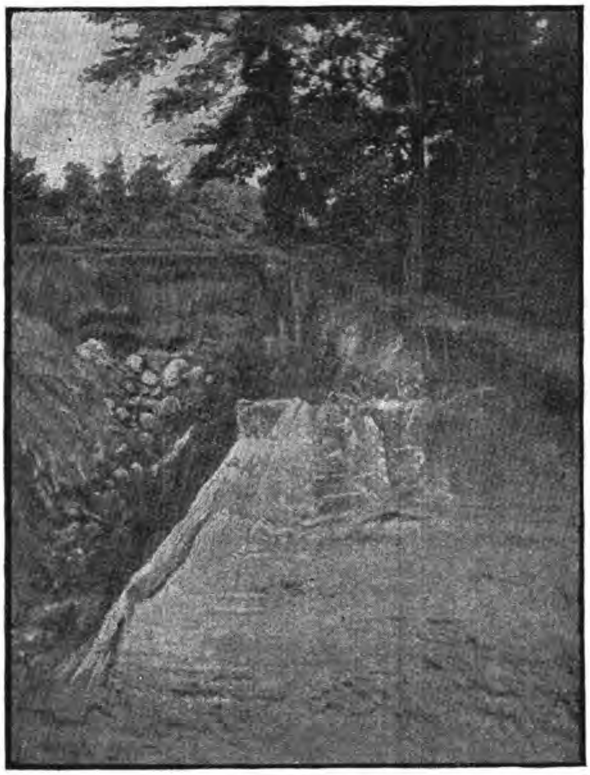


FIG. 60.—Structure of the Lafayette formation, near Holly Springs, Mississippi. Exposure, 30 feet.

gions and in the lower Mississippi region respectively; it can only be said that in the one region the geography was repeatedly revolutionized in such way as greatly to modify climatal conditions, while in the other the geography has undergone only minor changes of such character as not to modify climate, so that the flora has undoubtedly persisted in the remarkable fashion suggested by the present existence of Laramie or Lafayette plants in Louisiana.

Over the divide between the Tallahatchie and the Wolf, the relations between the Columbia and the Lafayette are well displayed. As in the Yalabusha basin and over the Yocona-Tallahatchie divide, the higher elevations coincide approximately with the Columbia shore line, only a few rounded eminences, like the two Lumpkins mountains, 5 miles southeast of Holly Springs, rising above the wave-fashioned plain. As usual, these knobs are crowned by clinking sandironstones of the Lafayette; and it is noteworthy that the maximum thickness of the Columbia loam usually appears in the vicinity of such knobs, and that the sheet attenuates over the lower lands. Moreover, a portion of the loamy sheet immediately circumscribing such elevations is exceptionally sandy, sometimes indeed made up almost exclusively of rearranged La-

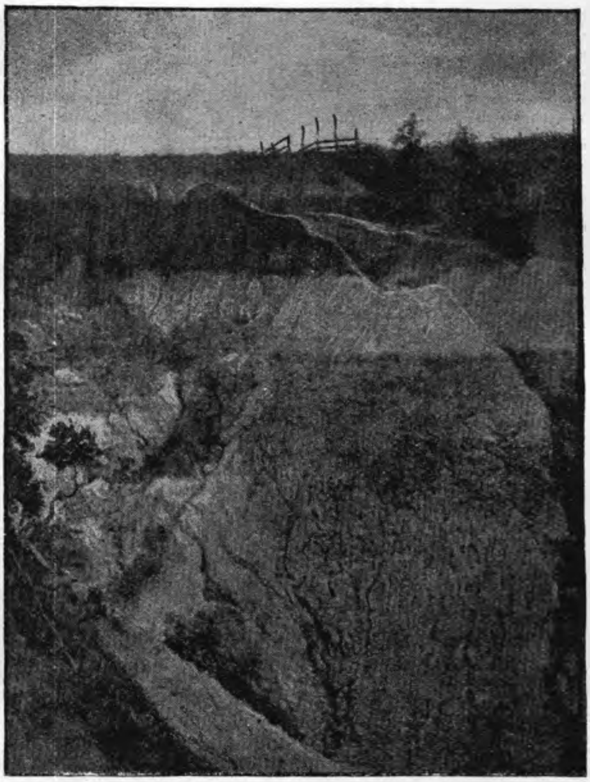


FIG. 61.—Structure of Lafayette formation; Lagrange, Tennessee. The light bed of the figure is the black, humus-stained bed of nature. Exposure, 60 feet.

fayette sands which can with difficulty be discriminated from the upper member of the earlier formation; while toward the lower lands the element of fine and far-traveled material increases. In one conspicuous case in the town of Holly Springs the formations are separated, however, by an old soil. Here, too, as in some other cases, the wave-fashioned plain constituting the upper surface of the Columbia is so uniform as almost certainly to indicate the original attitude; yet in this, as in all parallel cases in extreme northern Mississippi and western Tennessee, the plain inclines northward, while the rivers hug their northern bluffs, indicating that the Columbia submergence and the post-Columbia lifting culminate about the headwaters of the Tallahatchie.

From the Tallahatchie to the Wolf, in central Mississippi, gullies of the type displayed about Water Valley sometimes pass into "gulfs" of the Fort Adams type, and wherever the Columbia mantle is well developed these chasms abound. So there are exposures in scores; and the characteristics of the Lafayette formatiom are maintained in all respects save that the volume apparently increases, that the basal member is better developed, and that the siliceous clay sheets increase in thickness. Farther westward the same relations appear to hold except that the surface inclines, and the Columbia mantle thickens, riverward, so that exposures are rare. Moreover, the upper and obdurate member of the Lafayette frequently fails, and in such cases discrimination of the Pleis-

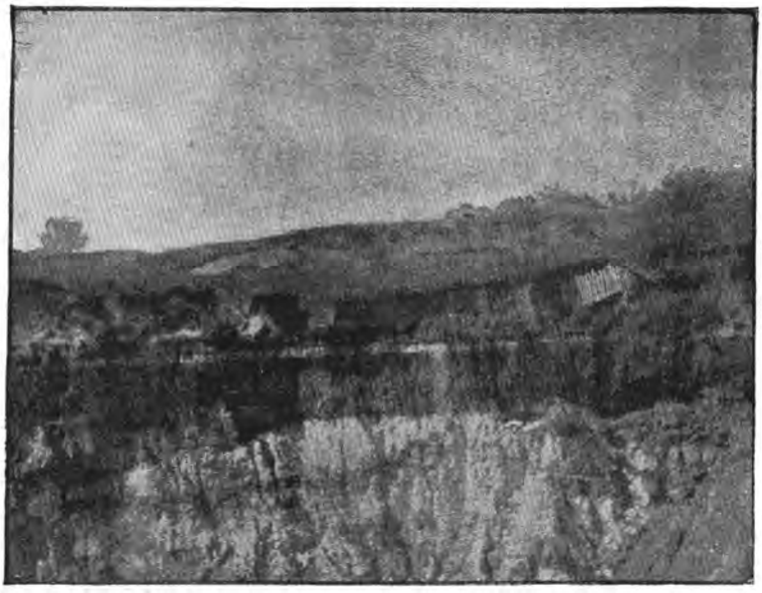


FIG. 62.—Forest bed between Columbia and Lafayette formations; Lagrange, Tennessee. The light band one-fifth way down the vertical face is the black soil; above lies Columbia loam, largely made up of rearranged Lafayette sand; below lies the Lafayette, at first massive, then bedded. Exposure, 65 feet.

tocene and late Neocene deposits becomes difficult. Thus, at Sardis, a few miles within the bluff rampart, the Columbia loam is characteristic in the upper portions of the exposures and the Lafayette is characteristic in the lower portions; but there is sometimes an intermediate zone which may be assigned only arbitrarily. In the development of modern erosion this intermediate zone is commonly obdurate and gives origin to characteristic erosion forms, such as are illustrated in Figs. 50 to 53. In this latitude, as farther southward, it is observable, on passing from central Mississippi to the rampart overlooking the delta, that the Lafayette becomes more and more pebbly; in the longitude of Holly Springs pebbles are exceedingly rare; but toward the "delta" pebbles are commonly disseminated through the upper part of the formation and accumulated in lines in the lower portion, while they are locally gathered in great beds, as for example, 2 miles southwest of Sardis, and in the railway cutting 3 miles north of Senatobia.

On crossing Wolf River and the Mississippi-Tennessee line no noteworthy change occurs in the Lafayette formation or in its structural relations save continued increase in thickness, but the exposures on the northern banks of Wolf River are of special interest in a historical way as well as by reason of the economic value of the pottery clays often contained in the formation.

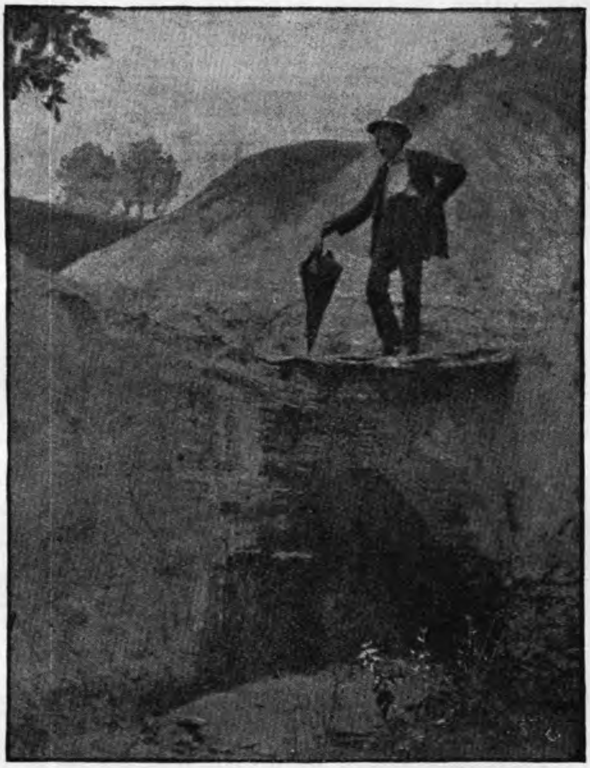


FIG. 63.—Structure of Lafayette formation; three-fourths of a mile west of Lagrange, Tennessee. Light colored stratified sands above, dark red, massive loamy sand below. Exposure (top of slope to bottom of gully), 30 feet.

The once flourishing town of Lagrange is located on a Columbia-mantled, northward inclining plateau, homologous in all respects with that upon which Holly Springs is built; the southern base of this plateau is washed by Wolf River; and modern erosion has extended into the plateau scarp in great gullies 100 to 150 feet deep, which are already invading the town and, as usual, growing with ever-increasing rapidity. The scarp is 200 feet high; from base to summit it displays characteristic Lafayette deposits, chiefly stratified sands with occasional lenses and pellets of clay, sometimes impure, but again the fine white siliceous material used for pottery making.

One of the gullies already invading Lagrange from the south is illustrated in Fig. 61, which is a mechanical reproduction of a photograph. As shown in this cut, there is a mantle of brown Columbia loam some 15 feet thick resting on an old soil, which grades down into black, sandy clay 6 feet thick. The body of the Lafayette below is without well defined structure lines, though it lacks the massive rocklike aspect characteristic of the upper member. The photograph reproduced in Fig. 62 looks northward on the opposite side of the road leading down to Wolf River, and shows a longer stretch of the old forest bed beneath the Columbia man-

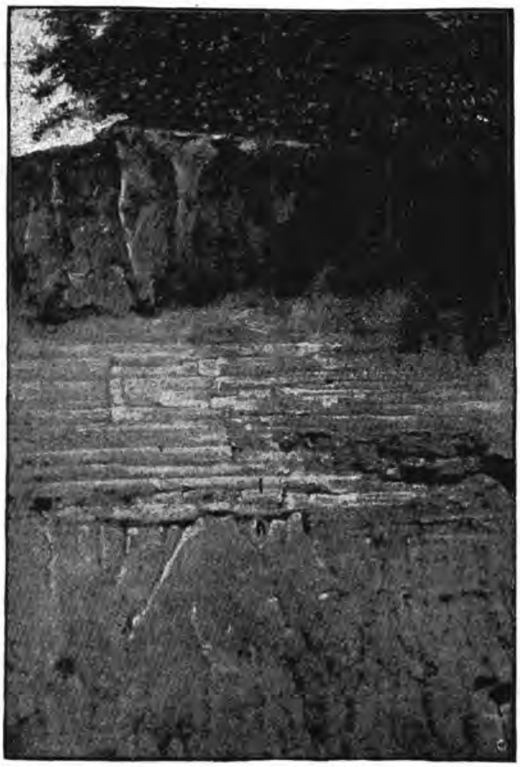


FIG. 64.—Structure of Lafayette formation; 1 mile west of Lagrange, Tenn. (The stratified layer is strengthened.) Exposure, 30 feet.

tle, which here rests on the massive upper member of the Lafayette. These exposures acquire value from the fact that this is one of the two known localities in which the formations are separated by ancient soils.

Figs. 63 to 65 are mechanical reproductions of photographs taken about a mile west of Lagrange; Fig. 63 illustrates the intercalation of a heavy bed of brick-red sandy loam resembling the massive superior member beneath the light-colored clays of the middle member, such as are sometimes referred to the Lignitic, and illustrates also the development of ferruginous plates along the structure lines; Fig. 64 displays the relation between the massive upper member and the stratified portion beneath, and Fig. 65 is of like import.

In general the divide between Wolf River and the Big Hatchie displays less pronounced local relief than that characteristic of the upland south of the Wolf, the configuration approaching in some degree the flat profile type displayed over the Yocona-Tallahatchie upland; yet the plains are not infrequently invaded by post-Columbia erosion in such manner as to give origin to dendritic drainage systems flowing in V-shaped ravines, and as usual throughout the Lafayette terrane the storm rills have gashed the valley sides and run into the abandoned fields and deforested uplands so extensively as to yield exposures by the hundred for each hour's journey. From these exposures it is learned

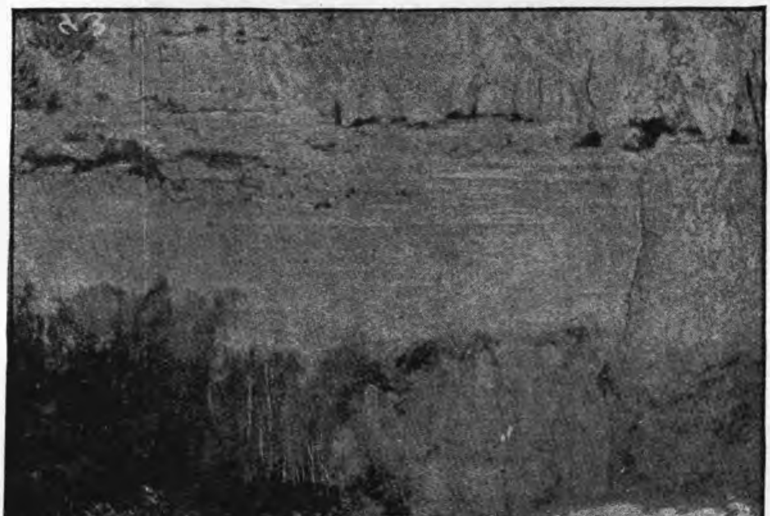


FIG. 65.—Structure of Lafayette formation, 1¼ miles west of Lagrange, Tennessee. The upper massive portion is the case-hardened, loamy sand forming the summital member of the formation. The laminated bed is of light gray sand, and frequently contains sheets of white siliceous clay; below lies the more heterogeneous stratified material constituting the basal member in case tripartition be accepted. Exposure, 35 feet.

that the Columbia mantle stretches northward, though in diminishing altitude, to beyond the Big Hatchie; they also indicate that the massive homogenous upper member of the Lafayette, frequently absent in the land of high relief between the Tallahatchie and the Wolf, resumes its prevalence and is displayed in nearly every gully; and with the recurrence of this obdurate stratum the gullies are transformed from narrow gashes at their heads to amphitheaters broad and steep walled as those of the Fort Adams region, though never so deep by reason of the higher base-level. The exposures show, too, that the snow-white beds of the middle member continue in scarcely diminished thickness, though commonly in slightly diminished fineness of material, pebbly grains and angular chert fragments occasionally appearing within them. The dearth of outcrops of the older rocks, even in the deepest exposures, indicates that the thickness of the formation is maintained if not increased. A representative exposure of this divide is that illustrated in Fig. 66 reproduced from a photograph taken half a mile north of Hickory Valley.

Farther westward on the same divide the Columbia loam soon thickens so greatly as commonly to conceal the Lafayette; but in occasional exposures this formation appears beneath the brown loam or loess with its basal gravel bed, as far west as 3 miles south of Millington. In extreme southwestern Tennessee the lifting of the land since the Pleistocene submergence appears to be less than usual, and consequently the Lafayette lies near or below the low-water level of the Mississippi if

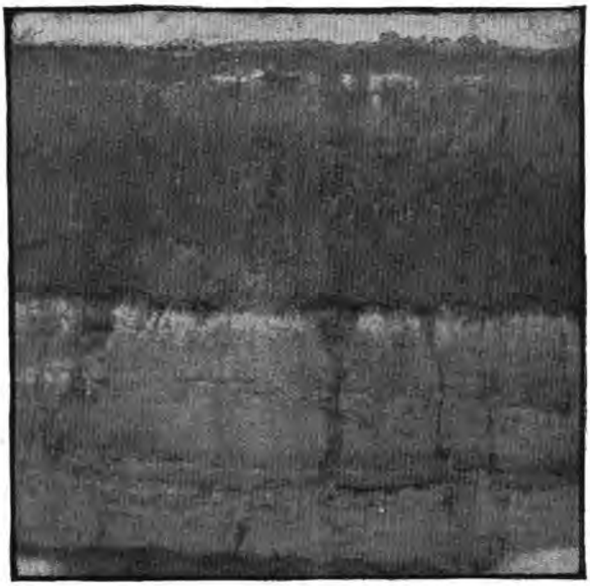


FIG. 66.—Structure of Lafayette formation, near Hickory Valley, Tennessee. The faintly defined upper member is Columbia loam, largely redeposited Lafayette sand; the indefinite light band is the silty base of the same; the heavy, massive bed with flecks of white is the typically developed superior member of the Lafayette; the stratified bed below is the more friable inferior member. Exposure, 25 feet.

it does not fail completely; although, as indicated by a section recently published by Safford, it appears under the Columbia brown loam loess and Orange Sand (of Safford) beneath the loam-mantled platform occupied by the city of Memphis.[1] This section, developed from artesian borings and excavations in considerable number, is reduced to form the accompanying Fig. 67.

Between the Big Hatchie and the Forked Deer the relief increases, the flat plains, such as lie southwest of the Big Hatchie all about Bolivar, disappear, the valleys deepen and widen, and the intervening divides,

[1] Bulletin Tenn. State Brd. Health, 1889.

crests, and spurs shrink in width and stretch in height until the road is a succession of hills with gullies and gulfs on every hand. So the structure may be traced from gully to gully, from mile to mile, with exposures always in sight, all the way from the Big Hatchie bluffs to those of the Forked Deer; and the Lafayette remains essentially unchanged, and essentially identical with the same formation as displayed about Waterford and Holly Springs, and again at Lagrange, save that the upper member is thicker and more persistent. Beyond the Forked Deer precisely similar exposures occur in equal abundance; and by means of them the formation may be traced with unchanged characters quite across western Tennessee in the longitude of Jackson, Milan, and Dresden, save that toward the Obion chert pebbles, such as characterize the Lafayette in the same longitude in southern Mississippi but fail in northern Mississippi, reappear and increase in size and number toward the Kentucky boundary; but on tracing the formation either east or west from this axial line, slight differences appear. Toward the west it inclines riverward and is overlain with ever-increasing depth by Columbia loam, and in its occasional outcrops it is found more and more pebbly, more and more heterogeneous in materials, and in structure often grading into the newer deposits through a hybrid zone, as at Friendship, in northwestern Alamo County, though sometimes it is distinct, as on the eastern shore of Reelfoot Lake, 4 miles south of Samberg; while toward the Tennessee River the Columbia mantle thins and comes to reflect more and more accurately the composition of the Lafayette until about the longitude of Paris, Huntington, and Lexington it fails and the surface which is formed of brick-red loams ever increasing in the content of pebbles until, about Camden and elsewhere in the same longitude, great ledges and even hills of ferruginous conglomerate take the place of the finer material. Quite beyond the Tennessee River, at Johnsonville, and even on the Tennessee-Cumberland divide at Tennessee Ridge, 800 feet above tide, great beds of gravel embedded in a matrix of brick-red sandy loam flecked with white in characteristic fashion, appear. Except toward the Tennessee River the thickness of the formation is indeterminate in this State; but immediately west of the Tennessee River it frequently forms hills 100 to 150 feet in height, and there are indications of thickening toward the Mississippi.

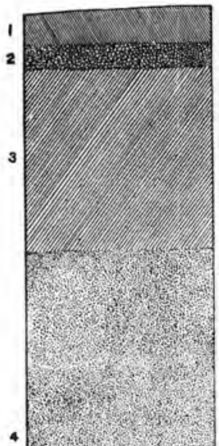


FIG. 67.—Section developed by artesian boring at Memphis, Tenn. (after Safford). 1. Loess and brown loam, 40 feet. 2. Sand and gravel (probably Columbia and Lafayette combined), 30 feet. 3. Ferruginous clays of the Lignitic, 200 feet. 4. Sands, probably belonging to the Lignitic, 400 feet.

In western Kentucky the land lies lower with respect to the great river than farther southward; but as in Mississippi and in western Tennessee, the depth of the Columbia submergence coincides remarkably with the general upland level, so that more than half of the "Jackson Purchase" (that part of Kentucky bounded by the Mississippi, the Ohio, the Tennessee, and the parallel of 36° 30′), is mantled by the Columbia loam, which passes into loess in the Mississippi bluffs.

By reason of the higher base-level, this portion of the ancient Mississippi embayment is not so deeply gashed by modern erosion as the Lignitic ridge of western Tennessee and northern central Mississippi. Yet there is no dearth of sections; except near the Mississippi where the land lies low and the Columbia is at the same time thick, there are many satisfactory exposures for each hour's ride, and by means of them the features of the Lafayette formation may be traced from river to river and correlated from divide to divide. The formation does not appear in the Hickman Bluffs; at Columbus it was not displayed in the principal bluff in the autumn of 1890, though characteristic brick-red and orange red sandy loams, flecked with white, considerably ferruginated pebbly beds, and cross-stratified sands with one or two continuous sheets of white siliceous clay, are revealed in a cutting on the Columbus Junction road near the cemetery in the eastern part of the city; but at Wickliffe the characteristic brick-red and pebbly and sandy loam appears in a railway cut half a mile south of the town, and also in the ravines eastward about Mayfield; at Boaz and Hickory Grove the deposit is well displayed in aspects approximating those characteristic of western Tennessee, save that the pebbles are everywhere more abundant, and save that the snow-white sheets of siliceous clay are rarer and less pure in material, though sometimes so thick and so pure as to be of high economic value. Eminently satisfactory exposures occur in the "gulfs" 4 miles northeast of Mayfield. Different views of one of these exposures are illustrated in Figs. 68 and 69. The upper pebbly bed near the top of Fig. 68 marks the junction of the brown Columbia loam with the brick-red and red brown Lafayette materials, perhaps somewhat disturbed and rearranged; and it is doubtful, but unimportant, with which formation this bed should be classed. The lower pebbly bed undoubtedly belongs to the Lafayette; the gravel is rather fine, subangular and rounded, made up of chert; it is imbedded in a matrix of firm sandy loam, and grades downward into clean, massive, obscurely jointed but generally otherwise structureless loam of similar character, commonly flecked with white (though in the upper part of the stratum the flecks are too fine to show in the mechanical reproduction). This bed is 10 or 12 feet thick. Toward its base it contains at first rounded pellets, and afterward angular and subangular fragments of laminated white siliceous clay, such as forms sheets in the subjacent stratified member, the whole sometimes making a sort of breccia quite similar to that frequently seen in exposures about Oxford, Mississippi. Still lower the admixture of light colored material increases until grays and whites predominate over reds, the brecciation gives way to stratification, and the lower (or middle) member appears in its usual aspect.

Farther eastward characteristic brick-red sands and loams approach the surface and are well displayed about Benton and nearly equally well about Murray beneath a veneer of brown sand continuous with the Columbia, but evidently composed largely of rearranged Lafayette materials. In these exposures the deposit is much more pebbly than toward the interior, and great ridges of conglomerate flank the eastern fork of Clarks River. The gradual modification in the character of the deposit toward the Tennessee River is well displayed between

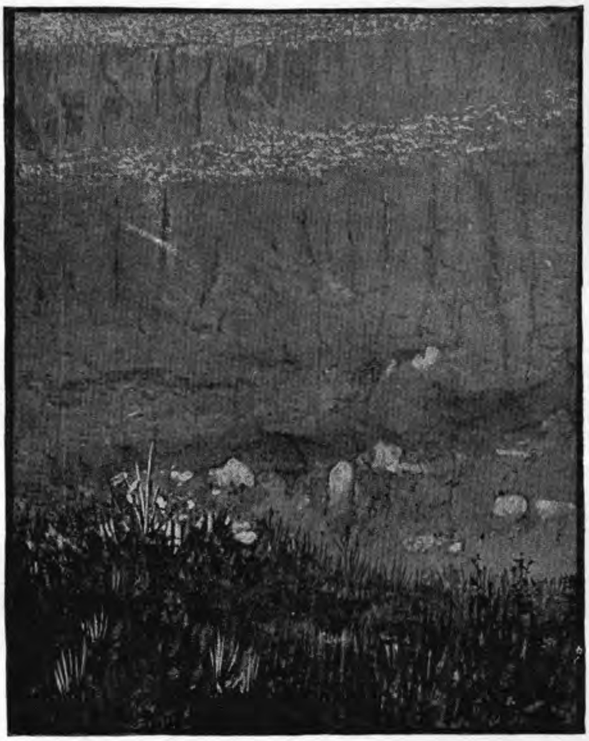


FIG. 68.—Structure of Lafayette formation, New Mayfield, Kentucky. Columbia (?) gravel at summit, Lafayette gravel and loam in central portion, with flecks, pellets, and rounded masses of white siliceous clay below. (The pebble beds are strengthened by retouching.) Exposure, 16 feet.

Benton, on Clarks River, and Birmingham, on the Tennessee; in exposures immediately east of Clarks River the pebbles are larger and more abundant than in the central part of the Jackson Purchase, and gradually increase in number and abundance toward the divide; but beyond the divide there is a much more rapid increase in the dimensions and number of the pebbles until half the volume of the formation displayed in the roadside gullies is made up of subangular and little worn fragments of chert, often 6 inches or more in diameter, and averaging twice as large as those on the Clarksward side of the divide and four times as large as about Mayfield. Beyond the Tennessee the surface rises into a high, rugose ridge separating that river from the Cumberland; but over much of this ridge great gravel beds, with intercalations and commonly with a matrix of orange-red loam, frequently appear; and near the newly projected town of Grand Rivers there are immense beds of gravel, usually nearly clean and bleached white, but sometimes imbedded in a matrix of the usual loam, sometimes stained and cemented by iron, and at one point displaying a bed of characteristic massive semi-glazed white-flecked sandy loam, all undoubtedly representing the same formation.

FIG. 69.—Structure of the Lafayette formation, near Mayfield, Kentucky. Another view of the section shown in fig. 68.

North of the Ohio River, beds of gravel apparently representing the Lafayette formation, occur at Villa Ridge, and exposures of gravel and red loam appear here and there farther northward quite to the summit of the Grand Chain crossing southern Illinois, between Jonesboro and Carbondale.

The characteristics of the formation as developed in western Tennessee, and as exposed before the modern erosion growing out of deforesting invaded that territory, were described in considerable detail by Safford in his report on the geology of Tennessee, published in 1869. By this geologist the formation was designated "Lagrange" and referred to the Eocene. The characteristics of the same formation as developed in western Kentucky have recently been set forth in considerable detail by Loughridge in a report on the geology of the Jackson Purchase (1888). By this author the lower member or members were correlated with the Lagrange of Safford, while the upper member (above the line of pseudo-unconformity displayed commonly in northern Mississippi and western Tennessee and illustrated in Figs. 62, 64, 65, 66, 68, and 69), was correlated with the "Orange Sand" (of Hilgard, not of Safford), the upper portion being assigned to the Quaternary and the lower member to the Eocene. Some of the exposures of southern Illinois were studied by Worthen and his collaborators during the progress of the State survey, and were simply classed as Tertiary; and Chamberlin and Salisbury have recently reexamined some of these, together with other exposures in Illinois, Kentucky, and Tennessee, and have followed Worthen's classification.[1]

West of the Mississippi River, deposits apparently analogous to those of the well differentiated Lafayette of the eastern embayment appear, notably at Little Rock. Here the mass of the deposit is made up of brick-red sandy loam, often packed with pebbles and sometimes containing bowlders 2 feet or more in diameter. The materials differ from those east of the Mississippi in that most of the pebbles are novaculite, while most of the bowlders are semimetamorphic Paleozoic rocks.

A typical exposure of the deposit as displayed in central Arkansas is given in Fig. 70, mechanically reproduced from a photograph taken 3 miles northwest of Malvern. The pebbly bed in the upper part of the cut represents the Lafayette. The massive material beneath is partially decomposed and ferruginated glauconitic sand of Eocene age. In a neighboring railway cut the Lafayette contains numerous blocks and slabs of an obdurate Paleozoic quartzite, sometimes reaching 10 feet in longest diameter and 20 or 25 feet in cubical content.

In southwestern Arkansas the Lafayette terrane expands from a narrow zone connecting the Mississippi flood-plain and the Paleozoic plateau, as at Little Rock and Malvern, and stretches from the Ouachita to Red River in a bed broken only by the larger waterways though half sheeted by Columbia loam. In this region it has been described in some detail by Hill as the "Plateau Gravel."[2] Here, as elsewhere, the features of the formation vary with the propinquity and size of waterways: Thus at Arkadelphia, which is founded upon the formation, it is made up largely of well rounded gravel, comprising novaculite, chert, quartzite, and quartz pebbles imbedded in a matrix of brick-red loam sparingly flecked with white in characteristic fashion and inconspicuously stratified towards the base; while in railway cuttings near the divides separating the Little Missouri from its neighbors, between Guerdon and Berne and also near Prescott the red loam element prevails and the pebbles are small and inconspicuous. So, too, about Washington and Center Point, which are near divides, the formation is made up of brick-red, white-flecked loam, with rather scant and small pebbles disseminated throughout, while at Nashville, which is located

[1] Am. Jour, Sci., 3d series, vol. 41, 1891, pp. 359-377.

[2] Ann. Rep. Geol. Surv. of Ark. for 1888, vol. 2, pp, 35-42 and elsewhere

on a mill stream (Mine Creek), pebbles are abundant and frequently 3 to 5 inches in diameter. It is noteworthy that in addition to the increase in number and size of pebbles toward waterways in this region, the number and dimensions of these materials increase northwestward toward the low mountain masses and ridges of Paleozoic rock, the more obdurate varieties of which are represented in the pebbles.

South and southwest of Red River the formation reappears in greater continuity and still broader development. Red River is flanked by broad terraces of brick-red loam analogous to the "second bottoms"

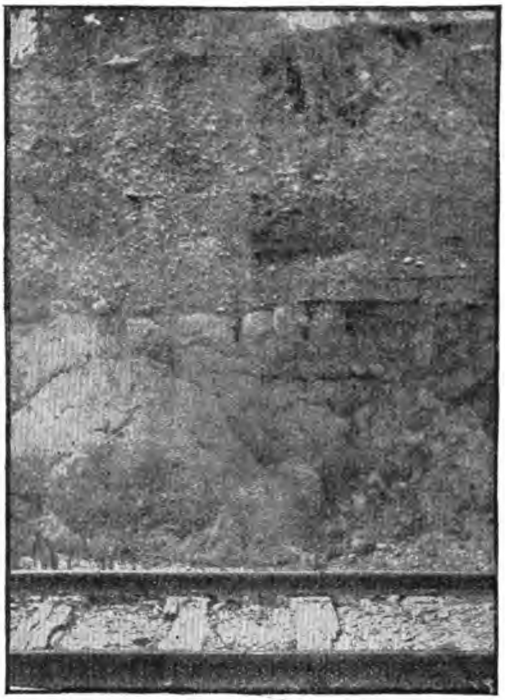


FIG. 70.—Contact between Lafayette and Eocene deposits, 3 miles northwest of Malvern, Arkansas. Exposure, 10 feet.

of Alabama, and toward Atchafalaya Bayou this slack-water deposit expands and merges into the wide-stretching homologue of the combined brown loam and Port Hudson phases of the Columbia formation, which extends thence southwestward to form the Calcasieu prairies of Louisiana. From Shreveport to Natchitoches, and on to the middle of Rapides Parish, the red-tinted terrace flanking the river is overlooked from the southwest by a rugose pine-clad peneplain made up of the more obdurate early members of the coastal plain series, mantled by the characteristic pebble-dotted and white-flecked orange loams of the

Lafayette. This peneplain extends well toward the Sabine, and throughout it is analogous with the cis-Mississippi peneplain in physiography and in structure, save that it lies nearer base-level and takes on gentler slopes, and thus gives fewer natural exposures.

Beyond Red and Sabine rivers, orange tinted loams, pebbly along waterways, cleaner over the divides, appear here and there throughout northeastern Texas. Farther southward these materials, which sometimes may be discriminated only with difficulty from the oxidized and ferruginated glauconitic sands of the Eocene, appear to grade into the sandy deposit described by Penrose under the name Fayette Beds.[1] In the southwestern half of the coastal plain in Texas, they are still farther modified, and display two well defined phases analogous to but more distinctive than those characteristic of the cis-Mississippi development. Along the waterways, particularly toward the interior of the coastal plain, the formation consists of heavy gravel beds of well-worn pebbles representing the terranes traversed by the rivers (though some appear to represent primarily the montanic rocks of which these terranes are built), imbedded in a loamy matrix, which is red, or orange, or pink from the Colorado eastward, generally gray, or creamy, or whitish in color and chalky in texture from the San Marcos southwestward. Sometimes the pebbles are associated with calcareous, perhaps chalky, nodules as at San Antonio; and frequently the beds are cemented into more or less firm conglomerates, the cement being lime rather than iron as in the east. Commonly the gravel beds and conglomerates occur in isolated patches near the rivers, so disposed and so related to the physiography as to indicate that they are remnants, spared by energetic degradation, of a mantle once continuous and thickest and most obdurate along lines nearly coinciding with the present drainage. Remnants of this kind occur at San Antonio and near Calaveras.

Elsewhere, unusually pebbly and thus particularly obdurate remnants of considerable extent are found on divides, as about Flatonia and Waelder, between the Colorado and Guadalupe, and still more notably on both sides of the Nueces and on the northern side of the Rio Grande in Texas, as well as beyond the Rio Grande in Mexico. The second phase of the formation, which apparently corresponds with the Fayette beds of the Texas geologists, is a nearly continuous sheet of predominantly calcareous sands interbedded with clays and loams, which toward the gulf grade into a regularly bedded earthy chalk, as at San Diego. So, in southeastern Texas the deposit corresponds fairly with its more easterly homologue, while in southwestern Texas it is materially differentiated; yet the diverse phases intergrade in such manner that there can be little doubt as to the identity of both phases with the widespread deposit of the eastern coastal plain.

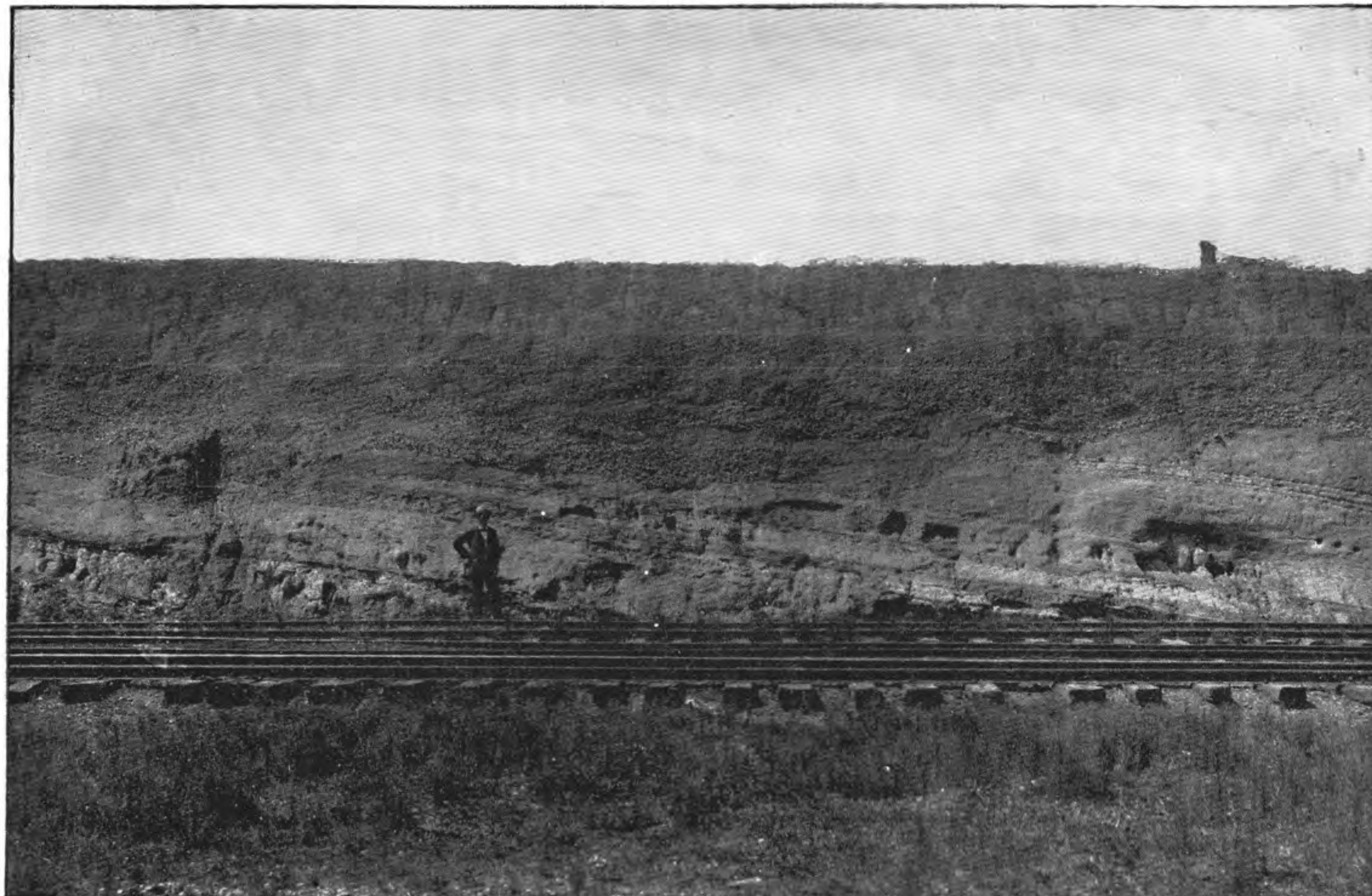
[1] First Ann. Rept. Geol. Surv. of Texas, for 1889–'90, p. 45, et seq.

In eastern-central Mississippi and western-central Alabama the Columbia loam concealing the Lafayette near the great river fails, except in so far as it is represented by the "second bottoms" of the gulfward drainage lines, yet the formation itself is so far attenuated and so frequently degraded that its features grow more and more obscure and the deposits more and more difficult to trace. Along the eastern side of the Mississippi embayment there are on an average half a dozen exposures to the mile, and no hiatus between exposures exceeding 2 or 3 miles; but in eastern Mississippi and Alabama, and indeed thence eastward and northeastward to the eastern type locality on the Appomattox, the exposures average only one to each half dozen miles, and the intervals between exposures on a single line frequently exceed a score to the mile, though they are much shorter where the lines of exploration form a network. Yet the distinctive features of the formation are so characteristic and so persistent that the identification may safely be carried from exposure to exposure and the correlation from river to river, over the whole area of the southeastern coastal plain.

West of Ellisville, on the Tallahala River, the surface is a strongly undulating one of autogenetic type, and the Lafayette is thin and frequently absent so that the Grand Gulf clays and mudstones frequently appear in road cuttings and in all of the smaller waterways not encumbered by second bottom deposits. Typical exposures occur on the peneplain 3 miles west of Ellisville. Here the deposit consists of obscurely cross-bedded orange tinted loam, with discontinuous layers of sand, thin lines and minute flecks of plastic white clay, and pebbles either arranged in lines or disseminated. The pebbles consist of a variety of cherts, generally subangular but sometimes well rounded. commonly ranging from an inch to one and a half inches in diameter, The thickness exposed is about 20 feet. The outcrops are in a remnant of the once continuous deposit, which is completely insulated and rests with marked local and general unconformity on the Grand Gulf mudstones. Perhaps the finest exposure of the Lafayette in eastern Mississippi occurs at and immediately north of Vosburg. Here are found vast accumulations of orange tinted loam, irregularly bedded and sometimes partially cemented. The vertical exposure exceeds 30 feet. North of Ellisville, and again north of Vosburg, are extensive areas without trace of the Lafayette deposits, which are especially significant as indices of a complex relation between this late Neocene formation and the subterrane, as will be more fully shown later.

Immediately west of Meridian lies the buhrstone hill-land, constituting the crest of the Eocene ridge of northern-central Mississippi and the principal divide of the Gulf slope. The configuration of this region is that of a miniature mountain range; there is the meandering crest line, buttressed by minor crests and spurs, rising into peaks and sending off subordinate crests to terminate in spurs and cusps; but every crest, peak, and cusp is blunted, though less notably so than in the upland formed by the Lignitic 100 miles farther northward. The local relief ranges from 100 to 250 feet. Now, over this miniature mountain land the characteristic orange tinted sandy loams appear here and there, not as a continuous mantle, but as shreds and remnants of the mantle caught on the crests, about the rims of the amphitheaters, and, more frequently, on the lower slopes, wherever the post-Lafayette degradation missed the lines of antecedent activity. Here, as usual, the deposit is a massive sandy loam, commonly orange red, rock like and semiglazed on weathering, flecked and streaked with white, and containing moderately abundant chert pebbles toward the lower levels. Northeast of Meridian, on the old Marion road, the structural relation is different. Here the characteristic and distinctive orange-tinted deposit rests on the little indurated clays of that portion of Hilgard's Lignitic which Johnson names the Hatchetigbee; and while the indications are that the Lafayette is nearly continuous, it so closely resembles disintegrated Hatchetigbee clays, and contains so large an element derived therefrom, that the two deposits, albeit of widely diverse age, can be discriminated only with difficulty and sometimes not at all. In the northern part of the city of Meridian the formation is well exposed in typical aspect; and here Johnson has found within it well preserved leaves, apparently of a magnolia identical with the species now living in the vicinity.

The numerous excellent exposures of the Lafayette about Tuscaloosa, Alabama, display the characteristic features of the formation, save that the pebbles are more numerous than in Mississippi and contain a considerable element of siliceous dolomite, with some quartzite. Here, as usual along the rivers draining into the Gulf, the formation is partly overlain by unconformable "second bottom" deposits, and in turn it overlies with still greater unconformity the Potomac (Tuscaloosa) formation; yet despite the widely diverse ages of the latter formations —one late Neocene, the other early Cretaceous—they sometimes merge so completely that no sharp line of demarcation may be drawn between them. This is notably the case in a railway cutting at Cottondale, 7 miles east of Tuscaloosa, where the Potomac is a cross stratified gravel with a matrix of sand, and the Lafayette a horizontally bedded mass of similar gravel in a matrix of loam; yet despite the discordant bedding the materials merge through a 2-foot zone which can not be certainly assigned to either formation. This confusing contact is illustrated in Pl. XXXIV, which is a mechanical reproduction of a photograph taken by Dr. E. A. Smith. Apparent intergradation of this character long misled geologists, including even the illustrious Lyell, as to the relations between the deposits. The resemblance in nature is even closer than in the photograph; for the colors are similar and the materials largely alike, save that those of the mantle are more completely oxidized than those of the subterrane from which they were derived, thus simulating



RELATIONS OF LAFAYETTE AND TUSCALOOSA FORMATIONS, COTTONDALE, ALABAMA.

the usual effects of weather. In some of the exposures on the Alabama Great Southern Railway between Cottondale and Tuscaloosa, however, the contact is marked either by ferruginous crusts or by sheets of pebbles of ferruginous sandstone evidently derived from the older formation.

Farther southward the formation is displayed at several localities, notably at Eutaw. Here it diverges from the usual character in two respects, each of which indicates an intimate relation to a subjacent and much older formation: North and east of Eutaw the deposit is exceptionally sandy and friable and the bedding is frequently obscure; and in numerous exposures on the Alabama Great Southern Railway and along the wagon road leading to the Tuscaloosa (or Black Warrior) River it may be seen to merge with the stratified sands of the Eutaw, and in general to take on the features of that Cretaceous formation—in short, it is as evident here that the Lafayette is made up in part of the immediately subjacent formation as it is in the numerous contacts with the Potomac (Tuscaloosa) formation at Lively, Macon, Columbus, and other points at which the materials obviously intergrade. Southwest of Eutaw a change in the composition and general behavior of the deposit quickly supervenes; only scattered ridges and irregular patches of the formation now remain overlying the peculiar middle Cretaceous formation which Smith and Johnson designate the Tombigbee chalk (the "Rotten limestone" of the books); in these outliers the deposit exhibits its usual characteristic features, but on close examination the sands and clays, such as those of which it elsewhere consists, are found to be intermixed with calcareous particles, while toward the surface it loses the peculiar massive aspect and dull glaze so commonly characteristic of the formation, and breaks down into pink sandy clays on weathering. Over the Tombigbee chalk in this vicinity the prevailing colors are lighter and grayer, and over the Eutaw sands darker and browner, than those displayed toward the fall line or generally elsewhere.

It is in Alabama that the Lafayette formation has been found nearest the coast. Between St. Elmo and Grand Bay, in the extreme southwestern corner of the State, two strongly contrasted types of surface appear. The first comprises the smooth, sensibly horizontal pine-clad sands or "pine meadows" of the coast; and the second consists of undulating bosses, knolls, and plateaus rising above and evidently protruding through the sand. The sand plains and pine meadows represent the local phase of the Columbia formation, while the protruding knolls and plateaus of ancient topography consist of regularly and rather heavily bedded loams, sands, and clays, commonly orange hued but weathering to dark reds and browns, which evidently represent a somewhat erratic phase of the Lafayette. The deposits are erratic, first, in the complete assortment of materials, the sands and clays being separated and laid down in alternating layers; second, in the fineness of the materials, clay forming the predominant element, while the pebbles are represented only by bits of quartz or chert, seldom over a quarter of an inch in diameter, sparsely disseminated through the sandy layers; third, in the exceptionally regular stratification; and fourth, in the absence of the distinctive clay-outlined cross stratification, though the sandy strata are sometimes cross-bedded. The formation here is exceptionally ferruginous. A thin layer in a cutting three-quarters of a mile east of Grand Bay is locally used as an ocher; the plowed fields and other exposed surfaces are sometimes besprinkled or even shingled with small ferruginous nodules (or buckshot) weathered out of the loam; the prevailing colors are harsher and generally darker than usual (though not so dark as at Columbia), ranging from orange-yellow mixed with gray in some strata, to prevailing orange-reds weathering to brick-reds and chocolate-browns; and the peculiar mottling characteristic of the deposit under certain conditions of exposure throughout nearly its whole extent is beautifully displayed.

In a railway cut in the eastern part of Grand Bay the relation between the mottling below the reach of ready oxidation and the formation of the ferruginous concretions found on the surface are clearly shown. The lower part of the exposure, extending to within 12 or 15 feet of the surface, is of fairly uniform orange or orange-yellow hue with some strata passing into gray; next follows a stratum of 5 or 6 feet, concentric with the surface and discordant with the stratification, in which the uniform hues are shot with vertical or oblique lines of darker color, increasing in number upward and finally uniting in a network of orange-red bands an inch or more in width, enmeshing polygons and irregular figures of original color 1 to 5 inches in diameter; while still nearer the surface the bands widen, the lighter colored polygons disappear, and a nearly uniform orange-red supervenes. Yet some of the lines of darker color persist as narrow bands of brown, perhaps marking jointage planes, and on closely approaching the surface these are frequently found to become partially indurated, so as to form a network of embossed chocolate-brown lines, enmeshing orange-red polygons. About the points of union of the embossed brown bands the segregation of ferruginous matter and the cementation are most decided, and quite near to the surface the nuclei thus formed may be found to grade into irregular ferruginous nodules, diminishing in size and increasing in hardness until they pass gradually into the state exhibited by the surface found concretions. So the mottling, the darkening of hue, the general ferrugination, and the formation of nodules are simple results of oxidation and hydration produced by weathering.

On the eastern shore of Mobile Bay Johnson has found a characteristic obscurely bedded orange-tinted loam, undoubtedly representing the Lafayette, running down in low salients washed by the waters of the bay at and below tide level; and Langdon has observed on

Mon Louis Island, beyond the mouth of the bay, stratified loams which he is disposed to correlate with the same formation.[1]

About the northern extremity of Mobile Bay the physiography is similar to that at St. Elmo and Grand Bay, save that the flat-lying Columbia mantle is intersected by Mobile River and its anastomosing tributaries and distributaries, this marshland being overlooked, particularly from the eastward, by a rugose peneplain, in which the local relief ranges from 50 to 100 feet. The structure of the peneplain is revealed in natural gullies and in artificial excavations, notably the cuttings and gravel pits of the Louisville and Nashville Railway; and all of the exposures display massive sandy orange-tinted or brick-red loam, case-hardening on exposure to the weather, dotted with small and well worn pebbles of snow-white matter, which grades downward into massive sands interbedded with gravel. In every exposure the Lafayette appears in distinctive character. Toward Perdido River, and more particularly toward the Mobile, the gravel is unusually coarse and abundant, and near Tensas Station this gravel is largely worked for railway ballast in pits at the base of the peneplain scarp skirting the head of Mobile Bay.

Extensive exposures of the Lafayette occur about Montgomery (particularly in cuttings on the Montgomery and Eufala Railway in the southeastern part of the city), where it rests unconformably upon the Eutaw sands, the junction being sometimes marked by a ferruginous crust, again by a sheet of pebbles, and elsewhere by a decided difference in hue, though it is sometimes indistinct; but the characteristics of the formation here are in no way specially noteworthy save that the pebbles contain an exceptionally large element of quartzite and semiquartzitic sandstone, together with large numbers of subangular fragments of chert and siliceous dolomite.

South of Montgomery the formation maintains similar characters, except that the pebbles diminish in size and number, across the Eutaw terrane. Over the broad zone of the Tombigbee chalk it appears in crenulate patches and scattered ridges diversifying the divides, for here as elsewhere it has ill resisted erosion over a calcareous subterrane. Still farther southward it reappears in volume, giving character to the topography and sanguineous color to the landscapes, as about Searcy, Greenville, and Georgiana, on the Louisville and Nashville Railway; and at Gravella it is so pebbly as to yield abundant material for railway ballast. In this latitude, as elsewhere, the formation is bipartite; the upper member is massive, homogeneous, orange-tinted, or brick-red, flecked with white and sometimes pebble-dotted, weathering into peculiar massive, semiglazed, rock-like forms, suggesting miniature copies of the storm-fashioned buttresses of red sandstone in western canyons, while the lower member is stratified, sometimes cross-bedded, generally friable, though sometimes cemented along bedding planes, and toward the main waterways interleaved with sheets of gravel.

[1] Am. Jour. Sci., vol. 40, 1890, p. 237 et seq.

The exposures on both sides of the Chattahoochee River at Columbus are specially noteworthy, not only by reason of the clear display of structural and textural features, but because the terracing which characterizes the formation at many localities is here particularly well displayed. Columbus is built on a terrace a mile broad, thinly veneered with "second bottom" (Columbia) loam near the river, but consisting generally of the orange-red loam of the Lafayette, massive above, mottled 8 to 15 feet below the surface, and more or less definitely bedded below; Phœnix, or Lively, on the opposite side of the river, is built on a higher terrace of bronze-tinted loam, here containing moderately abundant disseminated pebbles, and the many excellent exposures in the railway and street cuttings well display the stratification of its lower portion. The village of Girard, opposite Mill Creek from Phœnix, and on the western river bank, abounds in exposures; and north and northeast of Columbus, on the Georgia side, a broad terrace, built of materials similar to those displayed in Phœnix, stretches for 5 miles. Down the river the principal terrace level widens to 4 or 5 miles at Fort Mitchell, where it is overlooked by a 100-foot scarp, marking the margin of the general upland of eastern Alabama; and scarp and terrace are built of almost exactly identical material and display almost exactly identical structure and texture throughout many excellent exposures.

On examining the materials composing the formation at Columbus, certain new features appear. As usual, the upper part of the deposit is orange tinted loam, massive, rock-like, undergoing superficial cementation on weathering, and flecked or streaked with white; but the color is lighter than in Mississippi, the proportion of sand is smaller, the sand grains are coarser and more angular, and the flecks and streaks of white are no longer of siliceous clay or pulverulent amorphous silica but of kaolinic clay or kaolin. The lower portion of the formation displays a bedding as distinct as the stratification of Mississippi, but the bedding is simply a separation of the loam into heavy, rock-like ledges parted by leaves of clay, sand, and gravel, quite unlike the interstratification (with occasional cross-lamination) of sands and clays in the western part of the terrane; so, too, the materials of the intercalated clay leaves are changed—instead of the siliceous pottery clays of Mississippi and Tennessee they are chiefly a kaolin-like material, with occasional quartz crystals and mica scales included; and the pebbles are no longer of chert, as in Mississippi and Tennessee, or even the mixture of cherts and siliceous dolomites found on Tuscaloosa River, but mainly of granular quartz with occasional well worn bits of quartzite.

The exposed thickness of the formation about Columbus is generally 10 to 30 feet; and the combined exposures indicate that while the thickness is exceedingly variable it probably reaches a maximum of 50 or 75 feet.

Over the upland of southeastern Alabama the formation generally prevails, and it is noteworthy that it is much more continuous on the Cretaceous terranes toward the Chattahoochee River than in western Alabama, while it is much more continuous on the Eocene terranes in western Alabama than toward the Chattahoochee—on the Cretaceous terrane in the east it is generally unbroken save where trenched by waterways, while in the west it is reduced to isolated remnants; on the Eocene terrane in the east it is greatly tattered by erosion, while in the west it prevails over most of the surface except along the water lines. This inequality in distribution, be it noted, is not dependent on unequal altitude above base-level, for the highest and most rugose part of southern Alabama is the well mantled Cretaceous terrane and the next highest above local base-level is the nearly equally well-mantled Eocene terrane; while the denuded areas, both Cretaceous and Eocene, lie low with respect to present and past base-levels. The distribution is not, however, without law: Where the subterrane is calcareous, the Lafayette mantle is mostly gone; where the subterrane is made up of friable sands, there the Lafayette mantle is deeply tattered; where the subterrane is clay, particularly if the clay be somewhat siliceous, there the mantle maintains its integrity. And this law of distribution is not confined to southern Alabama, but is displayed in even more strongly marked fashion in eastern Mississippi, and is, indeed, more or less definitely revealed throughout the entire extent of the deposit.

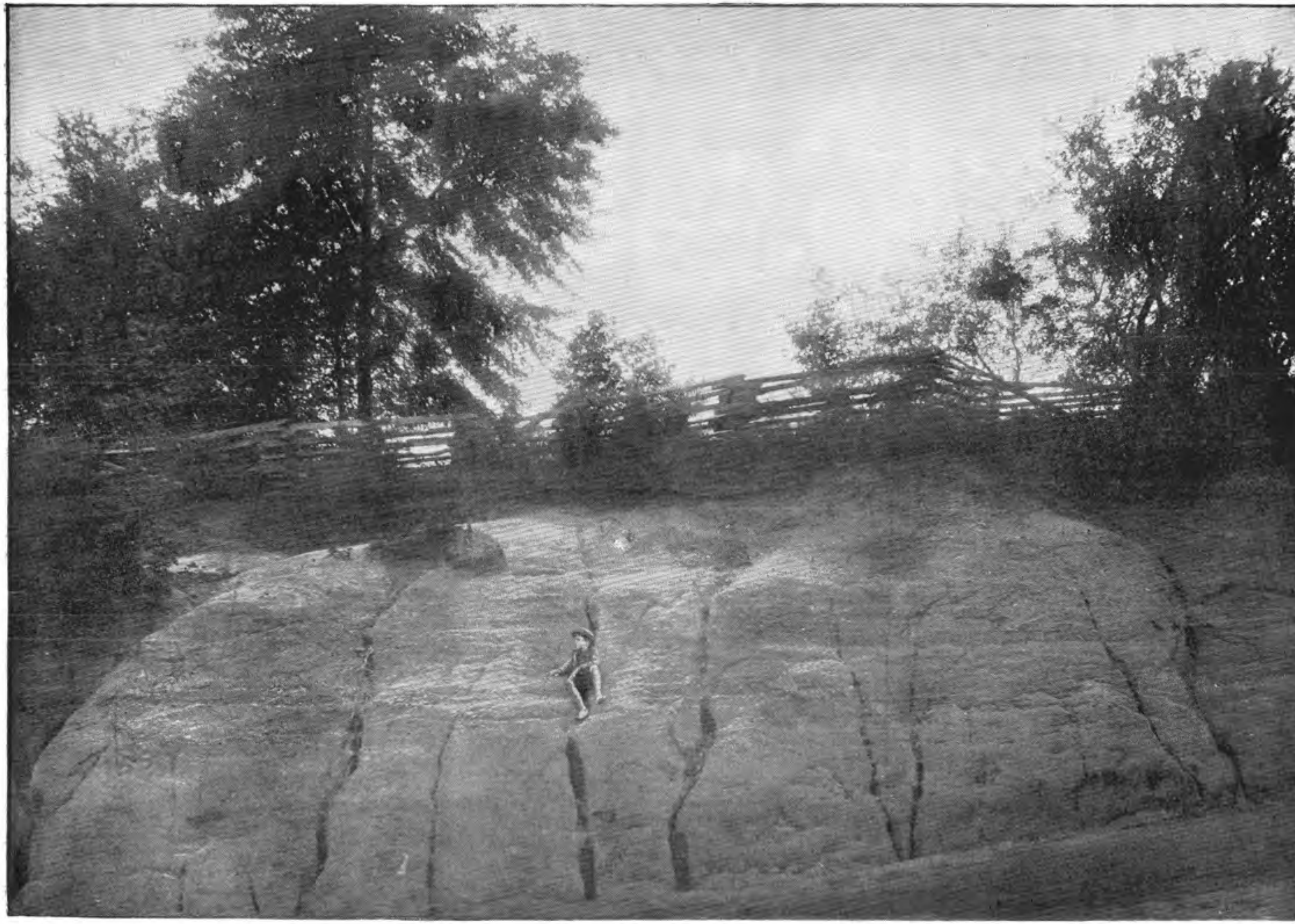
Along the Chattahoochee River about Columbus, and southward nearly or quite to the confluence of the Flint, the Lafayette deposits are not concealed by the newer Columbia formation save along the rivers, which are all flanked by the "second bottom" loams characteristic of the rivers of the eastern Gulf slope. These loams are well displayed immediately opposite the city of Columbus, as already indicated (Fig. 28); and it is particularly noteworthy that they rise little higher above the river in its lower reaches than at the fall line. About Eufala, as generally in southeastern Alabama, the Lafayette loams are more or less conspicuously stratified by reason of a linear arrangement of the white kaolinic matter elsewhere appearing in fortuitously distributed flecks and pellets. Yet it retains the habit of weathering into massive, rock-like buttresses, case-hardened as to surface, separated by miniature storm-cut runnels. The characteristic aspect is illustrated in Pl. xxxv, which is a mechanical reproduction of a photograph by Dr. Eugene A. Smith.

In the vicinity of Columbus, particularly on Mill Creek, between Phœnix and Girard, the Lafayette rests, either with or without marked unconformity, on the Potomac (Tuscaloosa) arkosic sand and clay; the materials of the terrace east of the river and north of Columbus generally lie on the eroded surface of the Piedmont gneiss; within 2 or 3 miles south of Columbus the Lafayette rests uncomformably (though sometimes the unconformity is inconspicuous or even imperceptible) on the sands of the Eutaw; while still farther southward it reposes with like unconformity successively on the Ripley, the various divisions of the argillaceous Eocene (Hilgard's Lignitic), the White limestone of Smith and Johnson, and the Miocene limestones. About Columbus the materials of the basal part of the Columbia, of the Lafayette, of the Potomac (Tuscaloosa), and sometimes of the Eutaw, contains certain common elements and sometimes approximate in composition so closely that they may be discriminated only by structural characteristics; and in some of the most conspicuous exposures near the mouth of the Mill Creek the Lafayette and the Potomac (Tuscaloosa) have not been certainly discriminated.

In general, the features displayed on the Chattahoochee River about Columbus are maintained over the Georgia lowland, and the phenomena are repeated with little variation on each river as it discharges from the Piedmont plateau to the lower lands stretching thence to the ocean.

The exposures about the falls of the Ocmulgee River at Macon are even more numerous than those on the Chattahoochee. The lower portion of Macon is built on a "second-bottom" plain, but the residence part of the city stands on the amphitheater-like slopes semicircling the terrace occupied by the low-lying business portion; and in every street and country roadway, in every excavation on railways entering the city from the west, northwest, and even from the southeast, the orange-tinted loams are well displayed, always with the prevailing color and frequently with characteristic structure; so the roads, streets, railways, and hill slopes of most of Macon gleam red against the dark green background of the pine-clad hills. Here as elsewhere the material is a loam, containing a sufficient element of clay to produce considerable coherence, orange red or sometimes brick-red above, mottled orange yellow at greater depths. Here as elsewhere the formation is characterized by irregular stratification and rather obscure cross-bedding in its lower portion, the structure lines being marked sometimes by ferruginous crusts and sometimes by lines of pebbles or gravel grains, but more frequently by sheets of white plastic clay, sometimes continuous, sometimes in layers of distinct pellets. Here as elsewhere the upper part of the deposit is massive, and displays in an eminently satisfactory manner the distinctive semiglazing or case-hardening by which the formation is generally characterized. Here as elsewhere the deposit is frequently pebbly, the pebbles being either arranged in lines of stratification or accumulated in pockets and in beds, sometimes assorted by size, and as usual the pebbles are commonly disseminated above and commonly bedded below; and here, as at Columbus, the pebbles consist predominantly of moderately well rounded and subangular fragments of quartzite and quartz, ranging from 3 inches in diameter downward, and there are in addition a few granitoid fragments.

The relations of the Lafayette formation to the Columbia "second bottoms" are not well displayed, but the relations to the Potomac are admirably displayed in many exposures. The eminence in the western



TYPICAL EXPOSURE OF THE LAFAYETTE FORMATION, NEAR THE CHATTAHOOCHEE RIVER.

part of the city known as Primrose Hill is a cusp of Potomac arkose only veneered with the Lafayette, and the street cuttings and gullies by which it is laid open along many lines display the two formations in contact, sometimes conformable in structure and concordant in materials to such an extent that they may not be demarked, but elsewhere strongly unconformable in structure and discordant in composition. Precisely similar relations are displayed in the half dozen or more excellent exposures on the Georgia Southern Railway in the western part of the city, in some of which the formations are quite distinct, while in others they intergrade.

Over the divide between the Ocmulgee and the Oconee the Lafayette appears in many exposures; east of the Oconee it reappears, but it is noteworthy that on departing from the fall line the structural features undergo some modification. Thus about Millen the upper member is attenuated, the distinctive coloration weakens, the lower member thickens, reaching 20 feet or more on uplands where the deposit is most attenuated, and definite stratification supervenes, some lines being silty and gravel being notably fine or absent; but on returning to the fall line the normal fall-line features recur, as in the fine exposure near Green's Cut (10 miles south of Augusta), where the usual aspect of the massive loam is well displayed. At this point the deposit is exceptionally pebbly, to the extent, indeed, that it has been largely worked as gravel for railway ballast, the pebbles ranging from 2 inches down, the most abundant dimensions being $\frac{3}{4}$ to $1\frac{1}{4}$ inches; the materials are predominantly quartz and quartzite, with no chert, the prevailing form being fairly well rounded, and the pebbles are accumulated in layers, sometimes discontinuous, in which it is occasionally cross-bedded, though even in these layers the gravel is nowhere clean, the pebbles being simply disseminated closely throughout a matrix of loam, just as the finer sand grains are disseminated through a clay matrix in the loamy parts of the formation.

In central Georgia the Lafayette forms the surface on the Ocmulgee and Oconee rivers, save where the "second bottoms" overlap it; but farther eastward, on the Ogechee as well as toward the Savanna, the distinctive "second bottoms" proper disappear, and the coast-sand mantle stretching up from the seashore, and along the Savanna finally overlaps the Lafayette and extends upon the Piedmont gneiss, from which the orange-tinted formation has been removed, if it was ever deposited. The subjacent formations are, toward the fall line, the Potomac and the Piedmont gneiss, and toward the coast the Eocene and Miocene formations discriminated by Loughridge and others.

In southern Georgia and in northern Florida the Lafayette is the prevailing surface deposit, though it has been deeply and broadly trenched by all the larger rivers and sometimes fails over the divides, particularly on the calcareous terranes; and while the areas in which it fails are sometimes such as to indicate erosion by dendritic drainage systems, there are many cases in which its remnants assume amphitheatral or even complete saucer-shaped forms, indicating that the destruction was wrought at least in part by leaching or by subterranean drainage, or by both combined. In southwestern Georgia, e. g., about Thomasville, the characteristic orange tinted or brick-red loams (in this direction the colors strengthen) are not concealed by the coastal sands of the Columbia epoch, except about the lower levels; but in southeastern Georgia there is a more or less continuous mantle of these sands, by which the Lafayette is commonly buried from sight. In passing southward from Thomasville the features of this formation and its relations to the Columbia are well displayed. Thus, at Monticello, Florida, the railway station well exposes 6 or 7 feet of friable brown sand, structureless or obscurely stratified in its lower portion; below, 8 or 9 feet of massive brick-red loam, hardening on exposure in such manner as to stand without cribbing or walling; then 8 feet of interbedded brown loam, white clay, and gray silt, the sandy layers bearing water. The tank well located near by but at lower level displays a like succession, save that the Columbia sand bed is thicker, more definitely stratified, and somewhat silty toward the base. The railway cutting a mile north of the town, and at somewhat higher level, displays the case-hardened sands passing down into interbedded white clays and brown sands, but the veneer of friable Columbia sand here fails, as it does everywhere above a certain level varying from place to place yet consistent throughout the various exposures in each locality. These Monticello exposures exemplify the conditions prevailing over a considerable territory in southwestern Georgia and western Florida.

Farther westward, near the Appalachicola River, the same features and relations continue, save that the relief increases until the Lafayette forms a series of 100-foot crests, peaks, spurs, and amphitheaters overlooking flat-bottomed valleys and lowlands lined with the coastal sands. Thus, at Tallahassee the flat-lying lowlands stand 100 feet above tide, while the rugose uplands rise 100 feet higher; and the ancient city of Tallahassee is built on one of the highest of these hills, protected by a rampart of only lesser elevations, and all overlook toward the south, southwest, and southeast, the lowlands, first of sand and then of marsh, which stretch thence to the coast. The Tallahassee hill is roofed and protected by a thick sheet of massive brick-red loam, so obdurate that when well drained it may be mistaken for brick pavement; as usual, this superior member of the formation is flecked and streaked with white everywhere below the reach of active weathering, and down to this limit and at greater depths in the exposed faces the deposit is dotted or even crowded with ferruginous nodules analogous to those about Grand Bay, and here, too, revealed in similar process of formation in deep exposures. The massive member is 10 to 20 feet thick; below, it is first diversified by pellets or irregular masses of white silico-argillaceous material which increase in number and size and expand into sheets downward, until the deposit gradually becomes an interstratified mass of brown sand and white matter; at still greater depths the white layers increase in number and the brown sand practically disappears, and the exposures strongly suggest, if they do not clearly indicate, that the white matter passes without definite break into the Neocene argillaceous limestone of western Florida. This transition, be it noted, however, is no more complete than that frequently observed farther northward between the Lafayette and the Potomac (Tuscaloosa), and does not necessarily indicate identity, but more probably a rearrangement and intermixing of the materials.

Another link between the Lafayette and the Neocene limestone at Tallahassee is found in chemical constitution; for the later deposit is slightly phosphatic, as is the earlier in richer measure. Four nodules were collected as follows, viz: (1) A structureless ferruginous nodule, such as those formed in so great abundance in the upper part of the deposit, 2 feet below the surface; (2) a ferruginous nodule of similar appearance, 15 feet below the surface; (3) a ferruginous nodule of like character, 28 feet below the surface in a deep street cutting; (4) a light-colored nodule of similar appearance, 40 feet below the surface. The first nodule came from the massive brick-red phase of the formation; the second came from the mottled orange yellow but essentially structureless phase of the formation; the third came from the part of the formation consisting of brown and drab sands separated by white partings; and the fourth came from the basal portion of the formation in which the white bands predominate. The four samples were tested for phosphoric acid by Prof. Norman Robinson, the State chemist, with the following results: The first gave a trace; the second gave a decided trace (estimated by Prof. Robinson at one-fourth of 1 per cent); the third gave a much more decided trace (estimated at one-half of 1 per cent); while the fourth gave a considerable element of phosphoric acid (roughly estimated at 10 per cent).

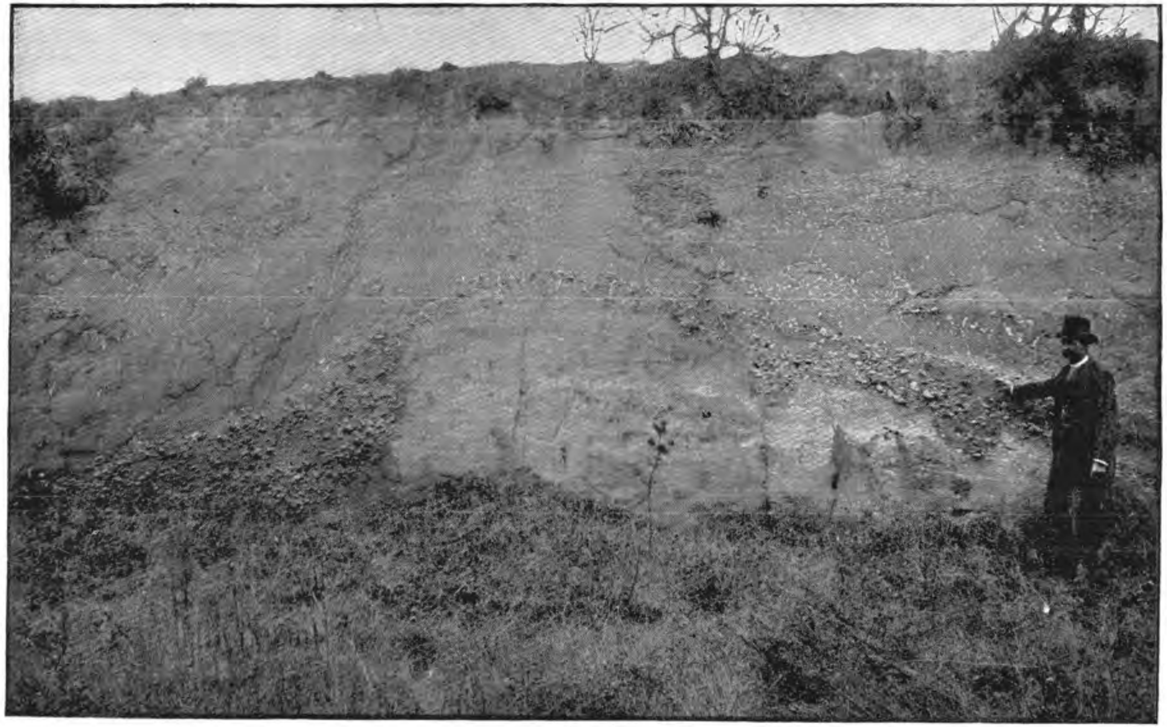
The thickness of the formation at Tallahassee may not be accurately given, first, because it has been completely denuded from half the area, and second, because the remnants probably mantle nuclei of older formations. Single exposures displayed in the street cuttings and gullies down the slopes of the Tallahassee hill aggregate over 60 feet; but it is probable that this is below rather than above the original mean thickness of the formation.

Passing eastward from the longitude of Tallahassee the relief diminishes, and beyond the Suwanee the entire surface is mantled by coast sands of the Columbia so deeply that the orange tinted formation seldom appears, and when it occasionally crops out in deeper waterways or railway excavations toward the Atlantic coast its aspect is so changed that it might hardly be identified without the aid of intermediate exposures Yet the progressively varying aspects are united by occasional outcrops from the Suwanee to the St. Johns, where it is commonly sheeted by shifting sands, to which the Columbia is there reduced.

The Lafayette is well exposed on the southern bank of St. Mary's River, near Traders Hill. Here the upper part is orange brown or drab and massive for a few feet, but it quickly becomes regularly bedded, the heavier layers of brown or gray clayey loam separated by leaves of gray silt and brown or drab sand. It is again displayed in many railway cuttings about Waycross, where the upper massive member is better developed yet decidedly less distinctly massive, orange-tinted, and casehardened than in central Georgia, while the lower part is always stratified. It is revealed to a depth of 40 feet or more at Doctortown in a railway cutting through a natural bluff overlooking the Altamaha; here the upper member is ill developed or absent and the mass is stratified throughout, consisting of alternations of brown loam and white silt above; and in the lower part of the exposure these become, respectively, blue or gray clay and light colored sand. Still farther northward the formation approaches within 10 miles of the sea islands and inlets in the Cherokee Ridge on the southern side of the Savanna. The upper massive member is fairly displayed here, though orange yellow rather than of the characteristic color, while the lower portion consists of stratified sand with fine gravel disposed in sheets.

Superb exposures of the Lafayette, displaying the usual fall-line features, occur on the Savanna River about Augusta. The characters and structural relations here represent those exemplified at Columbus and Macon, save that the "second bottom" phase of the Columbia is replaced by a series of sandy terraces running up into the prevailing coastal sands. Thence northward, across the divide separating the Savanna from the Santee system, the orange-tinted loam prevails, sometimes forming the surface, sometimes veneered with Columbia sands, which here attain the maximum altitude of over 600 feet above tide. Sometimes the formation is distinct, but in many exposures it consists partly of rearranged glauconitic sands of the Eocene, and may hardly be discriminated from that deposit; and in some cases the two deposits appear in the same exposure, the one characterized by pebbles and the other by fossils, yet intergrade so perfectly that no line can be drawn between.

About Aiken the Lafayette rests sometimes on the Potomac (Tuscaloosa) and sometimes on the Piedmont crystallines. On the divides the orange-tinted deposit generally laps far over the crystallines and deepens in color, sometimes to dark brick or turkey red, simulating in tint and to some extent in texture, in composition, and in dearth of structure the disintegrated crystallines of South Carolina. About the confluence of the Congaree and Wateree the Potomac reappears, and is unconformably overlain by the Lafayette, and this in turn sometimes by Columbia sands. The typical relation of these is illustrated in Pl. XXXVI, which is reproduced from a photograph taken by Prof. J. A. Holmes and Dr. R. H. Loughridge, the exposures being an abandoned railway cutting



RELATIONS OF COLUMBIA, LAFAYETTE, AND POTOMAC FORMATIONS, COLUMBIA, SOUTH CAROLINA.

a mile east of the State house in Columbia. Here the coastal sands of the Columbia are, as usual, friable and light brown or drab in color; the Lafayette is orange red, flecked or streaked with white, semi-glazed or casehardened, and therefore massive and rock-like in aspect and irregularly jointed, with considerable accumulations of pebbles toward the base; the Potomac is obscurely and irregularly stratified arkose, containing a few scattered pebbles.

In central South Carolina the Lafayette formation is so frequently displayed, either forming the general surface or cropping out from beneath the erosion-tattered Columbia mantle in natural and artificial cuttings, that its half-concealed surface may be projected with much confidence: It is an autogenetically carved peneplain, with the relief generally running from 50 to 100 feet, the slopes strong or even steep toward the larger rivers, weaker on smaller streams, and quite gentle over the divides, the configuration being thus strongly contrasted with that displayed among the Tallahassee hills or in the Fort Adams region. Over this characteristic surface the coastal sands of the Columbia are spread, once unquestionably as a continuous mantle; but while the streams born of the post-Columbia emergence commonly inherit the estates of their progenitors, they are sometimes larger, sometimes smaller, sometimes differently placed, and sometimes differently affiliated with neighboring families; and so the new drainage has here and there laid bare the old surface, and here and there left it deeply mantled by sand beds, themselves sculptured into autogentic forms. This relation was long ago perceived by laymen, and central South Carolina was classed agriculturally as "red hills" and "sand hills," the former representing the denuded Lafayette and the latter representing the sculptured Columbia mantle. It is perhaps unfortunate that Tuomey, finding the characteristic Lafayette sometimes to merge with the decomposed Eocene greensands of which it is in part made up, assigned the entire red-hill region to the Eocene.

In eastern South Carolina the land lies low and exposures are few and far between, but all the deeper railway cuttings, and here and there a stream, show that the prevailing surfaceward structure of the "high grounds" comprises, first, a sheet of loose, friable, brown, drab, yellow, or gray sand 5 to 20 feet in thickness, strongly demarked by texture (though not otherwise) from a subjacent bed of loamy sand commonly orange yellow in color; and although the correlation is less decisive than might be wished, it is almost certain that the upper deposit represents the Columbia sands and the lower the Lafayette. The land lies too low to expose the basal part of the inferior deposit, and its relations to the phosphatic beds found nearer the coast and commonly referred to the Pliocene have not yet been ascertained.

The Lafayette formation has been studied in detail in North Carolina by Holmes, who finds its features concordant in general with those displayed in South Carolina and Georgia on the south and in Virginia on the north.

It floors an extensive area running halfway from the fall line to the coast, where it commonly passes beneath the Columbia sands and loams and so disappears; it rests uncomformably on Piedmont crystallines and on the Potomac toward the fall line, and overlies the Eocene and Miocene deposits nearer the sea; it is markedly distinct from the estuarine phase of the Columbia formation, which is fairly well developed in the northern part of the State; but in some localities, principally in the southern part of the State, it has not yet been so well discriminated as might be desired from the overlying coastal sands constituting the interstream phase of the Columbia.

For some distance east of the fall line in northern North Carolina, i. e., over the Hatteras axis, which has long been a conspicuous feature in eastern American physiography, the formation displays certain peculiarities in structure and texture: Even near the fall line the deposit is parted into moderately regular beds, sometimes of sand, again of clay, but commonly of loam of varying consistency; and this bedding may extend quite to the surface, as on the Appomattox River. Still more noteworthy is the change in texture. Thus, at Wilson there is the local partition into several regular and rather heavy (2 to 5 feet) strata, the usual orange hue, and the usual distribution of quartzite and quartz pebbles either throughout the several strata or in banks or pockets; but the lowermost stratum (exposed in the northern part of town) is largely composed of arkose, slightly rearranged and sparsely intermixed with fine quartz pebbles, and there is some admixture of arkose in the superior layers. Then, half a mile south of Wilson a 9-foot railway cutting displays the usual heavy and moderately regular bedding, and the usual hues both in weathered and unweathered strata; while the lowest exposed bed (4 or 5 feet thick) is made up of interlaminated gray or white clay and orange or reddish loam, the clay being fine and plastic, the loam rather sandy and massive within each lamina, and the laminæ sensibly horizontal and ranging from an eighth of an inch to half an inch for the clay, and a quarter of an inch to an inch or more for the loam. Both of these exceptional aspects of the formation are exhibited in various exposures in this region; both resemble in some measure characteristic aspects of the Potomac formation seen in eastern Virginia; and it is significant that the Potomac is not found here (probably by reason of removal through degradation), that crystalline rocks approach and in the immediate vicinity reach the surface, and so that the Lafayette probably rests immediately upon the eastward extension of the ancient Piedmont crystallines.

In Virginia the distinctive sands and clays of the formation are typically exposed, as on and near the Appomattox River from its mouth to some miles west of Petersburg. A mile below Petersburg they are found at tide level in the river banks; in the eastern part of the city they appear overlying the fossiliferous Neocene beds, midheight of the bluffs;

and at the "Crater" a mile and a half east, in the railway cuttings in the southwestern part, and on the upland 2 miles west of the city, they occupy the highest eminences. The zone of outcrop here is at least 30 or 40 miles wide. As in North Carolina, the deposit is a regularly but obscurely stratified orange-colored clay or sand, sometimes interbedded with gravel or interspersed with pebbles. Perhaps the best exposure is at the "Crater" (a pit formed by the explosion of 8,000 pounds of powder in a mine carried by Federal engineers beneath a Confederate fort, July 13, 1864). Here the principal material is a dense, tenacious clay, orange, gray, pink, reddish, and mottled in color, plastic, yet firm when wet, and so hard and tough when dry that medallons stamped from it as souvenirs are as durable as rock; indeed, the well known strategetic measure to which the "Crater" is due was rendered successful by the firmness and tenacity of the clay through which the entire mine was excavated, save where it barely touched the subjacent fossiliferous glauconitic sands of the Neocene. At Butterfield Bridge, in the southwestern part of Petersburg, the railway cutting exposes some 20 feet of plastic clay (like that found at the "Crater"), pebbly and sandy clay, and cross-laminated clayey sand, all predominantly orange-colored, in alternating beds, and it is noteworthy that here, as at so many other points, flakes and lines of white plastic clay, similar to those of the Potomac arkose, are occasionally included in the formation. This clay corresponds in composition to that found in the Lafayette loams east and northeast of Montgomery, and it simulates in appearance the siliceous clays flecking the loam and expanding into beds in the embayment. In the vicinity of Richmond the formation is occasionally exposed toward the summits of the river bluffs, but is there less conspicuous than the subjacent Neocene, Eocene, and Potomac deposits. Its features here are much the same as on the Appomattox, save that the contained pebbles are larger and more abundant.

Quite recently Mr. N. H. Darton has collected a number of ill preserved molluscan shells from the basal stratified sands of the Lafayette formation at a point a mile north of Heathsville, Northumberland County, Virginia.[1] The association is such as to indicate that while the fossils were probably washed and redeposited from the Chesapeake formation, they may possibly have been in situ. They are *Venus mercenaria*, *Gnathodon grayii.*, and *Anomia simplex* (?). Of these the first ranges in coastal plain deposits from the Neocene to the Columbia, and continues to flourish to-day; the second is Neocene, but is not found in the Columbia, nor does it live in this latitude to-day, though abundant in the Gulf of Mexico; while the third is one of the so-called Pliocene forms, and is also an associate of the modern oyster. The fossils, accordingly, are insufficient to fix the place of the formation in the biotic scale.

[1] "On fossils from the Lafayette formation in Virginia;" Am. Geol., vol. 9, 1891 (in press).

Near the summits of the bluffs overlooking the Rappahannock River from the southward, a mile or two west of Fredericksburg, the distinctive, stratified, orange-colored sandy clays are found reposing upon Potomac sandstone, from which they are readily distinguishable by greater homogeneity, by more complete intermingling of the arenaceous and argillaceous materials, by more regular stratification, and by the more uniform and predominantly orange color. They are as readily distinguishable from the Columbia deposits, on the other hand, by vertical homogeneity, by comparatively regular stratification, by distinctive color, and by greater range of altitude, extending, as they do, from tide level to the highest eminences of the Piedmont escarpment between the Rappahannock and the Roanoke. At Fredericksburg the deposit is commonly thin and confined to limited isolated areas, especially at the higher levels; about the confluence of the Ni, Po, and Ta rivers it forms the surface over a meridional zone fully 10 miles wide; it is well exposed in the bluffs of the Taponi, along which it reposes upon the fossiliferous Eocene; and in the bluffs of the Mattaponi and the Anna rivers, as well as over the intervening divides, it is the prevalent surface formation, maintaining the characteristics exhibited at Fredericksburg, save that it is perhaps more pebbly.

The extension of the Lafayette formation north of the Rappahannock has recently been traced by Mr. Darton, who thus characterizes it:

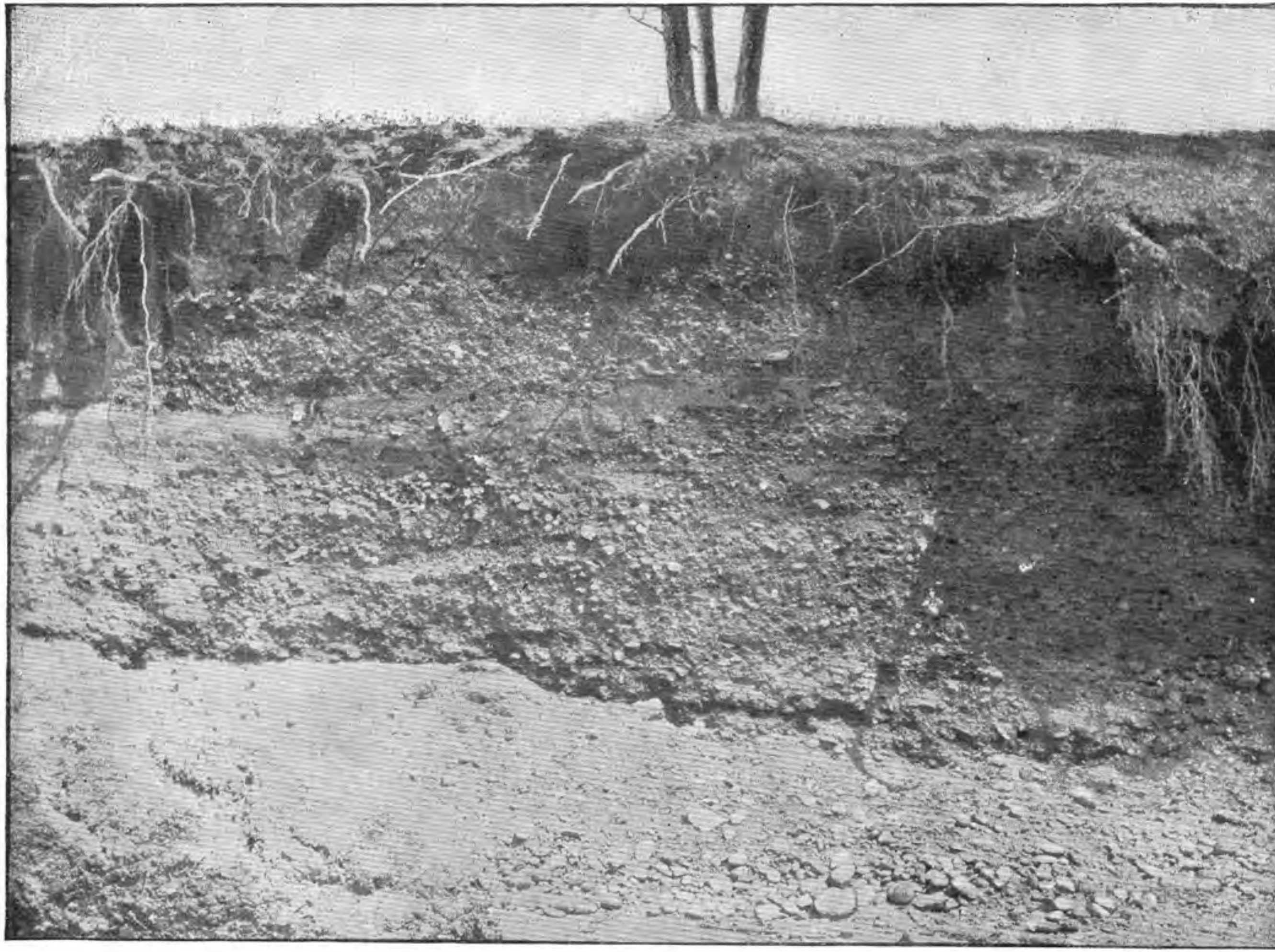
It is displayed in the high terraces about Washington, and it caps nearly all the higher terrace levels of the "western shore" of Maryland northward to the latitude of Baltimore. Still farther northward it is confined to outliers on the divides along the western margin of the coastal plain region, but at the head of Chesapeake Bay it extends farther eastward, and, in the high Elk Ridge, caps the Cretaceous and Potomac formations over a considerable area.

The * * * formation in eastern Virginia consists of light-colored loams of buff and orange tints, containing streaks and beds of pebbles and coarse sand in varying proportions and irregular deposition. Northward in Maryland coarser materials gradually increase in amount, and in the Washington-Baltimore region and northward gravel beds predominate. On Good Hope Hill, east of Washington, the high terrace is capped for some distance by beds consisting mainly of large pebbles and sand, with a buff loam matrix. Farther eastward the proportion of loam increases and the pebbles decrease in size and number. In the high terraces extending westward from Alexandria, in the outliers west of Washington and Baltimore, and generally along the crystalline border in Maryland and Delaware, the formation consists mainly of iron-stained pebbles in a matrix of more or less sandy orange or buff loam. Thin layers and lenses of ferruginous conglomerates are of frequent occurrence in the northern Maryland belt, in the capping on Elk Neck, and in the Pennsylvania and New Jersey outliers. In some cases the formation contains somewhat coarser materials adjacent to the larger drainage depressions, especially on the Potomac River, where the pebble beds are particularly noteworthy.

The thickness of the formation is variable, but it averages between 20 and 30 feet. In Maryland it is generally under 25 feet, but in Virginia it is usually somewhat thicker than this.[1]

The structure of the formation on Good Hope Hill, where it is typically displayed for this latitude, is illustrated in the photomechanical Pl. XXXVII, from a photograph by Mr. Darton.

[1] Bull. Geol. Soc. Am., vol. 2, 1890, pp. 445–446.



TYPICAL EXPOSURE OF THE LAFAYETTE FORMATION IN THE DISTRICT OF COLUMBIA.

THE GENERAL FEATURES.

The Lafayette formation may briefly be described as an extensive sheet of loams, clays, and sands of prevailing orange hues, generally massive above, generally stratified below, with local accumulations of gravel along water ways; the deposit varying in thickness from place to place, though in such manner that its local thickness expresses the strength of the local streams; the materials varying from place to place, but always in the direction of community of material, first, with that of the terrane drained by neighboring streams from the Piedmont, Appalachian, and Cumberland uplands, and second, with the older deposit upon which it lies; while as a whole the formation maintains so distinctive and strongly individualized characteristics as to be readily recognized wherever seen. This distinctive aspect of the formation is to some extent fortuitous. Thus, the resemblance between the Atlantic slope flecking and streaking and banding with white and the similar marking in the embayment depends on the accidental resemblance of two chemically and petrographically diverse materials; yet this diversity is a minor one, and the great fact remains that the vast Lafayette formation, the most extensive in the United States and one of the youngest in the geologic series, is more uniform, petrographically, than any other formation of even one-fourth of its extent throughout the length and breadth of the continent.

The geographic distribution of the Lafayette formation may be stated either simply and easily in terms of original deposition or in greater detail and with more difficulty in terms of outcrops.

In general distribution the formation is known to expand and strengthen southward from a few isolated remnants crowning the central axis of peninsular New Jersey, a few miles south of the Raritan, to a thick deposit forming a terrane 40 or 50 miles wide on the Roanoke; to expand thence southward, in a broad zone, at first widening but afterward narrowing with the encroachment of the overlapping coastal sands upon its area, quite across the Carolinas; to form the most conspicuous terrane of central Georgia, where it stretches from the fall line to the inland margin of the coastal sands all the way from the Savanna to the Chattahoochee; to again expand greatly in Alabama with the contraction of the overlying coast sands until it forms an essentially continuous terrane stretching from the fall line at Montgomery and Tuscaloosa to the waters of Mobile Bay and to within a dozen miles of the Gulf in the southwestern corner of the State; to expand still more in the Mississippi embayment until it overlooks the great river in a practically continuous scarp from Baton Rouge to the mouth of the Ohio; to reappear in extensive remnants beyond the Mississippi in central and southwestern Arkansas; and to extend over a vast area in northwestern Louisiana and southeastern Texas, and almost certainly to stretch thence southwestward, in a continuous belt toward the coast and as erosion-tattered remnants inland, quite to the Rio Grande.

If the direct observation be supplemented by legitimate and necessary inference, the formation must be so extended as to bridge the valleys from which it has been degraded and stretch beneath the various phases of the Columbia formation well toward the Atlantic and Gulf coasts, though its seaward extension is doubtless aberrant in composition and structure, until it merges with the continuous series of offshore Neocene deposits forming the great submarine shelf which represents the submerged portion of the coastal plain. With this inferential extension the field of the formation becomes coextensive with the coastal plain of the Atlantic and Gulf slopes (including perhaps Florida) and assumes an area of 200,000 or 250,000 square miles. Over the whole of this vast area the Lafayette formation must originally have stretched, and over all of this area, except in the deeper Mississippi embayment and in the southwesternmost Gulf slope, it must have possessed the wonderfully uniform composition and structure exhibited to-day by its stream-carved remnants.

The geographic distribution of the remnants of the Lafayette formation represented by present exposures is shown in a general way on the accompanying Pl. XXXVIII, in which, be it understood, the observations are greatly generalized, as the small scale demands, and also extended by inference, as the incompleteness of the investigation demands. There are, however, certain features of distribution not represented on the map which are too significant to be neglected.

Throughout the coastal plain the formation is deeply dissected if not completely divided by the larger rivers at, and commonly for long distances below its inland margin. The tributaries have invaded it as well, and so, too, have the smaller streams, down to the rivulet and the storm-filled rill; and thus its entire surface has been sculptured by running water in a manner well illustrating the type of configuration elsewhere classed as autogenetic. Now many of the tributaries, as well as some of the subordinate members of the wide-branching drainage systems have, like the principal rivers, cut completely through the formation and exposed the subterrane over considerable areas; and while the extent of the destruction of the formation in this manner is of course dependent upon the local efficiency of the several factors of degradation (declivity, stream volume, texture of the rockmass, etc.), it is evidently related in some degree to the character of the subterrane. This relation is well exemplified over the hill-lands flanking the Tombigbee and Alabama rivers on the west. Over the terrane of the Potomac formation the Lafayette generally prevails despite the considerable altitude and high local relief, save in the valleys of the largest rivers; over the less elevated terrane of the Eutaw sands it is more frequently and more widely cleft by drainage ways, and its remnants are thinner; over the next newer formation (the Tombigbee chalk), which lies low and flat, the greater part of the Lafayette has been carried away, not only in the vicinity of the Tombigbee River, but all the way from northeastern

Mississippi to beyond the Alabama River, so that it is commonly represented only by isolated belts and irregular patches which, as Smith has shown, most frequently lie on northerly slopes; over the terrane of the Eufaula sands, in which the local relief again increases, the remnants of the Lafayette quickly increase in number and expand in width until they once more form the prevailing surface of the uplands, though the Cretaceous deposits are laid bare along most streams and form the prevailing lowlands; and over the eight or nine lower Eocene formations into which the Lignitic of Hilgard has been divided by Smith and Johnson, and among which clay is the predominant material, the Lafayette still further expands until it forms almost the entire surface, highland and lowland alike, save in the valleys of the larger rivers. Still farther southward lies the great siliceous deposit of the middle Eocene long known simply as "buhrstone," now called the Meridian formation; its rocks are the most obdurate of the entire Neozoic series within the Gulf slope, and so its general surface is elevated and sculptured into a complex configuration of pronounced relief and sharp contours; yet despite these conditions so exceptionally favorable to degradation, the Lafayette frequently maintains its integrity over considerable areas. Beyond the hill-land of the buhrstone lies the lowland formed by the predominantly calcareous newer Eocene formations—the Claiborne, Jackson, and Vicksburg—over which the Lafayette is again trenched by almost every waterway, and reduced to ragged remnants only more extensive than those overlying the Tombigbee chalk; but upon the silico-argillaceous terrane of the Grand Gulf the remnants once more expand until they form the greater part of the surface, save along the larger waterways, as about Hattiesburg in central Mississippi. In short, the formation is generally preserved over clayey terranes and largely degraded over calcareous terranes; and this is true not only of the section from Tuscaloosa to Hattiesburg, in Alabama and Mississippi, but of the formation as a whole—except in the southwestern Gulf slope where the distribution of degradation is determined by continental attitude rather than by composition.

It has already been intimated that the composition of the Lafayette everywhere depends in part upon that of the subterrane, i. e., that its materials everywhere consist of local elements and erratic elements combined in varying proportions; and the variable friability and solubility resulting from this inequality in composition is evidently the reason for the unequal resistance which the formation has offered to degradation in various parts of its extent.

In hypsographic distribution the formation ranges from tide level in Mobile Bay and (probably) from some hundred feet below tide level in the trans-Mississippi territory to scant 500 feet above tide level over the Grand Gulf upland in southern Mississippi and fully 600 feet over the Eocene upland in northern Mississippi, with like altitudes in central South Carolina, to fully 800 feet at Tennessee Ridge, between the Tennessee and Cumberland rivers, to 400 feet over the "grand chain" of southern Illinois, to 350 feet near Malvern and 250 feet near Arkadelphia in Arkansas, to some 500 feet at Austin and about the same near Laredo, and to nearly or quite 1,000 feet near Uvalde and elsewhere near the Rio Grande. This range in hypsographic distribution evidently represents two factors: The first is unequal submergence, due to continental warping during the Lafayette period; the second is inequality in configuration, due to antecedent sculpture: the land sank as a mass yet warped in sinking, and the deposit was then laid down as a mantle over a former land surface.

In brief, the hypsographic distribution of the formation is essentially identical with that of the coastal plain, save that its northern extension has been degraded extensively and that its southwestern extension has been degraded only at the higher levels, and save that the formation extends a little farther inland than the older Neozoic formations, overlapping for a few miles of distance and a few yards of altitude upon contiguous provinces.

In several exposures on the Appomattox River at and below Petersburg the fluvial phase of the Columbia formation (as developed in the middle Atlantic slope) rests unconformably on the surface of the Lafayette, and a like relation to the interfluvial phase is displayed in several railway cuttings south of Petersburg. In the excellent section at Columbia the coastal sand phase of the Columbia formation rests unconformably upon the Lafayette, and at Phœnix, Alabama, the "second bottom" phase of the newer formation overlaps unconformably an eroded surface of the older one. In the sections at La Grange, Tennessee, and Holly Springs, Mississippi, the Columbia loam is separated from the Lafayette by old soils, and at Fort Adams and Ellis Cliffs the Columbia loess with its basal pebble bed lies unconformably on the Lafayette, while borings in southeastern Mississippi and the Calcasieu prairies of Louisiana reach the Lafayette beneath a variable mantle of the lowest local member of the Columbia formation, i. e., the Port Hudson clays. From these exposures in section the two formations are known to be diverse in age.

The unconformity between the Columbia and the Lafayette becomes more striking when the relations of the two formations to the larger rivers are considered. Every great waterway traversing the coastal plain from the fall line to the shore of ocean or Gulf has for scores of miles trenched the Lafayette to its base and commonly cut far into older strata, and the orange loams and sands are usually removed from the bottom and half the sides of the trough whose axis is marked by the water way; while the same rivers are flanked by terraced belts of Columbia loam overlying the degraded edges of the Lafayette and the older formation alike and little invaded by erosion (except on the Savannah and Congaree), save that of the river channel. It is true that the Chattahoochee, Tuscaloosa, Tombigbee, and several other rivers are locally flanked by terraces of Lafayette materials, but these terraces appear to be the product of estuarine wave work about the close of the Lafayette submergence, and are degraded deeply as the higher portions of the deposit.

Still more striking does the unconformity appear when the general configuration of the two formations is compared. About Grand Bay and St. Elmo, in southwestern Alabama, the Columbia forms a smooth, monotonous, sensibly horizontal plain, while the knolls and uplands of the Lafayette protruding through the flat-lying sands exhibit well-developed autogenetic sculpture; over the smooth plains of the Tombigbee chalk the Columbia deposits skirt the rivers in sharp-cut terraces, while the Lafayette, preserved only in remnants, has been largely removed by erosion; on the Oconee and Ogeechee rivers, in eastern-central Georgia, the monotonous plains formed by the coastal sands of the Columbia encroach upon and send tongues and fingers into the ravines and broader depressions of a boldly sculptured upland of Lafayette loam, and in North Carolina and Virginia the Columbia is little more than a flowing mantle masking the more rugged frame work of the older Lafayette. Indeed, throughout their extent these formations illustrate the contrast between "topographic youth" and "topographic old age" as defined by Chamberlin; the one is soft-faced, smooth, nearly featureless; the other hard-visaged, furrowed, strong-featured.

Local unconformities between the Lafayette and the several subjacent Neozoic formations are frequently exposed in section, and general unconformity with all these formations alike is indicated by its overlap upon all from the Grand Gulf of the Neocene to the Potomac (Tuscaloosa) of the Cretaceous.

Especially significant is the unconformity between the Lafayette and the Grand Gulf, the youngest of the series. In southern Mississippi generally, and notably in the vicinity of Tallahoma River about Ellisville, there are sufficiently numerous exposures of the Grand Gulf mudstones to show that the surface of the terrane is one of autogenetic sculpture, that the Lafayette was laid down as a continuous mantle upon this sculptured surface, and that after the close of the Lafayette period the rivers resumed approximately their ancient courses and have impressed a new and fairly consistent sculpture upon the old. So, while the newer formation crowns eminences and floors depressions alike where not profoundly eroded, its mass is little, if any, thicker on the upland than in the valley, and exposures are as common in the upper as in the lower slopes; and along the larger rivers the Lafayette has been frequently removed from the lower slopes, while it yet crowns the divides and highlands quite to the brows of the bluffs.

Especially significant, too, is the relation between the Lafayette and the obdurate strata of the Meridian buhrstone, since a rough record of great continental oscillation is contained therein. Southwest of Meridian and west of Corinne lies a prominent ridge of the peculiar siliceous rocks of this formation, making the divide between the Okatibbee and Chunkee rivers. This divide is a meandering crest, sending out lateral spurs and culminating in height at every bend, separating a plexus of steep-sided ravines, coves, and amphitheaters—the whole simulating a mountain crest line with its peaks, aretes, cols, gorges, and amphitheaters, save that every summit is blunted. This striking configuration tells a significant story, but one too long for repetition here—it suffices that it tells of a time when the land stood higher and the rivers were hence more energetic than to-day. Now, over this irregular surface the Lafayette was evidently spread mantlewise, just as over the qualitatively similar though less strikingly emphasized surface of the Grand Gulf; and here as there the post-Lafayette rivers sought their old courses, and the new drainage system corresponds substantially with the old;[1] but the lower base-level of to-day has tended to develop a flatter surface than the old, and while remnants of the orange loam are frequently caught on the crests and lodged in the amphitheaters, they have been commonly removed from the higher altitudes and are generally confined to the lower levels.

Perhaps the Lafayette merges into the phosphate-bearing Pliocene beds of South Carolina; probably it is continuous with some of the newer offshore deposits of Florida; unquestionably it represents but the landward portion of one of a vast series of deposits which at some distance beyond the present shores of ocean and gulf are unbroken; but certainly there is a great unconformity, first, between the Pleistocene Columbia and the Lafayette; and second, between the Lafayette and all of the subjacent Neozoic formations yet satisfactorily discriminated within the Atlantic and Gulf slopes.

The materials of the formation which may confidently be traced to their sources are (1) pebbles or gravel, (2) arkose, and (3) certain components of the more finely divided matter.

It has been stated incidentally that about the fall line the pebbles of the Lafayette are in large part identical with those of the Potomac, and that they are evidently derived therefrom. It has also been stated incidentally that the pebbles of both Lafayette and Potomac vary from river to river—quartzite with less quartz on the Susquehanna and Potomac rivers, quartz on the Rappahannock, quartzite with less quartz on the James and Appomattox, quartz with less quartzite on the Roanoke; quartz mainly on the Neuse and Cape Fear, quartz with less quartzite on the Santee system, quartz and quartzite in nearly equal proportions on the Savanna, quartz with less quartzite on the Ocmulgee and Chattahoochee; quartzite, siliceous dolomite, quartz, and chert (in order of abundance) on the Alabama, siliceous dolomite, chert, and quartzite

[1] The history of renewal of buried drainage systems in the eastern Gulf slope is recorded in wonderful fullness and clearness. Three and even four times has the autogenetically sculptured surface of the Meridian buhrstone been submerged and mantled with sediments, only to rise and resume more or less fully its old aspect under the influence of waterways following the old lines. Such resurrected or *palingenetic* drainage and sculpture is characteristic of much of Mississippi.

on the Tuscaloosa and Tombigbee, and chert on the Pascagoula and Pearl; chert and some siliceous dolomite with Iron Mountain jaspers on the Mississippi; chert and novaculite on the Arkansas, novaculite on the Ouachita, and flint, novaculite, and Rocky Mountain and Ouachita jaspers on Red River; flint and quartzite on the Colorado, and sublocal rocks on the San Antonio, with Cretaceous flints and siliceous limestones and semi-quartzites of the Pecos type toward the Rio Grande; and this variation goes exactly with the petrographic character of the most obdurate rocks traversed by the upper reaches of the respective rivers.

Arkose is but a limited and unusual constituent of the formation, and is known to occur only under two sets of conditions. It occurs when the formation rests directly upon crystalline rocks or when these rocks are exposed in such propinquity as to indicate absence of deposits intermediate in age, as at Wilson, North Carolina. It occurs, also, in less abundance and purity, where the Lafayette rests directly upon the Potomac formation, and the latter is made up largely or exclusively of the same material, as at Girard, Alabama. In both cases the material is evidently derived from an adjacent and older formation.

Most conspicuous among the finely divided materials, though commonly unimportant in relative volume, are the components of the white flecks, streaks, and bands generally characteristic of the upper portion of the formation, and sometimes enormously developed in the lower portion. On the Atlantic slope the fine material thus displayed is commonly found to consist chiefly of partly or wholly decomposed feldspar or kaolin. It is evidently related to the arkose, with which it is sometimes associated. The material of similar aspect found in the Mississippi embayment is a finely divided or amorphous silica more or less intermixed with clayey matter, a part at least of which appears to be a true silicate of alumina. This material is undoubtedly (as already suggested by Hilgard and believed by Safford) a decomposition product of chert, and its source is to be sought in the disintegration and redeposition of the great beds of Paleozoic chert which furnish so important an element of the Lafayette formation throughout the Mississippi embayment. In Texas the kaolin of the Atlantic slope and the silica of the embayment are replaced by a less conspicuous chalky material, evidently derived from the Cretaceous limestones.

Certain striking features in geographic distribution of the Lafayette formation already pointed out indicate that in many if not all cases a part of its materials were derived from immediately subjacent strata, and so that the character of this formation in a measure reflects that of the subterrane—the characteristic orange loams being exceptionally loamy over loams, exceptionally sandy over sands, exceptionally argillaceous over clays, and exceptionally calcareous over limestones.

The combined volume of pebbles and gravel, arkose, and the local elements of finely divided material, however, constitute but the smaller portion of the entire bulk of the formation.

Most abundant among the materials of which it is composed is the orange-tinted component of clay-like texture which forms a matrix for the sand grains in the loam, and for the pebbles in gravel. This material so closely resembles the usual residuum of secular rock decomposition as to be frequently mistaken for that product in place. On comparing this component with the residua of the coastal plain and contiguous provinces, it is commonly found to combine the characters of the decomposition products of the subterrane and of the terranes washed by the upper reaches of the neighboring rivers, and this similarity may safely be inferred to indicate its derivation. Thus the preponderant component of the formation may be ascribed to secular decomposition of a variety of rocks; and, since residua are always less diverse than the rocks from which they are derived, the origin of this component measurably explains the wonderful similarity in aspect in nearly all portions of the widespread Lafayette formation. The exceptional aspect of the formation in Texas is unquestionably due to the fact that it is here made up of mechanically triturated but only partly decomposed materials.

CHAPTER III.

DEFINITION AND SYNONYMY OF THE FORMATION.

DEFINITION.

In composition the Lafayette formation is a bed of loam, sand, and gravel, with several minor elements, notably kaolin or kaolinic clay, comminuted silica or siliceous clay, etc. The clay element of the loam and much of the sand are evidently residua derived from decomposition of a variety of older rocks, the local characters generally reflecting the characters of local terranes; the gravel and a part of the sand represent the terranes traversed by the upper reaches of the rivers along which they are found; and the gravel varies in abundance and size with the volume, declivity, etc., of these rivers.

In geographic distribution the Lafayette formation coincides approximately with the coastal plain of the southeastern United States.

In hypsographic distribution the formation ranges from altitudes of 700 or 800 feet to probably some distance below tide level.

In thickness the Lafayette deposits range from a mere veneer over many interstream tracts to 200 feet or more about the mouth of the Mississippi; and in general the thickness varies directly with the volume of neighboring rivers and inversely with the inland extension. The formation has, however, been degraded from considerable areas, particularly along the larger water ways.

In structural relation it is separated from the newer Columbia formation by the strongest unconformity of the coastal plain, an unconformity representing degradation of probably half the volume of the Lafayette formation and profound trenching of subjacent formations along the larger water ways; and it is separated from all of the underlying formations by a noteworthy unconformity of such character as to indicate that during pre-Lafayette time the coastal plain was a land surface and was wrought into a configuration much like that existing to-day.

In structural composition the formation is a unit, varying from place to place in local characters yet indivisible throughout its area of 250,000 square miles, save on arbitrary grounds.

Its position in the biotic scale is unknown, its meager flora combining Laramie (Cretaceous) and Pleistocene or modern features, and its still more meager fauna representing the entire Neocene.

In genesis it is a littoral deposit of materials carried into the Atlantic Ocean and the Gulf of Mexico by rivers still in existence, when the land stood from 200 to 800 feet lower than to-day, and when the waters of ocean and gulf extended from 50 to 500 miles inland of the present coast.

In age the Lafayette formation is many times older than the earliest known Pleistocene deposit, and much newer than any other well defined formation of the coastal plain. If the Cenozoic be not made to include the Pleistocene, and if the age be then divided into equal portions called Eocene and Neocene, and if then the Neocene be divided into ten equal parts the Lafayette period may be supposed to correspond with the eighth or perhaps with the seventh or the ninth of these parts.

SYNONYMY.

The Lafayette formation, as now defined, was first discriminated in northern Mississippi in 1855 and 1856 by Dr. E. W. Hilgard, and was named by him after Lafayette County, in which it is typically developed. It was then considered Quaternary (or Pleistocene).[1]

About the same time Dr. J. M. Safford recognized the same deposits in western Tennessee, but by reason of the rarity of exposures in the then little settled tract, and by reason of the hasty character of the reconnaissance during which it was observed, he combined it with certain petrographically similar but much older deposits. The several deposits were united under the name "Orange Sand group," and on the ground of the diagnostic features displayed by some of the lower beds, all were referred to the Cretaceous.[2]

A few years later Dr. Hilgard published officially the results of his studies of the formation in Mississippi; and in this document he adopted Dr. Safford's designation for the deposit, but gave reasons for referring it to the Quaternary rather than the Cretaceous. In the thinly populated and generally wooded condition of the country at that time exposures were less frequent and smaller than now, and in consequence the definition of "Orange Sand" was so extended as to include deposits both newer and older than those of the type county; e. g., the Columbia gravel bed at Natchez and at other points in Mississippi, and the Cretaceous sands and clays with lignitic intercalations at Pocahontas, Tennessee.[3] Subsequently he recognized corresponding deposits in Louisiana, extended to them the name Orange Sand, and referred them, like their Mississippi correlatives, to the Quaternary; and then and later he inferred the extension of the deposit not only throughout the lower Mississippi region, but throughout the coastal plain, even along the Atlantic border.

A few years later Dr. Safford revised and extended his survey of western Tennessee, and in his official report on the geology of the State expressed recognition of the fact that a portion of the beds included by

[1] Am. Geologist, 1891, vol. 8, p. 130.

[2] Geological reconnaissance of Tennessee, 1856, pp. 148, 162.

[3] Geology and Agriculture of Mississippi, 1860, p. 16.

him in the "Orange Sand group" belong to the Cretaceous; and he accordingly modified the primary definition, excluding the lower portion of the original group. At the same time he substituted the name "Lagrange group" for the newly defined series, and pointed out its distinctness as a whole from the "Orange Sand" of Dr. Hilgard.[1] As thus defined the "Lagrange group" of western Tennessee was diminished in vertical extent as compared with the original "Orange Sand group;" yet it included not only the distinctive deposit of Lafayette County, Mississippi, but also a portion of the subjacent deposits now commonly classed with the Lignitic. The entire group was referred to the Eocene on the basis of the characters displayed by the lower beds.

Meantime and later the same series of deposits was recognized in Alabama, and was described in detail in different official reports and other publications, notably by Dr. Eugene A. Smith, and Dr. Hilgard's name and his reference to the Quaternary were retained. For many years the designation was applied to the whole of a vaguely defined series of deposits which was subsequently divided by Dr. Smith and Mr. Lawrence C. Johnson, the lower beds being included in the Tuscaloosa formation, which was referred to the early Cretaceous, while Hilgard's name and age reference were restricted to the remaining upper portion.[2]

In 1886 the formation was discriminated in tide-water Virginia by Prof. Fontaine, Mr. Lester F. Ward, and the present writer. In 1888 it was defined and briefly described in print by the writer, and, in the absence of specific data concerning its southern extension, it was named, from the river of typical development in the middle Atlantic slope, the "Appomattox formation," the age then assigned being substantially that now recognized.[3] A year later the formation was traced southward through the Carolinas, Georgia, and Alabama, and into southeastern Mississippi, and it was soon after described at some length, the middle Atlantic slope name and the age reference being retained.[4] Still later the formation was traced throughout Mississippi and western Tennessee and Kentucky, as well as into Arkansas, and was completely identified with the deposits originally discriminated and described by Hilgard in Lafayette County, Mississippi; but in view of the uncertain definition of the series of deposits designated by the terms "Orange Sand" and "Lagrange," the name applied in the typical Atlantic slope locality was retained, the age reference also remaining unchanged.[5]

Meantime Safford restored the term "Orange Sand," but with modified definition; the name was now restricted to a superficial or subloam deposit of sand and gravel, apparently corresponding with the basal gravel bed of the Columbia, in western Tennessee, and probably corresponding in part also with the "Bluff gravel" of his 1869 report.[6]

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[1] Geology of Tennessee, 1869, pp. 150, 166, 424.

[2] Bull. U. S. Geol. Survey No. 43, 1887, pp. 95 et seq.

[3] Am. Jour. Sci., 3d ser., 1888, vol. 35, p. 328–330.

[4] Ibid., 1890, vol. 40, pp. 15–41.

[5] Bull. Geol. Soc. Am., 1890, vol. 2, pp. 2–6.

[6] Agricultural and geological map of Tennessee, issued by the Commissioner of Agriculture (J. M. Safford, State geologist), 1888.

Meantime also Dr. R. H. Loughridge recognized the formation in western Kentucky; and impressed by the pseudo unconformity between the superior massive member and the inferior stratified member, and impressed also by the similarity between the gravel beds of the formation and the Columbia gravel beds derived therefrom, he divided it, combining the Columbia gravels (Safford's Orange Sand) and the superior member of the Lafayette as the "stratified drift," which was assigned to the Quaternary, and setting apart the lower member as the "Lagrange" which was referred doubtfully to the early Tertiary.[1]

About the same time the formation was recognized in Arkansas by Mr. Robert T. Hill, and at least a distinctive phase of it was designated the "Plateau gravel," which was considered post-Miocene and ante-Pleistocene, and was correlated in a general way with Hilgard's "Orange Sand."[2]

During the same period the deposits were discriminated from the Pleistocene in southern Illinois, Kentucky, and elsewhere by President T. C. Chamberlin and Prof. R. D. Salisbury, and were classed and designated as "Tertiary gravel;[3] but, by implication at least, such newer gravel beds as the basal member of the Columbia at Natchez were thrown into the same category.[4]

Subsequently Mr. Nelson H. Darton discriminated the formation in tide-water Maryland, identifying it with certainty in the isolated remnants of a once continuous mantle stretching nearly or quite across this State, and with some doubt still farther northward. He retained for it the name "Appomattox," and referred it doubtfully to the Pliocene, recognizing its separation from the Columbia above and the Chesapeake below by noteworthy unconformities representing considerable erosion intervals.[5]

Still later, apparently corresponding deposits were recognized in Texas by Dr. R. A. F. Penrose; they were named the "Fayette beds," and were provisionally correlated with the Grand Gulf formation of Mississippi and Louisiana, and referred to the later Tertiary.[6]

About this time certain gravels of eastern Arkansas were described by Prof. R. Ellsworth Call, correlated with the "Orange Sand" of Hilgard, and referred to the Tertiary;[7] but whether the materials so referred represent the Lafayette, or the coarser member of the Columbia, or both combined, does not fully appear from the description.

With the view of unifying the diversity in nomenclature and harmonizing the discrepant definition of the formation, a conference was held

[1] Geol. Surv. of Ky. Rept. on the Jackson Purchase region, 1888, pp. 17 et seq.

[2] Ann. Rep. Geol. Surv. of Ark. for 1888, vol. 2, pp. 35 et seq.

[3] Am. Jour. Sci., 3d ser., 1891, vol. 40, pp. 359–377.

[4] Bull. Geol. Soc. Am., 1889, vol. 1, p. 470.

[5] Bull. Geol. Soc. Am., 1890, vol. 2, pp. 434, 445-447.

[6] First Ann. Rep. of the Geol. Surv. of Texas for 1889-'90, pp. 47, et seq. Since this paper was composed Mr. E. T. Dumble has announced a division of the Fayette beds, and designated the unconformable upper portion the Reynosa marl (communication before the Geological Society of America at Columbus, December 30, 1891). It is this upper member which represents the Lafayette formation in Texas.

[7] Ann. Rep. of the Geol. Surv. of Arkansas, for 1889, vol. 2, pp. 126 et seq.

in San Francisco in June, 1891, in which Dr. Hilgard, Dr. Joseph Le Conte, Dr. Loughridge and the writer participated in person, and Dr. Smith and Dr. Safford by correspondence. The outcome of the conference was the adoption of Hilgard's original name for the formation.[1] This was followed in September, 1891, by extended conference on the ground in and about the type locality of the formation in Mississippi and Tennessee, in which Dr. Hilgard, Dr. Safford, Dr. Smith, Prof. Joseph A. Holmes, Mr. Lester F. Ward, Mr. Robert T. Hill and the writer participated. The outcome of this conference was substantial agreement concerning the nomenclature, definition, age and genesis of the Layfayette formation.

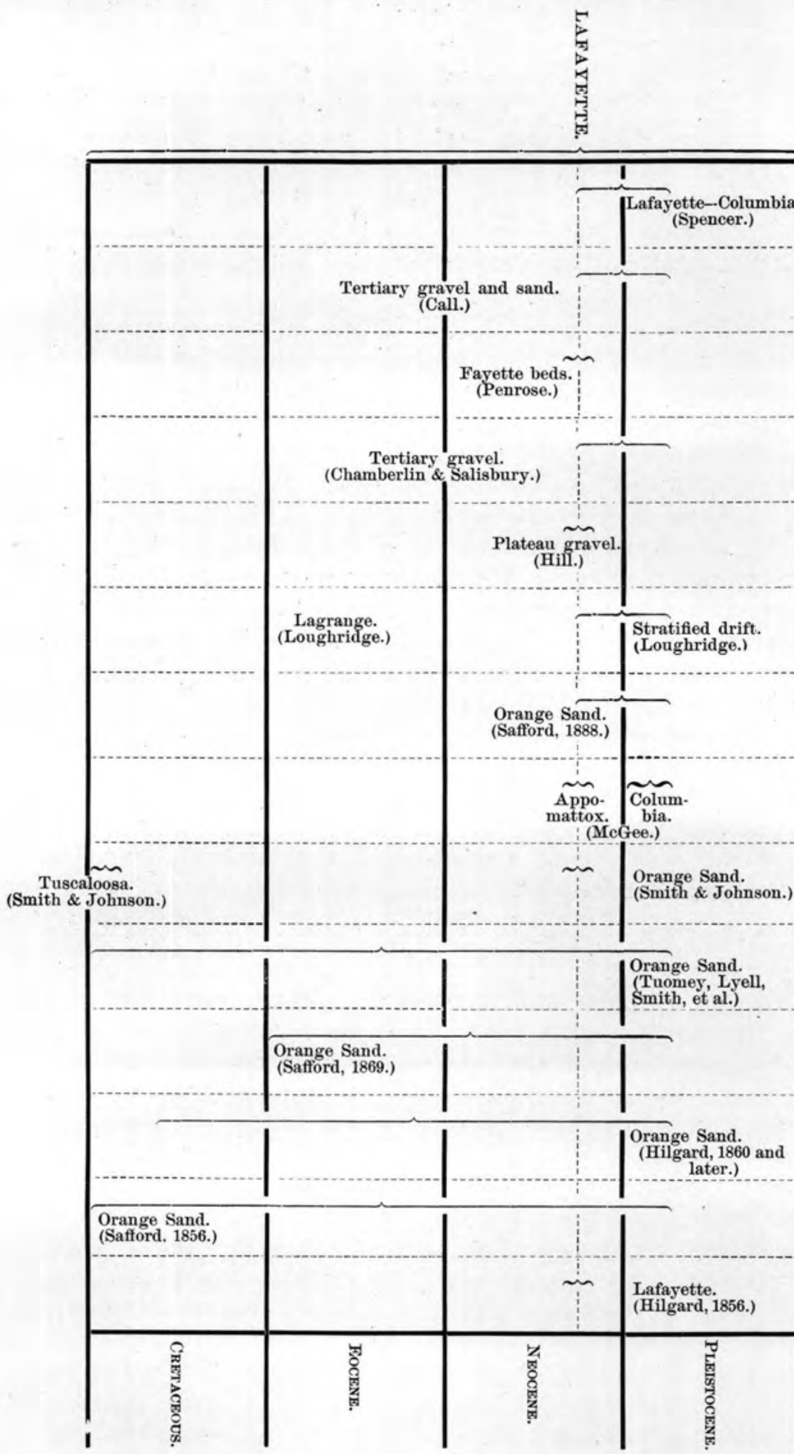
Still later, Dr. J. W. Spencer recognized both the Columbia and the Lafayette formations in Georgia, but combined them and referred both to the Pleistocene.[2]

Accordingly the synonomy may briefly be summarized as follows: Lafayette=Appomattox <Orange Sand (Hilgard) <Lagrange <Orange Sand (Safford.) Lafayette = Appomattox = (?) Fayette beds >Plateau gravel < Tertiary gravel.

Summarized graphically, the synonomy may be expressed as in the following table, in which the names cover the age references of the authors, and the braces the ages now assigned to the deposits comprehended under the names:

[1]Am. Geologist, 1891, vol. 8, pp. 129-131.

[2]Geol. Survey of Georgia, First. Rept. of Progress, 1891, pp. 61-62.



Geochronic synonymy of the Lafayette formation.

CHAPTER IV.

MATERIAL RESOURCES OF THE FORMATION.

STATE OF THE SURVEY.

In the progress of thorough geologic investigation, certain definite methods are employed and a certain definite succession of steps is commonly followed. In the survey of the coastal plain the method employed (which is set forth in detail on another page) involves scrutiny of each feature displayed by every rockmass with a degree of attention depending on its magnitude or importance from all points of view; while at the same time the relations of the features are sought with a view to ascertaining the genesis of each element in the rockmass and finally of the rockmass itself as a basis for classification; for it is held that the natural or genetic classification is the most widely applicable and the most useful.

The steps pursued in the investigation are, accordingly, first, reconnaissance and discrimination of characteristic features; second, correlation, including the elucidation of conditions of genesis as a means thereto; third, special study and detailed mapping of minor and local characters. The survey of the Lafayette formation has thus far reached only the second of these stages, and thus the material resources of the formation can be stated only in general terms.

SOILS.

Viewed from the agricultural standpoint, the components of the Lafayette formation are (1) loam, and (2) sand or gravel; or, analyzed more exactly, since loam is itself a compound material, (1) that finely divided and completely oxidized and lixiviated material which is called mud when abnormally wet and dust when abnormally dry, but for which in the normal state there is no name among either geologists or laymen; (2) sand, and (3) gravel. The finely divided rock matter intermixed with sand constitutes loam; sand with little or no finely divided matter forms sand beds; either loam or sand may form a matrix for pebbles which then forms a gravelly soil; but sometimes the matrix is so scant, that the gravels are clean and practically removed from the category of soils.

The superficial member, at least, of the Lafayette formation throughout the greater part of the coastal plain is a true loam, i. e., a uniform admixture of sand and finely divided rock matter. Now, the finer element is chemically degraded, or reduced toward a condition of chemical stability, by reason of long exposure to the action of air and water and the gases of which they are formed, as well as by the agency of acids liberated by living and decaying plants, etc. So it is in a less favorable condition for giving fertility than mechanically reduced yet chemically complex or unstable materials, such as the rock flour produced by glacial grinding. Yet, without following closely the extreme pendulum-swing of modern opinion that mechanical condition is as everything and chemical composition as nothing in determining soil fertility, it may be observed that the usual mechanical composition of the Lafayette loam is eminently favorable to plant production; it is friable, yielding readily to plant roots as well as to the agricultural processes; it is pervious, absorbing storm waters greedily, distributing them through capillarity, and holding them long for gradual consumption in times of drought; it is permeable, the air circulating freely through it and thus aiding in the innumerable minute laboratory operations of the plant roots, and at the same time maintaining, by one of the curious cumulative processes of nature, the flocculent and friable condition of the finer element of the soil. Thus the composition of the Lafayette is such as to give a soil of fair fertility and, by reason of its depth and the chemically stable condition of its finer element, of unusual durability.

The inference as to the character of the Lafayette soil drawn from composition is sustained by observation and experiment. From the Appomattox to the Sabine it was primevally clothed with luxuriant pine forests, and in the Carolinas and Georgia the pines pushed dozens or scores or even a hundred miles upon the attenuated margin of the Columbia sands, sending their long taproots down into the Lafayette loam below. After settlement the pine forests were replaced by plantations, which proved always fairly and sometimes highly productive, and in many localities the fields were found specially adapted to continued cultivation of the soil-exhausting tobacco, while in the southern Atlantic and eastern Gulf States the northward extension of upland cotton culture generally followed the spread of the orange-tinted loam, whose fertility the fields amply attest. In Mississippi, indeed, it is a question whether the cotton fares better on the Lafayette loam, albeit there exceptionally sandy and barren, or on the brown loam of the Columbia, albeit locally composed largely of ice-ground rock flour; and certainly it fares best of all on the soils formed by admixture of the two components in equal or subequal proportions.

Going with the excellence of the Lafayette soils there is an actually or potentially adverse condition worthy of grave consideration: That mechanical condition which gives friability, perviousness to water, and permeability to air tends to facilitate erosion when the primeval forest covering or the natural soil is removed; so that the fields formed of Lafayette loam are exceptionally liable to rain washing and storm gullying. This is especially the case when the upper massive member is thin and the relief is high, so that the storm waters gain access to the more friable sands below and invade the loam by sapping. The "old field" destruction in several Southern States, notably in Mississippi, is largely due to this condition of the Lafayette soil.

SILICEOUS CLAYS.

In western Kentucky and Tennessee and in northern Mississippi the medial portion of the Lafayette formation abounds in peculiar siliceous clays, commonly blue, gray, or lead colored, but quickly drying snow-white, which are largely used in the manufacture of low-grade pottery and are locally used in a smaller way in making finer ware. They are used also for fire brick, gas retorts and crucibles, and encaustic tiling; and varieties of the same material are largely used, particularly in Kentucky, for terra-cotta boards, etc.

The material is largely extracted in western Kentucky, as recently described by Loughridge;[1] it is abundant in quantity and excellent in quality, and is more or less extensively manufactured in the longitude of Milan, Jackson, Bolivar, Grand Junction, and Lagrange in Tennessee; it occurs in equal quantity and purity in northern Mississippi, particularly about Holly Springs, Oxford, Grenada, and Duck Hill, and is manufactured at the first-named town and elsewhere in this State; and it is known to extend southward to Fayette and other localities about the latitude of Natchez.

The material consists chiefly of finely comminuted silica, probably representing disintegrated Paleozoic cherts derived from central Tennessee and Kentucky. The composition is fairly indicated by the analyses of three samples from Hickman County and eight samples from Ballard County, Kentucky, made by Loughridge.[2] They are as follows:

Composition of "refractory clays" from Kentucky (Loughridge).

County.	Number.	Silica.	Alumina.	Ferric oxide.	Lime.	Magnesia.	Potash.	Soda.	Water, etc.	Total.
		Per cent.	*Per cent.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	
Hickman	2715	85.180	10.260	1.120	Trace	0.064	0.954	0.146	2.276	100.000
Do.........	2162	84.918	10.560	1.102	0.572	.108	.651	Undet.	2.089	100.000
Do.........	2161	76.360	14.951	2.109	.325	.173	1.171	.125	4.786	100.000
Ballard	2573	73.240	15.760	1.920	.325	.514	1.467	.147	6.622	100.000
Do.........	2568	74.840	16.580	1.400	.269	.209	1.293	.283	5.126	100.000
Do.........	2104	74.460	18.070	1.633	.314	.245	.940	.021	4.317	100.000
Do.........	2571	63.840	26.040	.740	Trace	.137	.714	.207	8.322	100.000
Do.........	2105	67.501	23.051	2.109	.257	.065	.412	·020	6.585	100.000
Do.........	4	71.940	20.700	Trace	.370	.350	.630	Undet.	6.200	100.190
Do.........	2570	76.540	14.820	.960	Trace	.331	.926	.229	6.194	100.000
Do.........	2569	71.180	20.800	1.780	Trace	.101	.247	.291	5.601	100.000
Mean	....	74.545	17.417	1.352	.221	.209	.855	.134	5.284	100.017

The variety and extent of manufacture of this material in Kentucky indicate that it will eventually form a resource of great importance,

[1] Geol. Surv. of Ky., report on Jackson Purchase Region, 1888, p. 84 et seq.
[2] Op. cit., pp. 102, 107.

not only in this State but in Tennessee and Mississippi. The deposit is the most extensive of the kind in this country and probably in the world; and the capabilities of the material in the arts are no doubt largely undeveloped.

GRAVEL.

About the inland margin of the formation, particularly along the larger rivers, a gravel composed largely of quartz and quartzite on the Atlantic slope, of chert, novaculite, etc., in the Mississippi embayment, and of a wider variety of obdurate materials in Texas, are characteristic; and since the localities of exceptional gravel development are usually selected as sites for towns and cities, the material acquires special value for road metal, railway ballast, etc. For such purposes it is incomparably superior to the ordinary macadam made by breaking or crushing quarry rocks; for the pebbles represent the most obdurate of rock materials, sorted out by a rigid and long continued process of natural selection from among the various terranes traversed by the streams, and neither dissolve into red mud like limestone nor grind into dust like granite, but commonly maintain their integrity under the beating of hoofs and the wear of tires for indefinite periods. The world affords no better material for such purposes than the gravel of the Lafayette formation.

IRON.

The Lafayette formation is nearly everywhere deeply ferruginated, and it frequently contains nodules, plates, sheets, and pipes of sand-ironstone, and in many localities it has yielded limonite of good quality. Commonly the ore is insufficient in quantity to give the formation rank with the great ferriferous deposits of Pennsylvania, Michigan, Wisconsin, Missouri, and Alabama, and in many cases indeed the quantity is sufficient only to delude the prospector and absorb capital; but the promise of the richer accumulations is such as to render this resource of the formation worthy of careful study.

In many localities the argillaceous layers of the lower and stratified member of the formation are ferruginated to such a degree as to form ochers. This is especially common about midway between the inland margin of the deposit and the coast, where the conditions of structure and texture of the formation are most favorable for such alteration. Red and yellow ochers are extracted at several points in western Kentucky and Tennessee. There are several known ocher banks in Mississippi. Red ochers have been extracted at Grand Bay and elsewhere in southeastern Mississippi and southern Alabama.

CHAPTER V.

THE HISTORY RECORDED IN THE FORMATION.

THE ANTECEDENT PHYSIOGRAPHY.

The Lafayette formation rests unconformably alike upon all the older coastal plain formations. Its distribution and local volume are such as to indicate that it was laid down mantlewise, thicker in depressions, thinner over water partings, thickest along the greatest water ways, thinnest over broad divides in which the shoal sea waters were not fed by local affluents. Yet the distribution of the remnants of the formation and the various local unconformities, viewed singly or collectively, indicate that the surface on which the formation rests was only moderately rugose and probably no more deeply broken by water ways than the monotonous coastal lowland of to-day. Detailed examination of the local unconformities and the distribution of the remnants indicates, however, that the quality of the relief was somewhat different from that of the present; the configuration of the modern coastal plain is largely terraciform, and the terrace plains are frequently so imperfectly invaded by erosion as to give accented contours and profiles made up of combinations of straight lines with V-shaped depressions, while the restored pre-Lafayette surface is not terraciform but soft contoured, giving profiles of easy curves. Now, the gently undulating surface of soft contours and easy curves is characteristic of long continued erosion at a low altitude, or of base-level planation; and it may accordingly be inferred that anterior to the Lafayette period the coastal plain was long a lowland much like that of the present. There are reasons, too, which need not be set forth here, for supposing that the seaward slope of the Lafayette lowland was less than that of the present coastal plain. Moreover, the abrupt scarps along the modern displacements extending from the Hudson to the Rappahannock, and from central Texas to the Rio Grande did not exist, at least in their present magnitude, for both displacements were initiated or renewed during a later period. Furthermore, since the diversion of the leading water courses of the middle Atlantic slope was also probably of later date, the present curiously peninsulated geographic configuration may not be supposed to have existed.

Thus, the pre-Lafayette configuration was so nearly like that of the present that the map of modern physiography, forming Pl. XXXII, may be taken fairly to represent it, save (1) that the Delaware and

Schuylkill, the Susquehanna, the Patapsco, and the Potomac embouched directly into the ocean; (2) that the scarps in the middle Atlantic slope and in western Texas were faint; (3) that the seaward slope of the coastal plain and contiguous land was gentler; and (4) that the minor coastal configuration of modern times did not exist.

It is to be borne in mind that the picture of a long past eon thus formed is neither chaotic nor obscure. With the minor exceptions noted, the Susquehanna, the Potomac, the Rappahannock, the James and the Appomattox, the Roanoke, each principal river of the Carolinas, the Savannah, the Ogeechee and the Oconee, the Chattahoochee, the Coosa and the Tallapoosa, the Tuscaloosa, the Mississippi, the White, the Arkansas, the Red, the Trinity, the Brazos and the Colorado rivers are known to have occupied their present positions, to have had about their present declivities, to have carried about their present volumes of water, and in other ways to have conformed to their present condition; and while precisely the same can not be said of the Hudson, the Delaware, the Tennessee, the Cumberland, and especially the Rio Grande, it is known that these rivers have been modified in certain ways, and thus their discrepant behavior only adds to the definiteness of the picture of past configuration conveyed by the Lafayette phenomena. So, in pre-Lafayette times most of the streams flowed in their present channels, drained their present basins, and fell into the sea not far from the present shore line, and the land was configured in detail much as at present.

THE LAFAYETTE DEPOSITION.

The record of Lafayette deposition is one of oceanic invasion, not of catastrophic swiftness, yet of such rapidity that the waves rolled over the sinking hills without carving shorelines, without even building broad beaches such as the modern keys of the southern coast; and the inundation was not stayed until it reached inland, drowning the southeastern margins of the continent in a zone 100 to 500 miles wide. Before the inundation the land lay about base-level and the rivers were idle, neither transporting pebbles nor carving canyons, nor filling their channels with sediment; with the inundation the land warped as it sank and tilted seaward to such a degree that while the lower reaches of the rivers were cut off their upper reaches were stimulated to renewed activity. So the storm waters gathered the red residuary soil with which the surface was mantled, the rainborn rivulets washed into the brooks and carried forward the well ground grist, and at the same time attacked their beds and gathered bowlders, cobbles, and pebbles; and the entire burden was swept into the rivers to be borne down stream in ever-increasing volume and finally cast into the sea, where the waves and currents spread it here and there along the new-made coast, mixing it with the materials gathered from the new-made sea bottom. In this way only could have been accumulated the widespread Lafayette mantle, composed chiefly of the residua of slow rock decomposition and subordinately of material from local formations, together with great gravel beds about the waterways.

The extent of the oceanic invasion is shown approximately in Pl. XXXIX, from which it appears that the Atlantic and the Gulf were united (though it is not absolutely certain that southern Florida was submerged), and that the water flowed over the sites of New York and Philadelphia, Washington and Richmond, Charleston and Augusta, New Orleans and Memphis, Cairo if not St. Louis, Little Rock, Austin, and San Antonio. Along the Gulf slope the extent of the invasion is fairly well known; about the Mississippi embayment the data are less definite; in the southwest the records are still more incomplete, and there are indications that here the seaward tilting of the land was less decided than in the East, so that the rivers became engines of deposition rather than degradation far toward their sources, converting channels into estuaries and basins into lakes, and filling these with materials brought down from the higher mountains; yet in all parts of the area the data are sufficiently complete to justify this presentation of Lafayette physiography.

The duration of the inundation may not be stated in definite terms, although it is known that, expressed in geologic time units, it was short; for, although the agencies of degradation and deposition were stimulated by the continent movement, the mantle of Lafayette deposits is of limited thickness. A rude, even crude, estimate of the duration of Lafayette deposition may easily be made. Let it be assumed that the drainage basin of the Mississippi during the invasion was a million square miles; let it be also assumed that the stimulated degradation proceeded at twice the commonly assigned rate of a foot in 6,000 years; let it be assumed likewise that the material gathered by the river was deposited in an embayment 100,000 square miles in area (the part carried farther being balanced against the material gathered by the waves below tide level); and let it be assumed finally that the original thickness of the deposit was 200 feet; then the area of degradation being ten times that of deposition the sediments may be estimated to have dropped at the rate of a foot in 300 years, and so the dropping may be estimated to have continued for 60,000 years. The data for the estimate are, of course, far from adequate, because of evidence in the character of deposits that the Mississippi embayment was supplied chiefly from the greatly stimulated Appalachian drainage on the east rather than from the greater but relatively indolent northern river, because the postulate of uniformity in the efficiency of geologic processes is not established, and for a variety of other reasons; yet even if it be accepted with a "factor of safety" of 50 or 100 or 500 it may be useful.

The increase in stream declivity attending the inundation may not be measured with any approach to accuracy, though it may roughly be estimated. It has been stated that during pre-Lafayette times the coastal lowland was reduced to a base-level plain; it may be added that this base-level plain was not confined to the lowlands, but extended over the Piedmont plateau, throughout the intermontane valleys of the Appalachians, and probably joined a coincident but more rugose base-level peneplain in the Cumberland plateau. Now, actual continuity of the base-level planation throughout the several physiographic provinces of eastern United States may be inferred from the qualitative similarity and quantitative equivalence in the configuration (which was produced by well known processes of degradation); it is indicated, also, and perhaps more strongly, by the tenuity and fineness of materials among the coastal plain deposits corresponding to this period of sluggish process; and it is indicated as well by the correspondence (set forth in some detail later) in lowland, plateaus, and mountains alike, of the distinctive degradation and peculiar deposition inaugurated by the Lafayette continent movement. From the concurrent records it is found that since the seaward tilting was initiated, the Appalachian, Piedmont, and Cumberland rivers have carved narrow gorges 100 to 400 feet deep in the old base-level plain, and are still actively deepening their channels, for they are yet some hundreds of feet above the level of inaction. Now, some part of this lifting no doubt postdates the Lafayette tilting; yet on comparing the coarseness of materials transported by the rivers during the Lafayette period and to-day, it seems probable that the greater part of this continent warping must be referred to the time of the inundation. If this inference be just, then the Cumberland, Appalachian, and Piedmont regions must have risen, relatively to the surrounding lowlands, somewhere between 100 and 2,000 feet, a fair estimate for the average uplifting of the entire tract being 800 feet. In quality the uplift was probably a gentle warping without localized deformation, so that the amount diminished from a maximum somewhere about the axis of the Appalachian zone to nothing toward the Atlantic on the east, the Gulf on the south, and the embayment on the southwest. If the general sinking and the warping of the continent were synchronous, as seems probable, then the absolute lifting of the Appalachian zone was much less than the relative rise; so that if the average sinking of this part of the continent was 400 feet, then the average lifting of the mountains as the ocean approached their bases was probably about the same, and the mean continental altitude was about the same as before; yet when the inundation ended and the continent rose once more, the Appalachian Mountains were far more conspicuous elements in the geography of the continent than during the earlier Neocene, the Eocene, and probably the Cretaceous.

Noteworthy as was the seaward tilting attending Lafayette deposition, it was apparently confined chiefly or exclusively to the eastern lands centering in the Appalachians. Although the formation is gravelly along the northwestern affluents of the Gulf, the pebbles are so disposed as to indicate littoral distribution of materials rather than the pronounced stimulation of streams attested by the great Mississippi and cis-Mississippi gravel beds; and, moreover, the embayment deposits tell rather of accelerated work on the part of the rivers entering it from the east than of generally increased activity among the longer and stronger tributaries from the north and northwest. Certain phenomena, indeed, suggest that the Lafayette low level reached far northwestward, and that the Lafayette deposits are represented by the Llano gravels of Hill, the mortar beds of Hay, and possibly the puzzling Wyoming conglomerate of King, though here caution-burdened conclusion hardly follows the flight of winged hypothesis.

Many phenomena indicate that when the Lafayette inundation ended, the waters of Gulf and ocean retreated rapidly as they had advanced; for the surface of the formation reveals no sea cliffs, no well defined shore lines, no wave built beaches, but only a few relatively narrow terraces apparently of estuarine or semifluvial character along several of the southeastern water ways.

THE LAFAYETTE DEGRADATION.

Before the Lafayette invasion on the part of the Atlantic and the gulf, the five physiographic provinces of the eastern United States were reduced to a gently undulating base-level plain, strongly relieved only by the Appalachian Mountains; during the invasion a third of the land was drowned and the remaining portion was tilted seaward from an axis coinciding with the Appalachian zone. Then follow abundant and unmistakable records that as the waters retreated the seaward tilting persisted, while the land rose not only to, but much above, its pre-Lafayette altitude; and through the period during which land stood high the five physiographic provinces, and the submarine extension of the continent as well, were deeply and distinctively sculptured by the lengthened and greatly strengthened streams. Over the higher provinces this sculpture persists to-day; over the portion of the coastal plain buried beneath Columbia deposits the deep and broad incisions have been filled and obliterated as land forms, though the old surface may readily be projected from stratigraphic relations; and over the submerged part of the coastal plain the sculpture is not only buried but drowned, yet may be projected in general terms within certain limits.

The eastern portion of the Mississippi basin is a gently undulating plain, diversified chiefly by distinctly scored drainage ways; the Cumberland and Piedmont plateaus are peneplains diversified most prominently by deeply incised drainage ways; the Appalachian zone is a montanic tract characterized by distinctly positive and distinctly negative forms, the first being ridges embossed upon and the second narrow gorges engraved within a peneplain; and the provinces together constitute a modern peneplain rising highest about where relieved by the Appalachian ridges, and everywhere scored to depths averaging some hundred feet by narrow gorges. The general peneplain stands for a base-level epoch; the gorges for a high-level epoch. Now the fine and slowly accumulated early Neocene, Eocene, and later Cretaceous deposits of the coastal plain indicate that during the periods of their deposition the land lay low and the rivers were sluggish, and there are no interbedded coarse deposits to indicate that this equable condition was interrupted by decided continent movements from the beginning of deposition of the Severn to the beginning of deposition of the Lafayette. So, too, the configuration interpreted by means of geomorphology indicates that the land stood low and the rivers were sluggish throughout a vast period of base-level planation terminating with the initiation of Lafayette deposition. These independent records coincide so exactly as to warrant correlation of the fine deposits on the one hand with the base-level planation on the other, and this correlation gives a datum plane from which the post-Lafayette degradation may be measured.

The degradation of the post-base-level period thus defined in the Piedmont and Appalachian zone is represented along the Susquehanna by a steep-sided gorge 2 miles and less in width, 100 to 350 feet in depth; along the Potomac by a similar incision in the old peneplain reaching a mile in width and 100 to 400 feet in depth, and along all other waterways of the provinces by corresponding gorges of dimensions closely proportionate to the magnitude of the streams. The post-base-level (and also post-Lafayette) degradation in the coastal plain is represented by the profound yet broad gorges which, albeit half filled or even brim full of Columbia deposits, form the remarkable estuaries, savannas, and fluvial marshlands by which the coasts are indented. Among these post-Lafayette gorges are Delaware and Chesapeake bays, the Potomac estuary, Albemarle and Pamlico sounds, the half-drowned savannas from which the principal river of the southern Atlantic slope takes it name, Mobile Bay and the tide marshes through which Mobile River meanders, and, by far the most conspicuous of all, the gorge of the lower Mississippi, extending from Cairo to the Gulf and from Memphis and Baton Rouge to Little Rock and Natchitoches; and each smaller waterway has a corresponding gorge of depth and width proportionate to the volume of the stream occupying it. Now these partially filled gorges are excavated not only in the Lafayette formation, but entirely through that comparatively thin mantle and far into the underlying rock masses of Neocene, Eocene, even Cretaceous age. Along the Delaware and Chesapeake gorges the Lafayette mantle is entirely degraded, save in isolated remnants representing but a tithe of its original area, and the pre-Columbia gorges are carved into all of the older coastal plain formations to widths reaching a dozen or a score of miles and to depths unquestionably reaching several hundred feet. The pre-Columbia Savannah River flowed in a gorge 3 to 15 miles wide and hundreds of feet deep, cutting through every pre-Lafayette formation of that part of the coastal plain; the Alabama and Mobile, with the confluent Tombigbee, carved soft-contoured canyons reaching 20 miles in width and 400 feet in depth, cutting entirely through the Lafayette and far into if not through the subjacent Neocene formations, during the post-Lafayette degradation period; and during the same period the Mississippi first degraded the entire thickness (albeit exceptional) of the Lafayette formation from its present base-level tract, 500 miles long and 100 miles wide, save in the few isolated remnants represented by Crowley Ridge, then attacked and completely cleft the deltaform rock mass of the Grand Gulf, and next cut far into if not entirely through the subjacent Eocene formations, to depths below its present level, reaching 200 feet at Memphis, 400 feet at Helena, 600 feet at Greenville, and 800 or 900 feet at New Orleans (as long ago pointed out by Hilgard). Beyond the Mississippi the indications of post-Lafayette erosion are equally decisive, though different in quality. These profound gorges prove beyond peradventure that during the post-Lafayette period of degradation the land along the line of the present coast stood from at least 200 to fully 700 feet above the present level. So the configuration of the continent during this high-level period must have been something like that represented in the map forming Pl. XL.

In addition to the unmistakable evidence of high-level altitude in southeastern United States afforded by the buried and flooded gorges of the coastal plain, there is strong presumptive evidence that it was at the beginning of the post-Lafayette lifting that the fall-line displacement of the middle Atlantic slope and probably that of southeastern Texas were initiated; and also that it was at this juncture that the main waterways of the middle Atlantic slope were diverted in such manner as to peninsulate the northern districts of the coastal plain. There is strong presumptive evidence also that the warping of the eastern land, by which the Appalachian axis was lifted more than the seaward margin, persisted during the high-level period and indeed persists to-day; and there are similar indications that during the same high-level period the trans-Mississippi land was not only lifted less than the cis-Mississippi area, but was tilted seaward in such manner that the rivers worked more energetically and more widely in their upper reaches than toward their mouths, and thus degraded the Lafayette deposits toward their inland margin rather than toward the Gulf. These lines of evidence need not now be pursued.

It is significant that while the magnitude of post-Lafayette gorges is proportionate to the volumes of the streams by which they were excavated and are still occupied, the depth is variable. Now, in the dearth of borings the depths are seldom known with precision; but in general they may be inferred from scattered borings, from the width of the gorges and the slopes of their walls, from the degree of local degradation of the Lafayette deposits, and from other indirect data, with some approach to accuracy. Measured thus it is found that the sinking was unequal. In the northern district of the coastal plain, including the Maryland and New Jersey peninsulas, it reached fully 500 feet, and the

Lafayette mantle was reduced to trifling remnants; it diminished southward to the Cape Hatteras axis, where the lifting was probably only 200 or 300 feet, so that the gorges are narrow and shallow and the Lafayette mantle nearly intact; still farther southward it again increased to several hundred feet, culminating at nearly 1,000 feet about the mouth of the Mississippi; and in the southwest it again diminished to such an extent that the pre-Columbia gorges are inconspicuous and the Lafayette mantle nearly continuous beneath the later deposit along the line of the coast. So, in addition to the general bulging beneath the Appalachian zone, the land warped as it lifted and in irregular fashion; and there is a curious correspondence between the irregular warping of the continent during the post-Lafayette high-level period and that characterizing the Lafayette low-level period—in general where the land sank lowest during the period of deposition, there it rose highest during the period of degradation. This correspondence extends also to the later continent movements recorded in the Columbia formation and its less conspicuous degradation.

THE BURIAL OF THE LAFAYETTE.

South of the Raritan and of the Delaware at Trenton, and of some line in the Mississippi embayment not yet accurately traced, the youngest formation of the coastal plain is the Columbia. In general it is a continuous mantle, rising and stretching inland from tide to heights ranging from 100 to 600 or 700 feet and to distances running from a score to many hundred miles. Throughout the greater portion of this area it is an open-water deposit, and its presence gives a minimum measure of continent submergence; throughout a lesser portion of its extent it is an estuarine or semifluvial deposit, and its presence gives a ruder measure of submergence and of continent tilting along lines orthogonal to the coast; and in still smaller part it is a littoral deposit, and gives a maximum measure of submergence and of continent warping along the coast line. Unlike the Lafayette, this formation has been but slightly degraded, probably 90 per cent of its volume yet remaining where originally laid. Accordingly the extent of the Columbia invasion of oceanic waters, both vertical and horizontal, may be ascertained with a high degree of accuracy; and thus it is known that the geography of the period was about that represented graphically in Pl. XLI.

Apropos to the evidence of submergence afforded by the Columbia period, there is an equally decisive line of evidence of a post-Columbia high-level period during which the land was lifted to such height above its present altitude that the Hudson, the Delaware, the Susquehanna, and the Potomac, and probably other Atlantic slope rivers, as well as the Mississippi and probably other affluents of the Gulf, corraded channels at depths reaching some scores of feet below present tide along the coast and some hundreds of feet off shore. During this high-level period a part of the Columbia filling of the great post-Lafayette gorges was removed. This high-level was quickly followed by sinking of the land which has perhaps, even probably, continued without serious interruption to the present days of slow oceanic invasion and reef building along the Atlantic and Gulf coasts.[1]

THE RELATIONS OF THE CONTINENT MOVEMENTS.

On comparing quantitatively the two inundations and their attendant desiccations, it appears that the earlier was in all respects the more important. In the first place, the earlier invasion of the waters rose higher by 150 or 200 feet on the average, and extended proportionately farther inland; in the second place, the earlier inundation was the longer, since a much greater volume of deposits was accumulated; again, the land stood higher during the post-Lafayette high-level than during that following the Columbia deposition, and the earlier gorges are the deeper; and finally, the earlier period of high-level was by far the longer, since the degradation of the Lafayette is many times as great as that of the Columbia.

On comparing quantitatively the irregular continent movements of the two periods, certain significant resemblances and certain significant differences appear. Thus, during the Columbia submergence as during that of the Lafayette period, the land warped as it sank and in similar fashion; the sinking was considerable over the northeastern portion of the coastal plain; it diminished southward to the Hatteras axis and again culminated along a line connecting Savannah River with the great bend of the Tennessee at the northeastern corner of Mississippi and probably continuing westward; it then diminished southward nearly to tide level along the central Gulf coast on both sides of the Mississippi; and in the southwestern stretch of the coastal plain it gradually increased both inland and toward the lower Rio Grande. So, too, during the post-Columbia high-level epoch the lifting reached several hundred feet in the northeastern district of the coastal plain, as attested by the drowned channels of the Hudson, the Delaware, the Susquehanna, and the Potomac, and by the general stream invasion of the Columbia terraces; over the Hatteras axis it was materially less, as indicated by the low relief and the integrity of the broad terrace plains of Columbia deposits which are little invaded by modern erosion; still farther southward the lifting again increased to such an extent that the "second bottom" deposits of the Georgia, Alabama, and eastern Mississippi rivers are trenched to their foundations and to half of their width, and that much of the Columbia mantle of northern Mississippi and western Tennessee was swept away by the accelerated action of the streams; while toward the coast the records of post-Columbia high-level generally diminish in magnitude of measure despite the conspicuous testi-

[1] Recent observations, chiefly by Chamberlin and Salisbury, suggest that the later Pleistocene oscillations extended well toward the Gulf in the Mississippi embayment.

mony of the submerged prolongation of the Mississippi. Thus, in general terms, the land warping was alike in the two inundations; also the land warping was alike in the two desiccations; and most remarkable of all the warping of each downthrow and its attendant uplift were roughly reciprocal, the local departures from the mean continent attitude, both upward and downward, approximating equality.

Of the two most noteworthy differences between the Columbia movements and the Lafayette movements, one is especially significant in that its effect on continent configuration is apparently magnified in a fortuitous way: During the Columbia inundation the interior portion of the coastal plain in the eastern Gulf slope was not submerged, and indeed the expanded ocean barely flooded the coastal portion; yet, as attested by the "second bottom" deposits, this tract must have been tilted landward to such an extent that the rivers were converted into long estuaries with ill drained lowlands between, something like the district of the present coastal plain lying between the Potomac and the Neuse, save that the estuaries were longer. Accordingly, the land lay so flat that had the submergence been a few score feet more the waves would have rolled inland as many scores of miles, and might easily have washed the Piedmont margin and the southwestern extremities of the western plateau and the mountains. Now, during the Lafayette inundation the waters were everywhere deeper than that of the Columbia, the average difference being 100 or 200 feet; and so if the land warping during the earlier period corresponded exactly to that of the later, it might nevertheless carry the entire "second bottom" region below the oceanic waters. Accordingly, the diversity in configuration shown in the maps of the physiography during the Columbia and Lafayette periods is not indicative of inequality in warping during the two inundations. Moreover, there is some evidence in the character of the deposits over the "second bottom" territory that the land tilted northward during the Lafayette period just as it did during the Columbia flooding; for here the coarseness and heterogeneity of materials extend farther seaward than elsewhere in the coastal plain, indicating a broader stretch of ocean water, a wider tract of slight and uniform submergence.

A second difference is especially noteworthy in that it serves to connect the coastal plain with other provinces. In the cis-Mississippi lands there are records of long-continued base-level planation followed by a seaward tilting probably coeval with the initiation of Lafayette deposition but persisting to the present, and of two similar and subequal inundations followed by similar and subequal desiccations; while in the trans-Mississippi land the records are less closely concordant. Thus the phenomena seem to indicate Gulfward tilting after rather than before the Lafayette inundation; and here, too, the Columbia inundation fell unusually far short of that of the Lafayette. Again, the records show that there was a landward tilting in the southwestern district, culminating during the Columbia low-level period just as it did in the "second bottom" district of the eastern Gulf slope, and that this continent movement was subsequently reversed so as to stimulate the rivers until they were able to trench their "second bottoms," yet not to clear the post-Lafayette gorges nor even deeply to indent the coast line when the waters began to return upon the land in modern times. Probably connected with this aberrant movement in the southwestern district of the province is the aberrant physiography of the western Gulf coast. In general the shore line of the Gulf is a sweeping curve, interrupted by deltaform projections at the mouths of some rivers, by reentrants at the mouths of others; and in general terms it may be said that the prominence of the projections is proportionate to the magnitude of the rivers, and that the depth of the reentrants is proportionate to the propinquity to the mouth of the great river of the continent. Yet the projection at the mouth of the Rio Grande, the second in magnitude of the Gulf affluents, is shorter than that of the Appalachicola, and little, if any, greater than that about the mouths of the relatively small Brazos and Colorado rivers. Now, a hypothetical explanation of the aberrant behavior of the land during the Columbia period and at the same time of the inactivity of the Rio Grande in delta building may be suggested: The Columbia inundation was coeval with the first great ice invasion of the Pleistocene, as repeatedly pointed out, and as recently demonstrated by Salisbury from the phenomena of northern New Jersey; and during this episode the climate of considerable portions of the United States was materially modified. There is little indication that the climatal modification extended even so far southward as the latitude of Cape Hatteras in the cis-Mississippi land, and little evidence that the ice-born floods materially affected the general climate of the Lower Mississippi region—the increased water surface probably counterbalanced the chill of the ice floes, which seem to have carried material nearly or quite to the thirty-first parallel; but in the subhumid and arid regions of the southwest the climatal change seems to have been greater. The increased precipitation resulting from the expanded water surface is notably impressed upon the configuration of the inner zone of the coastal plain as already indicated (page 406), and still further inland there are coincident records. Thus, the drainage area of the upper Rio Grande, above the confluence of the Pecos, is a series of basins lined with lacustral or torrential deposits simulating those of the Bonneville and Lahontan basins and other landlocked lowlands of the Great Basin; in the northern portion of the drainage area the lacustral deposits have been called the Santa Fé marls by Stevenson and referred to the Pliocene on paleontologic grounds, just as have been the Bonneville and Lahontan and other analogous deposits on similar grounds. Farther southward the deposits have been examined and correlated with those of Santa Fé by Hill; and about El Paso, where the Rio Grande enters the purlieu of the coastal plain province, the deposits are found to be of Pleistocene aspect, and their erosion forms have been found to correspond, cæteris paribus, with those produced by post-Columbia work in other localities. Now, just above the mouth of the Pecos the Rio Grande traverses a narrow and evidently new gorge, manifestly excavated after the basin deposits were laid down ; and it may be inferred that the overflow began about the culmination of the early Pleistocene humid period, during which the various landlocked basins of the arid region were filled, some to overflowing; and it may further be inferred that the weighting of the western land beneath snow sheets and glaciers in the higher altitudes and beneath immense lakes in the lower, destroyed the equilibrium so delicately adjusted in the eastern land and led to the inland tilting of the Columbia period. This far-reaching correlation is consistent with a wide range of phenomena, and, indeed, derives its chief strength from that fact, yet it does not aid in explaining the aberrant continent movements of the Lafayette time.

On comparing chronologically the two records of continent movement found respectively in the Lafayette phenomena and Columbia phenomena, certain fairly definite results useful in interpreting the history of the continent are reached. In the first place, the unconformable superposition of the Columbia upon the Lafayette indicates that the superior and little degraded formation is much newer than the inferior and deeply degraded one. Then, comparing quantitatively the respective amounts of the degradation accomplished during the two high-level periods, a rough quantitative idea may be formed of the relative antiquity of the periods. Let it be understood that the post-Columbia erosion is measured in the soft deposits by the modern estuaries and submerged channels, such as those of the Hudson, Delaware, Susquehanna, and Potomac, and in the hard rocks by such gorges as that of the Susquehanna below Peach Bottom, and that of the Potomac below Great Falls (the latter and more definite being 15 miles long, half a mile in average width, and 40 to 145 feet in depth); and let it be realized that the post-Lafayette erosion is measured in the soft deposits by the immense ancient gorges of the Atlantic rivers, reaching dozens or scores of miles wide and hundreds of feet deep, and by the far grander gorge of the Mississippi, reaching 100,000 miles in area and 1,000 feet in depth, and in the hard rocks by the steep-sided gorges in which every principal Cumberland, Appalachian, and Piedmont stream flows, in length averaging hundreds of miles, in width averaging half a mile, and in depths averaging 200 or 250 feet; and it will become evident that the erosion of the earlier high-level may not be estimated at less than five hundred times, and that it may exceed five thousand times that of the later period of similar continental attitude.

The interpretation of the erosion records may then be carried a stage further: On examining the quality of the configuration impressed upon the land by the post-Lafayette degradation (and again by the post-Columbia degradation), it appears that the chief land forms are flat peneplains partially invaded and divided by narrow, deep, steep-sided gorges, i. e., the configuration indicates that the base-level peneplain of pre-Lafayette times, stretching through the Cumberland, Appalachian, and Piedmont regions, has been modified only as to water-lines and not as to interiors by the post-Lafayette erosion. Now, the chief factors in the general processes of hydrodynamic degradation are declivity and time; and these factors are so related to the subordinate factors residing in rock constitution, etc., that the rate of degradation may be inferred from the quality of the land forms produced thereby. Thus, if the declivity be high for a short period degradation will be concentrated along the water lines, and deep channels and canyons will be excavated, and high and steep hills will be left between; while, if the declivity be low and the period long, the degradation of a like amount of material will result in broad shallow valleys, bounded by low hills of gentle slope; and, similarly, other modifications in these and other factors of degradation leave definite records of their relative and absolute efficiency, which may be readily interpreted through the aid of geomorphology. Now, the record of the post-Lafayette degradation of the pre-Lafayette peneplain is one of high altitude for a relatively brief period; and the post-Columbia record, though shorter and less clearly legible, is of like tenor. It is a corollary from this conclusion that the relative erosion measure of the two high-level periods, namely, 500:1, or 5000:1, is deceptive, since the land was far higher, the declivity far greater, and the degradation consequently far more rapid during the earlier degradation period. Yet, despite this correction, the earlier degradation period must have been by far the longer.

The relative duration of the periods of deposition and degradation, respectively, has not been ascertained in chronometric terms either of history or geology; though the records indicate in a general way that each degradation period was far longer than the preceding deposition period. This is tangibly true of the Lafayette in particular; for half the material of the formation was degraded from large areas in which the streams represent local precipitation, while the same materials represent the products of degradation from a many times larger area. The measure is, however, so indefinite that it may only be said that the deposition periods were relatively short, the degradation periods relatively long.

Before the initiation of Lafayette deposition there was a long period of continental quiescence, followed by strong and relatively rapid oscillation below and above the mean position; and there was a similar oscillation attending the Columbia deposition and degradation. Now, it

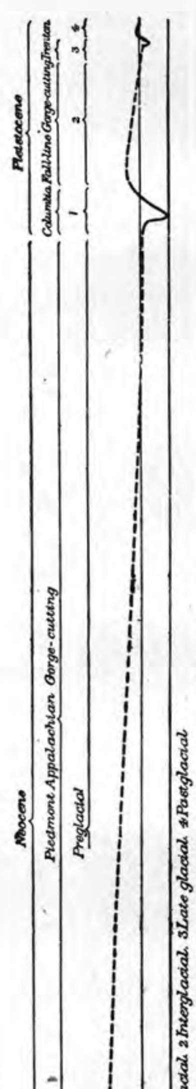


FIG. 71.—Graphic epitome of Lafayette history.

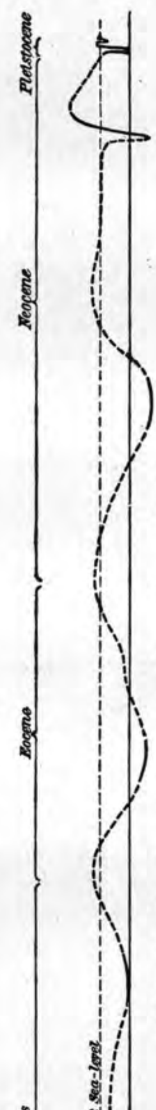


FIG. 72.—Graphic epitome of later geologic history of the coastal plain.

is desirable to ascertain the relative duration of the periods of oscillation and the intervals of quiescence; but the records upon this point are unfortunately incomplete or incompletely interpreted—the degradation record of the post-Lafayette and pre-Columbia interval is vague or equivocal in that the essential factors of declivity and time can not be severally evaluated. There remains, however, the useful though thus far only qualitative measure found in lithifaction, decomposition, ferrugination, etc. Estimated by means of this measure it may be said, first, that the early Pleistocene Columbia deposits are many times older than the later Pleistocene deposits associated with the terminal moraine; and second, that the Lafayette deposits are many times older than those of the Columbia. In the case of the Columbia this estimate is corroborated by collateral data; for the physiography and hydrography of the unsubmerged portions of the coastal plain in the middle Atlantic slope indicate that the post-Columbia high-level ended so long ago that great submarine banks have been built across the post-Columbia submarine channels. This is particularly true of the Delaware channel; not only has the great bank of Cape May stretched half way across Delaware bay since the land subsided, but its much greater submarine extension has pushed nearly or quite across the entire width of the bay and fairly cut off the submarine channel. These phenomena give an expression of the relation between the oscillation periods and intervals of quiescence, which may be extended by analogy to the Lafayette period.

Summarizing the various quantitative and qualitative records concerning the relative antiquity and magnitude of the oscillations, concerning the absolute and relative departures of the continent from mean position, and concerning the chronologic relations of the episodes comprised in and the intervals falling between the periods of special activity in continent movement, a conception is formed which may best be represented graphically as in Fig. 71, in which the horizontal element represents time and the vertical element attitude with respect to present sea level. The time units, be it observed, are not at all reducible to the units of historical chronology, and only uncertainly reducible to the far greater units of geochrony. The relation of the arbitrary time units of this diagram are roughly reduced to geochronic units; or, in other words, the time relations of the Columbia and Lafayette periods to the Cenozoic and later Mesozoic eons are expressed in the diagram forming Fig. 72. In this diagram, too, the horizontal element of the curve represents time and the vertical horizontal element continent movement, and the time units are so far reduced as greatly to condense the curve.

THE NORTH AMERICAN CONTINENT DURING CAMBRIAN TIME.

BY CHARLES D. WALCOTT.

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By Charles D. Walcott.

INTRODUCTORY OBSERVATIONS.

It is exceedingly difficult to restore the topography of the continent at any comparatively recent geologic period. It is doubly so for the far distant Cambrian time. The unknown so far exceeds the known that the presentation is necessarily more or less incomplete, suggestive rather than decisive, and the imagination must be called in to aid in drawing a picture of the Cambrian land, if such is desired. There were rivers, lakes, and seas, much like those at present, and there must have been plains, hills, mountains, and valleys, but we do not find traces of land life, either animal nor vegetable, although there may have been bogs and morasses filled with mosses. For the geologist, however, there are data outlining, in a broad way, the form of the continent at the beginning, during, and at the close of the period under consideration.

The beginning of the period is one of the most marked geologic epochs in the history of the evolution of the continent. At the close of the period the central portions of the pre-Cambrian continent were covered by the ocean, as were more or less of the ridges on the east and west that formed the outlying barrier lands between the great oceans and the inland seas during the earlier epoch.

The data for the construction of the maps are obtained by assembling the evidence afforded by the traces that have been preserved of the physical phenomena and the animal life of the period. We have to consider, (*a*) the absence or presence of rocks of Cambrian age in contact with the earlier subjacent rocks; (*b*) the physical character of the Cambrian sediments and their probable source; (*c*) the question whether the sediments were littoral or pelagic deposits; (*d*) the presence of similar forms of organic remains at the same relative stratigraphic horizon; (*e*) the similarity of the order of succession of the subfaunas of the Cambrian fauna where they are present.

Before proceeding to describe the sections of strata as they now occur, I wish first to call attention to what actually takes place at the present day when the sea is transgressing upon the land, wearing it away and depositing the sediments derived from the immediate shore and that received from the tributary rivers and streams.

It is well known that the coarse sediment will be found near the shore and that a gradation from the coarser to the finer will take place as we proceed outward from the shore line to deeper water, and a limit will finally be reached beyond which the mechanical sediments will not pass except in the form of the finest silt or mud that can be carried by oceanic currents.

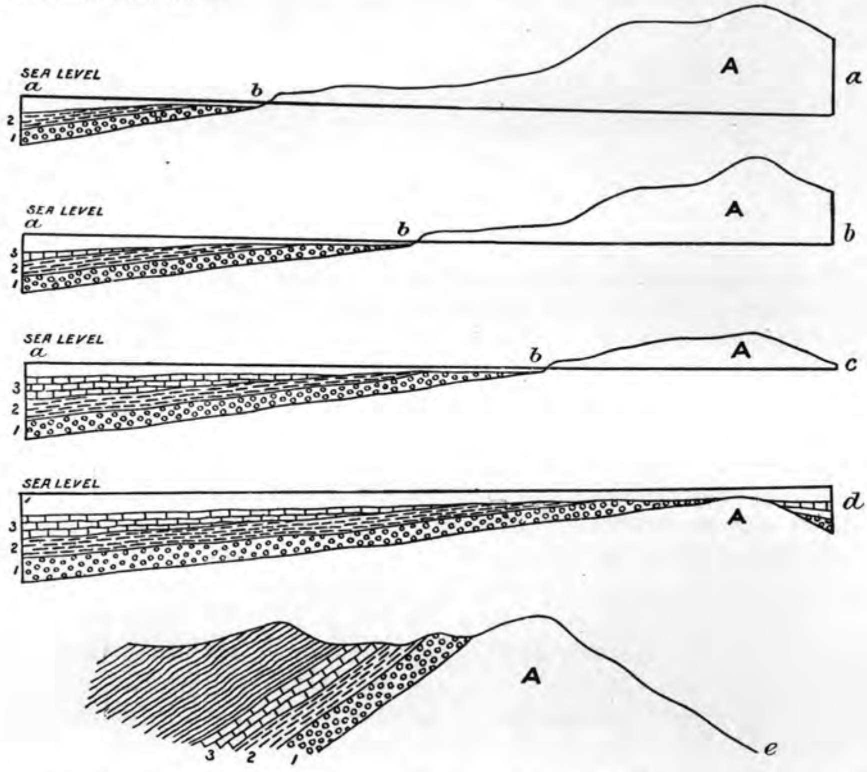


FIG. 73 *a*, *b*, *c* *d*, *e*.—Diagrammatic sections to illustrate the deposition of sediments on a seashore that is being gradually depressed in relation to sea level, and a section of sediments so deposited when elevated as part of a mountain range.

The accompanying diagrammatic sections illustrate this action of the sea and the resulting deposits of sediment where the land is gradually sinking in relation to sea level.

In Fig. 73*a* the sea front is attacking the land area (A) at *b* and depositing the sediment in adjoining waters; in Fig. 73*b* the coast line has advanced to the position shown at B and a portion of A has been reduced nearer to the sea level by surface erosion and also from the advancing of the sea by the gradual depression of the land; in Fig. 73*c* this is carried still further, and in Fig. 73*d* the entire land area has passed beneath the sea. The deposition of the mechanical sediments has now ceased, as there is no longer a source of supply. The soluble minerals that have been carried in solution into the ocean have been and are now being removed and segregated by the animal and vegetable life and deposited upon the undisturbed ocean bed. The result of all this is that the sediment accumulated in the immediate vicinity of the advancing sea front is the coarse beach deposit of pebbles and sand which, when consolidated, forms the conglomerates and sandstones; farther from the shore the finer sand and mud occur which, when hardened to rock, form the arenaceous and argillaceous shales; superior to the latter comes the calcareous mud which now forms the limestone. It is to be distinctly noted that several types of sediment may be accumulating at the same time and thus be synchronous and imbed the same species of plants and animals. It is not to be understood that all the sediments were derived from the shore line by the action of the waves. Vast quantities of silt, sand, and pebbles were carried into the sea by streams and rivers, and along a steep shore line the river sands and gravels, when distributed by the waves and tidal currents over the bottom of the sea, largely formed the deposits now classed as sandstones and conglomerates. The actual shore erosion was undoubtedly large, but it alone can not account for the presence of alternations of sandstone, conglomerate, shale, and limestone. It is only by the distribution of irregular supplies of sediment from large and different drainage areas that the sedimentation of the Appalachian trough can be explained. Owing to varying conditions there are wide departures in detail from the typical mode of sedimentation; they are usually the exceptions and do not readily mislead the geologist when he is searching for an ancient shore line.

Now, if the central mass (A) of Fig. 73*a*, *b*, *c*, *d*, is elevated so as to bring it into the same position that the pre-Paleozoic rocks of the Green Mountains of Vermont occupy in relation to the sandstones, shales, and limestones westward of them, we have the result shown by Fig. 73*e*, in which the coarse mechanical sediments (1) rest upon the older unconformable mass (A), and then, in turn, upon them occur the shales (2), and, still above, the limestones (3).

Assuming the preceding interpretation of the mode of sedimentation to be correct, the geologist in the field infers that he is approaching the shore line when he finds the sediment changing from limestone to fine shales, and sandstones to coarser sandstones, and finally to conglomerate. This is considered proof that the land area from which the sediments were derived was not far distant. It is rendered doubly certain by the presence of ripple marks and trails and tracks of animals that were made in the zone between high and low tide.

This form of deductive reasoning is illustrated by the use made of it in interpreting the section occurring in the trough between the Adirondacks and the Green Mountains. Both on the eastern and western sides of this a quartzite is found, resting upon the ancient crystalline rocks, that contains bowlders and fragments derived from them. In some localities the next superjacent rock is a shale resting upon the quartzite, and in others it is a calcareous sandstone that passes into a limestone. The presence or absence of the shale in the section depends largely upon the local conditions of sedimentation and the former existence or not of tidal or shore currents that removed the finer sediments into deep quiet waters, or into some bay or indentation of the coast line. It quite frequently occurs that the finer sandstone passes above directly into a calcareous sandstone and then into limestone, owing to the absence of the shales. This is the case where the sandstone on the Adirondack side, and in some localities on the Green Mountain side, passes above into calcareous shales and sandstones and thence to limestones.

Having thus set forth a method by which the shore lines of the ancient pre-Cambrian land areas may be approximately determined, the description and discussion is arranged under the following heads:

(*a*) Deposition of sediments now forming the Cambrian group of rocks and their relation to pre-Cambrian and post-Cambrian formations.

(*b*) Pre-Cambrian land.

(*c*) Middle Cambrian land.

(*d*) Post-Cambrian land.

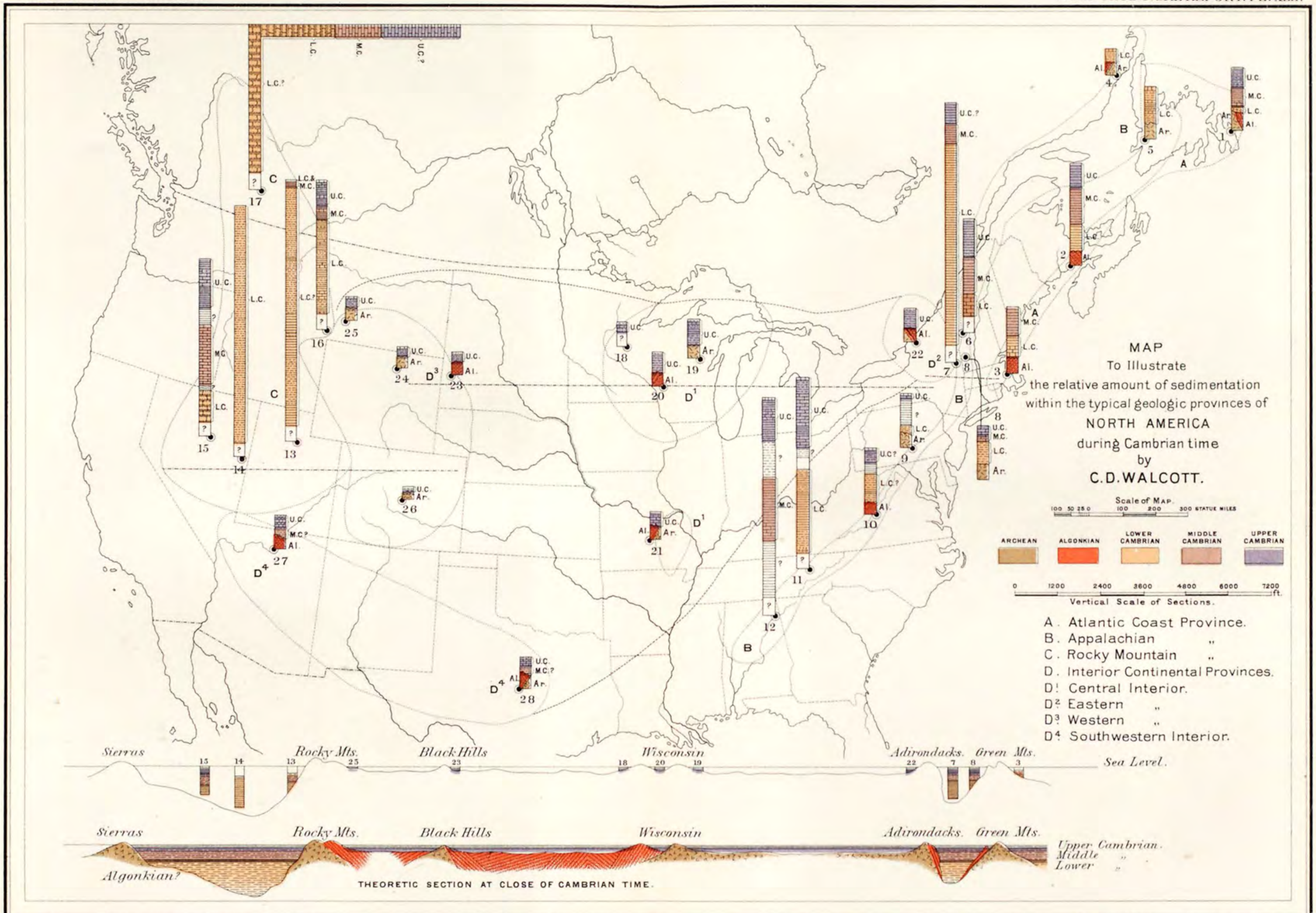
(*e*) Conclusions.

DEPOSITION OF SEDIMENTS.

The sequential form of presentation of the data would be to consider the evidence of the existence and character of the pre-Cambrian land and seas before describing the sediments deposited in those seas and on and against the land. From the fact that the proof of the existence of the land and seas results from the study of the sediments and their relations to the pre-Cambrian rocks, this natural order is omitted. To obtain a graphic presentation of the existing data relating to the sediments, typical sections of each geologic area or province have been restored by a uniform scale to a columnar form, and placed with their base at the typical locality of each respectively, as it is impossible to represent all the sections on the map as they occur in nature. This illustrates the amount of sedimentation and the nature of the base upon which it rests when the latter is known. This, in connection with the geographic distribution of the outcrops and the outlines of the geologic provinces, is shown on the map. (Pl. XLII.)

DESCRIPTION OF PLATE XLII.

Map of the central belt of the North American Continent, to illustrate the relative thickness of the strata composing the Cambrian group in the various geologic provinces. (The small ring with the dot in the center indicates the geographic location of the section.)



GEO. S. HARRIS & SONS, LITH. PHILA.

The sections are grouped in the following geologic provinces:

Atlantic coast province.

Appalachian province.

Rocky Mountain province.

Interior continental province.

The latter consists of the central interior or Upper Mississippi, the western or Rocky Mountain, the southwestern or Arizona and Texas, and the eastern or Adirondack subprovinces.

ATLANTIC COAST PROVINCE.

The detailed descriptions of the various sections on Pl. XLII are given in Bulletin No. 81, U. S. Geological Survey, 1891, pp. 253–359.

SECTION 1: *Conception Bay, Avalon Peninsula, Newfoundland.*—The Cambrian rocks of the Avalon Peninsula rest unconformably upon the strata of Archean and Algonkian age, as represented in the section. The section illustrated is formed by the union of portions of those of Manuels Brook, Kelleys, Great Bell, and Little Bell islands.

SECTION 2: *Vicinity of St. John, New Brunswick.*—This section is unconformably superjacent to the Archean and unites the sections at the city of St. John and that of Handford Brook.

SECTION 3: *Vicinity of North Attleboro and Braintree, Massachusetts.*—In this section the Lower Cambrian series of North Attleboro and the Middle Cambrian of Braintree are united in one generalized section. The basal series is unconformably superjacent to the Archean.

APPALACHIAN PROVINCE.

SECTION 4: *North side of the Straits of Belle Isle, Labrador.*—If ever deposited, the upper portion of the section is not now preserved; the base rests unconformably upon the Archean.

SECTION 5: *Central western Newfoundland.*—The base rests upon the Archean, but the summit of the section is not clearly defined, owing to lack of data to determine the range of the fauna.

SECTION 6: *Franklin County, Vermont.*—This represents the Red Sandrock series with its superjacent Georgia shales in the township of Georgia. The base is cut off by a fault line, and the exact limitation at the summit is unknown.

SECTION 7.—This represents the great shale and slate section of Washington County, New York. It is cut off at the base by a fault line and the summit is not well defined.

SECTION 8.—The shore-line deposits of the Green Mountains or the "granular quartz," above which comes limestone, in which Cambrian fossils have been found. At the base it rests unconformably upon the crystalline pre-Cambrian rocks.

SECTION 9.—Typical section in southern Pennsylvania, showing the "granular quartz" resting unconformably upon the subjacent crystalline rocks and extending above into the shale series beneath the limestone.

SECTION 10.—This section is that of central Virginia, not far away from the shore line. The base rests unconformably upon the pre-Cambrian rocks and above it passes into the base of the "valley" limestones. In September, 1891, I discovered the Olenellus fauna at the summit of the Balcony Falls section, and the Upper (?) Cambrian in the shales east of Natural Bridge. These discoveries remove one of the interrogation marks from the column on the map.

SECTION 11: *Rogersville, East Tennessee.*—The base of this section is cut off by a fault line, and above it passes into the Knox dolomite, the lower beds of which carry the Upper (?) Cambrian fauna. The Chilhowee Mountain section comes beneath the Rogersville, and it is so represented in this section, an interrogation point marking the hiatus between the two sections. The data for this section are given by Mr. Bailey Willis, chief of the Appalachian division of geology, U. S. Geological Survey. In September, 1891, I discovered the central portion of the Middle Cambrian fauna near the base of the Rogersville section, in the basal sandstone of the section. This replaces the interrogation mark on Section 11 by M. C.

SECTION 12.—The line of this section extends through Georgia westward into Alabama. At the base it is cut off by a fault, and above is delimited by the Knox dolomite. The data for it is given by Mr. Willard Hayes, of the Appalachian division of the U. S. Geological Survey. From observations made in 1891 this section includes the Middle Cambrian zone.

SECTION 13: *Western slope of the Wasatch Mountains, Utah.*—In this section the 12,000 feet of quartzite and siliceous slates are tentatively referred to the Cambrian. The fossiliferous zone is confined to the upper 250 feet.

SECTION 14: *Central eastern Nevada.*—This represents the great quartzite series beneath the fossiliferous Cambrian limestone. The base is concealed and the summit has been removed by erosion.

SECTION 15: *Eureka district, Nevada.*—In this section the fossiliferous lower Cambrian strata rest conformably upon the quartzites, which pass down some 1,500 feet before being concealed. The quartzite may correspond to the upper beds of section 14. The summit of the section passes into the superjacent Pogonip limestone of the Silurian (Ordovician).

SECTION 16: *Gallatin River, near Gallatin City, Montana.*—This is essentially the same as the Mount Stephen section of British Columbia (Sec. 17). The subjacent series of quartzite and siliceous slates are tentatively included in the Cambrian. (After Dr. A. C. Peale.)

SECTION 17: *Mount Stephen section of British Columbia in connection with the subjacent Bow River quartzite and siliceous slates.*—The relations of the section are the same as those of the Eureka section of central Nevada, with the addition of the Bow River quartzite and slates.

CENTRAL INTERIOR CONTINENTAL SUBPROVINCE.

SECTION 18.—The western section of the central Interior Continental province as it occurs in Minnesota.

SECTION 19.—Section of the Upper Cambrian sandstones of eastern Wisconsin.

SECTION 20.—Section of southern central Wisconsin, showing the unconformity between the Cambrian and the subjacent Algonkian and Archean rocks. Sections 18, 19, and 20 are all of Upper Cambrian age except their base, and pass conformably above into the superjacent Lower Silurian (Ordovician) or Magnesian limestones.

SECTION 21: *Ozark Mountain, southeastern Missouri.*—The relations of the Cambrian and the Archean are the same as those in the Black Hills section. (Sec. 23.)

EASTERN OR ADIRONDACK SUBPROVINCE.

SECTION 22: *Eastern and northern slopes of the Adirondack Mountains, New York.*—In this section the Potsdam sandstone of the Upper Cambrian rests unconformably upon and against the Archean and the Algonkian rocks.

WESTERN INTERIOR CONTINENTAL, OR ROCKY MOUNTAIN SUBPROVINCE.

SECTION 23: *Black Hills, Dakota.*—The Upper Cambrian rests unconformably upon the Archean.

SECTION 24: *Eastern section of the Big Horn Mountains of Wyoming.*—It is essentially the same as that of the Black Hills. (Sec. 23.)

SECTION 25.—This section of southern Montana is very much like that of Wyoming and of the Black Hills.

SECTION 26: *Central Colorado.*—A section representing the sandstones that lie between the subjacent unconformable Archean or Algonkian and the superjacent Lower Silurian (Ordovician).

SOUTHWESTERN INTERIOR CONTINENTAL SUBPROVINCE.

SECTION 27: *Grand Canyon of the Colorado, northern Arizona.*—In this section the Cambrian strata are unconformably superjacent to the strata of the Algonkian.

SECTION 28: *Llano County, Texas.*—This section is similar to that of the Grand Canyon in having an unconformity between the Algonkian and the Cambrian, and in representing nearly the same geologic horizon.

CHARACTER AND EXTENT OF THE SEDIMENTS.

The sediments of the northeastern Atlantic coast province are almost entirely shales with a small proportion of sandstone and a little limestone. Tracing the long Appalachian province from the Gulf of St. Lawrence to the southwest and south, we find an immense accumulation of shale with some interbedded sandstone and limestone. This extends to the Lake Champlain region of New York and Vermont. In northern Vermont a great limestone of Lower Cambrian age is subjacent to several thousand feet of shale, in which lenticular masses of sandstone and limestone occur at irregular intervals. Farther to the southwest, in southern Vermont and eastern New York, great thicknesses of argillaceous sediment were deposited. These now form the series of shales and slates in which massive beds of finely laminated roofing slates occur. To the eastward, near the pre-Cambrian shore line, the Lower Cambrian sandstones are followed by arenaceous, dolomitic, and purely calcareous limestones of Lower and later Cambrian time. This condition of sedimentation continues far to the south, varied more or less by the presence of considerable thicknesses of shale above the lower quartzite. In this case the limestone of Cambrian age forms a belt varying from a few feet to several hundred feet in thickness at the summit of the group.

During the field season of 1891 I examined, in company with Messrs. Bailey Willis and M. R. Campbell, the Cambrian rocks of East Tennessee. We found in the section west of Cleveland, in the southeastern portion of the State, that a great series of variegated shales of Lower Cambrian age occurred beneath a sandstone containing the Olenellus fauna (Knox sandstone of Safford). In the upper portion of the sandstone the central Middle Cambrian fauna occurs, and in the superjacent shales and limestones the upper Middle Cambrian fauna. The variegated shales and sandstone appear to be equivalent to the massive quartzite nearer the shore line, as at Chilhowee Mountain.

In the Rocky Mountain province the siliceous sediments, sandstones, and quartzites are followed by limestone, and nearer the shore line the sandstones are subjacent to shale. Over the Interior province the record is sandstone, followed on the west and southwest by alternating limestones and sandstones.

It is to be observed that over the Interior Continental area the basal beds of the upper division rest unconformably upon pre-Cambrian rocks. This is also true of the lower division on the Atlantic coast and along the old shore lines of the Appalachian and Rocky Mountain provinces. In the Lake Champlain Valley and the Southern Appalachian and the Rocky Mountain provinces there is no positive assurance that the conformable series of strata beneath the lowest known Cambrian zone do not pass down into some pre-Cambrian group. This does not affect the sedimentation of the Cambrian further than to show that it began in those deep troughs in pre-Cambrian time, and that no orographic movement disturbed the areas for a long time before and during Lower Cambrian time.

An illustration of the shore and off-shore sedimentation occurs in the area between the Green and Adirondack mountains, as shown on the map (Pl. XLII). In section No. 8 the coarse basal sandstone rests unconformably upon the subjacent crystalline rocks and is succeeded by a thin bed of shale and then a series of limestones. In this instance it is assumed that the crystalline rocks of the Green Mountains originally formed a land area not far to the eastward of the shore line from which the sediments forming the sandstones were derived.

Section 7 is taken at a point some 15 miles distant from the shore line, and its base is unknown. That portion which is preserved shows an immense accumulation of mud, such as would be carried out by tidal currents into a relatively shallow sea.

Section 23 illustrates the series of deposits on the western side of this trough, next to the crystalline rocks of the Adirondack Mountains, where only the sandstone is now found in the immediate vicinity of the subjacent crystalline rocks. A little to the eastward, however, the superjacent sandy limestone rests upon the sandstone, and superjacent to this a great series of purer limestones.

Before proceeding further I wish to state that the series of strata referred to the Cambrian group are characterized in their vertical thickness by three subfaunas. The upper is found in the closing deposit of the group, subjacent to the strata of the superjacent Lower Silurian (Ordovician) group. The middle occurs beneath the upper fauna in all sections where the succession is complete, and the lower is found beneath the middle fauna wherever the two have been observed in the same section. It is by the evidence afforded by the occurrence of the three subfaunas that the sediments of the Cambrian group are divided into three divisions—Lower, Middle, and Upper—and correlated when their stratigraphic continuity is interrupted.

It is assumed that when a subfauna is found in several different sections in the same relative position in relation to another subfauna, that it existed in practically the same period of time, and that the sediments in which it is found should be correlated in the same general horizon. It is by this means that three horizons are outlined and correlated in the Cambrian group.

On the map showing the sections (Pl. XLII) the upper division is characterized by purple, the middle division by pink, and the lower division by yellow. It will be observed by the sections that the greatest accumulation of sediments has been along the line of the Appalachian range and in the western Rocky Mountain region. If we prepare a diagrammatic cross section of the continent between the fortieth and forty-fifth parallels we obtain the sections at the base of Pl. XLII by assuming the Upper Cambrian as the horizon upon which to arrange the sections. The latter was the last and closing epoch of sedimentation of the Cambrian group, and the superjacent deposits of the Lower Silurian (Ordovician) rest conformably upon it wherever they have been recognized.

The Upper Cambrian part of the section is not preserved in all the sections on the immediate line of the cross section. It is found in all but three, and it is known to occur above the basal sediments of the latter sections within their respective geologic basins. As has been stated, the Lower Silurian (Ordovician) strata are conformably superjacent to the Upper Cambrian terrane whenever they have been recognized. This holds good over a great area, and it is now known that the latter horizon has a great geographic distribution and is distinctly marked in the American geologic series. The Middle Cambrian division is nearly as great, while the basal division, or Lower Cambrian, is found only on the margins of the pre-Cambrian plateau. (See Pl. XLII.)

With the sections arranged upon the line of the Upper Cambrian the sections across the continent show that upon the eastern side along the line of the present Appalachian range there was a trough in which the Upper, Middle, and Lower Cambrian sediments accumulated to a great thickness. Between this trough and the Rocky Mountains there is only the Upper and a small portion of the Middle Cambrian sandstones which indicate the transgression of a sea upon the Great Interior area toward the close of Middle Cambrian time. The western or Rocky Mountain area has a somewhat similar trough to that of the Appalachian region in which a great accumulation of sediments occurred during Lower and Middle Cambrian time, prior to the deposition of the Upper Cambrian sediments.

The study of all the known evidence bearing upon the sedimentation of the rocks referred to the Cambrian indicates that the greater portion of them were accumulated in relatively shallow seas, in the immediate vicinity of the shores of land areas that were being slowly depressed in relation to the surrounding sea level. There are some exception, as, for instance, the deeper water limestone series of central Nevada, British Columbia, and western Vermont, the upper limestone of the Cambrian of Tennessee, Georgia and Alabama, the lower Middle Cambrian limestone of Alabama and Georgia, and perhaps the black shales of the Atlantic province.

The evidence assembled on the map, Pl. XLII, and the cross sections and others of a similar character, in connection with the distribution of the faunas sustains the view that at the beginning of Lower Cambrian time the area of the Great Interior province formed part of a continent, to the eastward and westward of which long ridges of pre-Cambrian rock separated interior seas and straits from the continental area, and protected their contained life and sediments from the ravages of the open ocean. As the continent was slowly depressed and the waters advanced upon the land the sediments now forming the rocks of the Lower and Middle Cambrian series were accumulated in the various interior bodies of water, to the eastward and westward of the main land area and between it and the outlying ridges. What the contour of the south and southeastern side of the continent was, and to what extent the sea advanced upon it from the south during this time, is unknown, and may never be known, as only the formations that were deposited around the pre-Cambrian islands of Texas and Missouri are now accessible for study. From the evidence afforded by these two localities and that along the eastern front of the Rocky Mountains and the exposures of Cambrian strata in Wisconsin, Canada, etc., it is very probable that the main portion of the continent north of the thirtieth and south of the fiftieth parallel did not disappear beneath the advancing sea until near the close of Middle Cambrian time. The unconformable position of the Upper Cambrian rocks of the Interior Continental province upon the subjacent Algonkian and Archean rocks sustain this conclusion.

As the sea was transgressing upon the surface of the continent on its way northward across the broad interior in late Middle Cambrian time it was also working along the base of the border ridges and depositing the sediments derived from them and the adjoining drainage areas conformably upon those deposited while the main mass of the continent was above the sea. That these deposits were practically contemporaneous with those of the Interior province is proved by the presence of the same types of animal life and to a considerable extent of identical species.

Toward the close of Cambrian time a large portion of the pre-Cambrian continent had disappeared beneath the surface of the sea (section at the base of Pl. XLII) and the great limestone-forming period of the Silurian (Ordovician) began. In some areas, as about the Adirondack Mountains of New York, argillaceous and arenaceous sediments were derived from the adjoining coast line, but as a whole mechanical sediments are absent.[1]

I do not think it probable that any considerable amount of sediment accumulated in the southern portion of the Interior Continental area during early Cambrian time. The sections of the Champlain Valley, East Tennessee, Utah, and Nevada, and of British Columbia prove the accumulation of from 10,000 to 12,000 feet of sediment along the eastern and western flanks of the pre-Cambrian continent before the sea deposited the formations about the Llano Hills of Texas, the Ozark Mountains of Missouri, and other portions of the Interior Continental province. This leads to the belief that the continent stood at a considerable elevation above sea level and that the great accumulation of sediment during late Algonkian and early Cambrian time resulted from the distribution of material worn from the shore by the waves and brought

[1]In speaking of the conditions of sedimentation, Messrs. Campbell and Ruffner state that "changes such as these occurred during a series of geological ages of unknown length in a great inland sea which was once connected with what is now the Gulf of Mexico on the south, limited, probably, by the highlands of Canada on the northeast, having the Archean ledges of the Blue Ridge for its southeastern border, and in all probability separated, in part at least, from the Pacific Ocean by the Rocky Mountain range. This extensive sea, with Archean rocks for its bottom that now constitute the surface rocks and soils of the Mississippi Valley." (A physical survey extending from Atlanta, Georgia, across Alabama and Mississippi to the Mississippi River, along the line of the Georgia Pacific Railway. New York, 1883, pp. 9, 10.)

into the sea by the rivers of the Interior Continental region and the outlying ridges.[1]

Our knowledge of the sediments of the eastern and western sides of the pre-Cambrian continent is considerable, but of that deposited along the southward facing front we know nothing. From the fact, however, that the same species of fossils occur in the Lower Cambrian fauna of Labrador, Vermont, New York, Massachusetts, Tennessee, Nevada, and British Columbia, I think we may hypothetically assume the continuance of the Lower Cambrian beneath the deposits of the Gulf States and westward through Texas, New Mexico, and Arizona. There is no known line of Lower and lower Middle Cambrian sedimentation across the continent to the north of this that indicates that the fauna might have been distributed along a more northern shore.

The pre-Cambrian ridges, or protaxis of the present ranges of the northeastern side of the continent, have been outlined by Prof. J. D. Dana, from the known exposures of pre-Cambrian rocks.[2] The Paradoxides, or Middle Cambrian fauna, lived in the depression between two of the eastern ridges of the Atlantic province in the New Brunswick area, and in the bays and protected shores of the seaward slope of the western ridge where the outer or eastern ridge was absent, as in Massachusetts and Newfoundland. The sediments that accumulated to the eastward of the New Brunswick sea form the supposed Cambrian shales and slates of Nova Scotia. The inner ridges of Maine, New Hampshire, and Massachusetts bounded long, narrow seas, in which the Cambrian faunas are not yet known to have penetrated. The Lower Cambrian fauna probably passed from the Atlantic along the ancient Labrador shore into the interior Appalachian sea. A few types of the Middle Cambrian fauna followed, and then the passage appears to have been closed, as the greater portion of the latter fauna and none of the Upper Cambrian types of the Atlantic fauna have been found in the deposits of the interior seas.[3]

PRE-CAMBRIAN LAND.

For the land that existed on the North American continental plateau at the beginning of Cambrian time I proposed, in 1886, the name Ke-

[1] It is not improbable that the area of the great coastal plain of the Atlantic slope was then an elevated portion of the continent and that much of the sediment deposited during Cambrian and later Paleozoic time was washed from it intc the seas to the west. If this be true the source of much of the sediment of the Appalachian series of rocks is accounted for and the absence of the deposits of the eastern coast line is explained by the sinking of the coastal region during or at the close of Paleozoic time. This view is strengthened by the presence, in the Middle Cambrian fauna of Alabama, of a number of species that are closely allied to, if not identical with, species of the Middle Cambrian fauna of Newfoundland and Sweden. This fauna is unknown in the Appalachian province north of Alabama. It leads to the inference that it was distributed along the shore of the Atlantic coast and that the series of deposits containing it, between Massachusetts and Alabama, are buried deep beneath later deposits of the coastal plain.

[2] Areas of continental progress in North America and the influence of the condition of these areas on the work carried forward within them. Bull. Geol. Soc. Am., 1890, vol. 1, pp. 36–39.

[3] The study of the Middle Cambrian fauna proves that strongly defined zoologic provinces existed in Cambrian time and were as well differentiated as any during Paleozoic time.

weenaw continent.[1] This was done with the view in mind that the Keweenawan rocks of the Lake Superior region, Grand Canyon and Chuar rocks of the Grand Canyon of the Colorado, and the Llano rocks of Texas are outcrops of a group of strata of pre-Cambrian age. These were united with the Huronian and other clastic sedimentary rocks beneath them and the still older Laurentian or Archean basement, to form great land areas over two-thirds or more of the present continental surface. The pre-Cambrian age of all of these rocks is proved by the unconformable overlap of the Cambrian sediments upon and against them wherever the contacts of two series of rocks have been observed. Since 1889 the name Algonkian has been proposed for the sedimentary bedded rocks beneath the Cambrian and superjacent to the crystalline basement series. As these rocks enter quite largely into the structure of the land area of pre-Cambrian time, the name is now adopted for the continent at the beginning of Cambrian time.

The data for a study of the Archean and Algonkian rocks that form the Algonkian continent, and their relations to each other and to the superjacent Cambrian rocks, are sufficient to establish the fact that great orographic movements, followed by long-continued erosion, took place between the Archean and Algonkian and between the pre-Cambrian and Cambrian strata all over the continental area, with perhaps the exception of the sediments deposited in the great Appalachian and Rocky Mountain troughs. (Pls. XLII and XLIII.)

ATLANTIC COAST PROVINCE.

In the Atlantic coast province the rocks forming the Algonkian continent comprise both the Archean and Algonkian series. The relations of the two are beautifully shown in some sections prepared by Dr. Alexander Murray, and published in the report of the Newfoundland Survey for 1868.[2]

In a section from St. John to Great Bell Island, in Conception Bay, 11,370[3] feet of the "Intermediate Rocks" of Murray, or the Algonkian of the more recent classification, rest unconformably upon the Archean granite and gneisses, and the Lower Silurian of Murray, or Cambrian of the present classification, also rest unconformably upon the Archean. On the map, published in 1881, of the Peninsula of Avalon, the Cambrian strata at the head of St. Marys Bay are shown to transgress over the subjacent beds of the Algonkian series.[4]

Farther to the southwest, in New Brunswick, the Cambrian strata fill a number of narrow trough-like basins lying between the Bay of Fundy and the central Carboniferous area. According to Mr. G. F.

[1] Am. Jour. Sci., 1886, vol. 32, p. 155.

[2] Geological Survey of Newfoundland. Report for 1868, p. 160 of revised edition published in 1881.

[3] Op. cit., p. 146.

[4] For the intermediate series of Dr. Murray, Dr. T. Sterry Hunt proposed, in 1870, the name Terranovan series, stating that he believed this series to also include certain rocks in Nova Scotia and New Brunswick that rest unconformably upon the Laurentian series (Am. Jour. Sci., 2d ser., 1870, vol. 50, p. 87).

Matthew the sediments forming the base of the Cambrian series are derived from the subjacent Huronian rocks, and the conglomerate at the base indicates a time when the Cambrian Sea invaded the valleys of the Huronian formation near St. John.[1]

The Cambrian rocks of the Boston basin appear to have been deposited upon the pre-Cambrian Algonkian and Archean rocks, as in the New Brunswick and Newfoundland areas. At a later date, however, they were broken up and thoroughly disturbed by intrusive masses of diorite, followed by granite and felsites.[2]

Farther to the south in the North Attleboro district, near the Rhode Island line, Prof. N. S. Shaler found that Cambrian rocks apparently rest upon pre-Cambrian gneissoid rock of various combinations, and what appear in part, at least, to be metamorphose conglomerates and shale.[3] Prof. Shaler thinks that the rocks of apparently pre-Cambrian age may possibly be assigned to the Huronian period.

A glance at the map of the Peninsula of Avalon, already mentioned, indicates that Cambrian rocks were deposited in the depressions that now form the numerous bays penetrating the peninsula. This is also shown by the sections of Dr. Murray, and from a personal examination of the strata about Conception and St. Marys Bay I do not think there has been any material change in therelative geographic position of the coast line of the great bays since pre-Cambrian time.

In Labrador and southwest, up the northern side of the St. Lawrence Valley, the pre-Cambrian rocks appear to belong to the Archean or basement series, and on the south side to the Algonkian.

APPALACHIAN PROVINCE.

From Montreal southwest to the Lake Champlain Basin the pre-Cambrian rocks of Sutton Mountain and the western slopes of the Green Mountains appear to belong to the Algonkian series.

North of Westport, New York, on the Adirondack side of the basin, the Cambrian rocks rest unconformably upon gneisses and the norite of the basement series. To the south of Westport the contact is with the Algonkian that rests unconformably upon the subjacent strata upon which the Cambrian rests farther to the north. The relation in this region of the Potsdam sandstones of the Cambrian to the Algonkian and pre-Algonkian rocks are such as to prove that they were deposited in bays along a shore line that had essentially the same topographic features as at present. These same conditions prevail wherever the contact with the Cambrian and pre-Cambrian rocks is clearly shown in New Jersey, Pennsylvania, Maryland, Virginia, Tennessee, and Alabama. The Cambrian rocks are frequently tilted and broken by the upward movement of the pre-Cambrian series, but as a whole they pre-

[1]Trans. Roy. Soc. of Canada, 1883, vol. 1, pp. 87-88.

[2]Crosby, W. O., Teachers' School of Science, Bost. Soc. Nat. Hist., Physical History of Boston Basin, 1889, pp. 19-21.

[3]Bulletin, Museum of Comparative Zoology, 1888, vol. 16, pp. 15-17,

serve to a remarkable degree their position in relation to the rocks over and against which they were originally deposited.

ROCKY MOUNTAIN PROVINCE.

Of the areas of Algonkian rocks in the Rocky Mountain region Mr. S. F. Emmons said, in a late communication:

> Only a few isolated exposures have yet been discovered in the Rocky Mountain region, and these have not been sufficiently studied to attempt any correlation between them.[1]

Over the other portions of the Rocky Mountains the Algonkian continent seems to have been formed of the Archean basement or the distinctly crystalline rocks. The areas where the relation of the Cambrian, Algonkian, and pre-Algonkian rocks are shown are those of the Grand Canyon of the Colorado in northern Arizona; on the north slope of the San Juan Mountains, near Ouray, Colorado; in the hills east of the Arkansas River, at Salida, and south of the South Park, also in the Medicine Bow Range and the eastern flanks of the Colorado Range. Quartzites have also been noticed connected with the Archean of the southern end of the Sangre de Cristo Range, Colorado.[2]

Of the rocks forming the Black Hills uplift of South Dakota, Prof. C. R. Van Hise says: "The Black Hills rocks exhibit a remarkable lithological analogy to certain of the iron-bearing series of the Lake Superior region, which in the past has been included under the term Huronian. While this correlation is not beyond doubt, there is no question that these series in common belong to the Algonkian period."[3]

INTERIOR CONTINENTAL PROVINCE.

In his beautiful memoir on the classification of the earlier Cambrian and pre-Cambrian rocks, Prof. R. D. Irving has shown that the pre-Cambrian continent in the Lake Superior region is formed of the Archean basement, unconformably upon which rests the Algonkian series, composed of several distinct groups of rocks.[4]

In Llano County, Texas, there is a great deposit of the Algonkian rocks similar to those of the northern Arizona section in the Grand Canyon of the Colorado, and there are probably some of the remnants of the Archean basement beneath the Algonkian. In Missouri the pre-Cambrian rocks apparently belong largely to the Archean basement series.

RÉSUMÉ.

From the brief outline that has been given it appears that the Archean basement rocks of the continent occupied a considerable area or areas above sea level at the beginning of Algonkian time, and there is little

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[1] Bulletin of the Geological Society of America, 1890, vol. 1, p. 256.
[2] Op. cit., p. 257.
[3] Bulletin, Geological Society of America, 1890, vol. 1, p. 242.
[4] Seventh Ann. Rept. U. S. Geol. Surv., 1888, pp. 365–454.

doubt that the Algonkian rocks were deposited during the downward oscillations of that continental area or areas. Over and against the Archean rocks of the continental plateau several successive series of sediments were deposited, which now form the various Algonkian terranes. In the Lake Superior region Prof. Irving states that these reach a thickness of 60,000 feet or more; in Canada,[1] north of Lake Ontario,[2] the Hasting series is credited with a thickness of 21,130 feet, of which 9,000 feet or more will fall into the Algonkian. In the Ottawa district this series is probably over 20,000 feet in thickness;[3] in the Grand Canyon of the Colorado, northern Arizona, there is over 11,500 feet of unaltered Algonkian rocks;[4] in Newfoundland Dr. Murray measured a section of nearly 12,000 feet in thickness,[5] between the Archean basement and the known Cambrian, and wherever erosion has removed later deposits so as to deeply expose the Archean basement to any considerable extent, there are traces of Algonkian sediments.

At the close of the deposition of the Algonkian series there appears to have been an orographic movement that affected more or less of the entire continental plateau. It was not as profound as the one preceding Algonkian time, as is proved by the more highly contorted and disturbed Archean rocks beneath the relatively less disturbed Algonkian series. Locally the Algonkian rocks are inclined, distorted, and broken, but not with the same intensity as the subjacent Archean basement. I fully realize that this statement is open to criticism, as the line of demarkation between the Archean basement andAlgonkian is not yet well determined; but where the two are well defined, as in the Lake Superior region, this condition is found to prevail. Again, I do not wish to imply that all the Algonkian orographic movements were of one date, as there were several between Archean and Cambrian time.

With the close of the Algonkian period of deposition and the subsequent orographic movement, erosion began to prepare the surface upon which the Cambrian sediments were deposited. Before proceeding to describe what is known of this I wish to draw attention to the series of conformable pre-Cambrian rocks now found in the Appalachian and Rocky Mountain troughs. Referring to the theoretic section at the base of Pl. XLII, the position of these beds is readily seen, especially in the Rocky Mountain trough. From numerous sections in Utah, Nevada, Montana, and British Columbia we find that there is from 10,000 to 20,000 feet of sediments conformably beneath the known fossiliferous Cambrian rocks. What the relations of these sediments are to the disturbed Algonkian rocks of the Lake Superior, Grand Canyon, and central Texas region is unknown. They are apparently some portion

[1] On the classification of the early Cambrian and pre-Cambrian formations. Seventh Ann. Rept. U. S. Geol. Surv., 1888, p. 438.

[2] Geol. Surv. Canada, Rept. Prog. for 1866-1869, 1870, pp. 144-145.

[3] Geol Surv. Canada, Rept. Prog. for 1863, p. 45.

[4] Am. Jour. Sci., 3d ser., 1883, vol. 26, p. 441. Ibid, 1886, vol. 32, p. 143.

[5] Geol. Sur. Newfoundland, Rept. for 1868, Revised Ed. 1881, pp. 145, 146.

of the deposits accumulated in the interval of erosion between the uplifting of the Algonkian deposits of the central and northeastern portions of the continent and the beginning of known Cambrian time. That they represent the sedimentation of a portion of that interval is quite probable, but to what extent can not be known until the faunas are obtained to furnish the necessary data for correlation. If the faunas are of a Cambrian facies the rocks will be referred to the Cambrian, as is done at present on structural evidence.

GEOGRAPHIC DISTRIBUTION.

The geographic distribution of the pre-Cambrian land is based upon (*a*) the evidence afforded by the absence of Cambrian deposits upon known pre-Cambrian rocks; (*b*) the existence of shore lines during earlier Cambrian time; (*c*) the presence of deep-water deposits.

The pre-Cambrian areas over which there does not appear to have been any sediments deposited during Middle, Upper, and post-Cambrian time are limited to the nucleal V of the northern portions of the continent about Hudson Bay; the Appalachians and the Atlantic coast ridges, and those of the Rocky Mountains and Coast Range on the opposite side of the continent. The two points recognized in the great interior basin are the Ozark uplift of Missouri and the Llano area of central Texas. These areas were larger at the beginning of Cambrian time than at its close, owing to erosion and the gradual depression of the continental surface during that period. The area is fairly well represented by the horizontally lined portions marked A, A, A, and the islands of Missouri and Texas, as shown on Pl. XLIII.

DESCRIPTION OF PLATE XLIII.

Hypothetical map of the North American continent at the beginning of and during Lower Cambrian time.

This map is based upon the columnar sections shown on Pl. XLII and many others not represented and the theoretic sections at the base of Pl. XLII. The geographic position of the columnar sections on the two maps is indicated by a circle with a corresponding number on each map. The shaded portions indicate the relative areas that are supposed to have been above the ocean during later Algonkian and Lower Cambrian time.

A=Archean; K=Keweenawan; B=Black Hills of Dakota; T=Llano area of Texas; M=Ozark uplift of Missouri; C=Grand Canyon area of Arizona. The area marked X X X indicates a hypothetical land area of the existence of which we have not at present any absolute proof, as it is now covered by sediments of later age than the Cambrian. The portions left white within the boundary of the continental plateau were either covered by the sea or are areas of which there is not sufficient data to express an opinion upon the relations of the land and water.

Over all the shaded areas, with the exception of a large central area marked X X X, there is data to establish fairly well the presence of land at the beginning of Cambrian time. Within the area marked X X X the pre-Cambrian rocks are covered and concealed by later deposits, but from the topographic features of the continent and the distribution of the Lower Cambrian fauna in the Appalachian and Rocky Mountain troughs, it is assumed that the area marked X X X formed a portion of the continental surface at the beginning of Cambrian time. How much greater the area was in the Northwest and South is unknown at the present time. It is quite probable that the Pacific Coast Range extended northward into Alaska and that the western arm of the Archean "nucleal V" continued on to the Northwest, and much of the area north of Hudson Bay was probably above the sea at that time. How many bays and inland seas existed over the area marked X X X is necessarily unknown and probably never will be known. Great fresh-water lakes may have existed and either marine or nonmarine sediments may have been deposited. From the distribution of the older Cambrian faunas, however, there does not appear to have been any continuous connection by water from the Appalachian to the Rocky Mountain trough except along the southern side of X X X.

With the present data the geographic distribution of the land is theoretically represented at the beginning of Lower Cambrian time on Pl. XLIII.

SURFACE OF THE PRE-CAMBRIAN LAND.

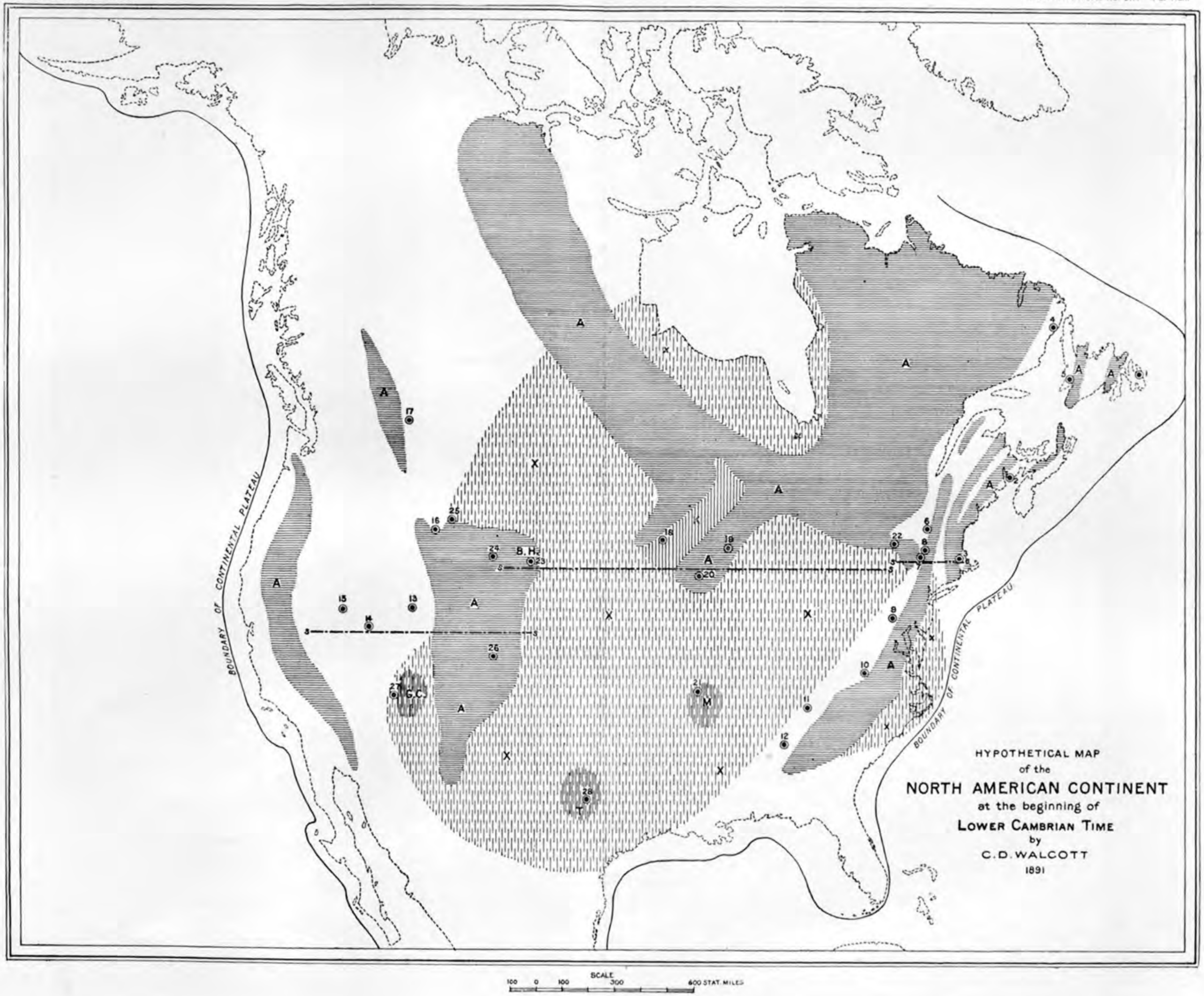
The features of the pre-Cambrian surface are indicated by the relation of the known Cambrian and post-Cambrian formations to that surface where it is exposed. The data will be assembled and discussed under the geographic provinces as outlined on Pl. XLII. These are:

A. Atlantic Coast province.
B. Appalachian province.
C. Rocky Mountain province.
D. Interior or Continental province.

The latter is subdivided into D^1 or the central interior, or the Upper Mississippi Valley and Missouri; D^2, the northeastern interior; D^3, the western interior; D^4, the southwestern interior.

ATLANTIC COAST PROVINCE.

At all points on the eastern coast of Newfoundland where Cambrian rocks have been observed they rest unconformably upon the subjacent Archean and Algonkian rocks. The study of the map of the Peninsula of Avalon, published by the Geological Survey of Newfoundland in 1881, indicates by the geographic distribution of the Cambrian rocks that they were deposited in the deep bays that penetrate the peninsula. After a personal examination of the deposits of Conception and St. Marys Bays and their relations to the Archean and Algon-


BOUNDARY OF CONTINENTAL PLATEAU
BOUNDARY OF CONTINENTAL PLATEAU
A
B. H.
G. C.
M
T
X
HYPOTHETICAL MAP
of the
NORTH AMERICAN CONTINENT
at the beginning of
LOWER CAMBRIAN TIME
by
C. D. WALCOTT
1891
SCALE
100 0 100 300 600 STAT. MILES

kian rocks, I fully agree with the views set forth in the sections accompanying the report of 1868 of the Geological Survey of Newfoundland, by Dr. Alexander Murray. These indicate that Conception Bay existed as a bay in pre-Cambrian time, and that erosion has removed a great amount of Cambrian sediment that originally extended far inland from the present coast line. The fragments remaining prove that the sediments were accumulated in bays and along the shore line east of the Archean ridge that crosses the island just west of the Avalon Peninsula, and it is quite probable that a barrier existed to the eastward toward the eastern margin of the continental plateau. The Algonkian rocks about St. Johns may possibly be a portion of it.

In speaking of the Paleozoic rocks of southwestern Newfoundland Dr. Alexander Murray said:

> Rocks of Lower Silurian age were found reposing upon the upturned or corrugated edges of the older system, usually in depressions on the axis of undulations, frequently in a perfectly horizontal attitude, and with but few exceptions, rarely showing a dip from the horizon of more than 10° or 12°. These are arranged in the form of elongated narrow troughs, extending lengthwise in the same direction as the axis on which they rest.[1]

In a section a little to the south at the head of Conception Bay the Lower Cambrian rests directly upon the eroded pre-Cambian Archean gneiss. The accompanying section illustrates the contact and position of the Cambrian rocks in relation to the Archean.

FIG. 74.—Section from St. Johns, Newfoundland, to Great Bell Island, Conception Bay, by Portugal Cove. L=Laurentian. G=Granite. ABC=Algonkian Rocks. PS=Red, green, and black sandstones and shales with Paradoxides. PK=Kelleys Island sandstones and shales. PX=Dark gray shales and thin micaceous sandstones with Cruziana. PY=Sandstones and shales with Cruziana and Lingulella. PZ=Whitish quartzose sandstone with Lingulella. In the Topsail Head section there is limestone, slate, and conglomerate beneath PS. In the limestone and slate the Olenellus or Lower Cambrian fauna occurs beneath the Paradoxides fauna which occurs in PS. (After Dr. Alexander Murray, Geol. Newfoundland, 1881, Fig. 4, opposite p. 160.)

A ridge of Archean rocks separates the Cambrian deposits of the Avalon Peninsula from those occuring farther to the west about Despair Bay.

Farther to the southwest in New Brunswick the Cambrian strata fill a number of narrow trough-like basins lying between the Bay of Fundy and the central Carboniferous area, and Mr. G. F. Matthew concludes that these sediments were deposited in valleys of the Huronian formation.[2]

[1] Geological Survey Newfoundland. Report for 1868, p. 140 of reprint, 1881.

[2] Trans. Roy. Soc. Canada, 1883, vol. 1, pp. 87, 88.

Dr. W. O. Crosby, in speaking of the slates that he refers to the primordial period on the coast of Maine which are superjacent to granites and schists, states that they occur only in arms of the Gulf of Maine and nowhere far above the present level of the sea, thus indicating that the existing coast line, at least in its main features, is of very great antiquity and stability.[1]

FIG. 75.—Section on Manuels Brook, Conception Bay, Newfoundland. The strata of the Lower Cambrian rests unconformably upon the Archean. Above the basal conglomerate the shale and sandstone, etc., dip at an angle of 12 degrees away from the Archean and are conformable throughout the Olenellus and Paradoxides zones and into the Orthis beds, where the section is cut off by the shore line.

The Cambrian rocks of the Boston basin appear to have been deposited in a bay upon the pre-Cambrian, Algonkian, and Archean rocks, as in the New Brunswick and Newfoundland areas. At a later date, however, they were broken up and thoroughly disturbed by intrusive masses of diorite, followed by granite and felsites.[2]

It is not to be understood that the Cambrian rocks now hold the same relation to sea level that they did when deposited. On the contrary, in the Boston basin, and also in New Brunswick in the vicinity of St. John, they have been greatly disturbed by the movements of the subjacent Archean and Algonkian rocks, and even in Newfoundland, where the disturbance is least, they dip at angles varying from 2 to 20 degrees. About Conception Bay they are nearly horizontal, but to the south, around the shore of St. Marys, they are much more disturbed. It is by the study of the undisturbed portions and the general relations of the entire exposures to the older rocks that the configuration of the pre-Cambrian surface is determined.

The Cambrian rocks undoubtedly extended in the Atlantic coast province over very much larger areas than the remnants of them now found indicate. That they have been subjected to long-continued erosion, perhaps since Paleozoic time, appears to be fair inference from the recorded observations.

APPALACHIAN PROVINCE.

On the northern side of the Strait of Belle Isle' Labrador, the Cambrian sandstones rest unconformably upon the gently sloping Archean rocks. Numerous streams have cut channels from the higher upland rocks through the sandstones down to the sea, so as to show that the slope of the sandstones is about 60 feet to the mile.[3]

[1] Geology of Frenchmans Bay. Bost. Soc. Nat. Hist. Proc., 1881, vol. 21, p. 117.

[2] Teacher's School of Science. Bost. Soc. Nat. Hist. Physical History of the Boston Basin, 1889, pp 19–21.

[3] Geology of Canada, 1863, p. 864.

When describing the Potsdam group of the St. Lawrence Valley and the northern side of the Adirondacks, Sir William E. Logan wrote as follows:

> That portion of the Potsdam group which has here been described appears to have been deposited in shallow water along the margin of the Lower Silurian Sea, and a wind-mark on one of the surfaces connected with the track beds at Beauharnois proves incontestably that these beds were uncovered at the ebb of tide. In the eight localities in which these tracks have been met with, extending on the strike of the formation for about 400 miles, the beds on which they are impressed are always of the same lithological character, and seem to stand in the same relation to the summit of the formation where this can be ascertained. We have thus good reason to believe that all these beds were at nearly the same geographical level at the same time. Three of the localities occur along the foot of the Laurentide Hills, from which the beds stretch out at a very low angle into the Silurian plain in front. The hills, at no very great distance from the outcrop of the Potsdam formation, rise to heights varying from 500 to nearly 4,000 feet; and while the sand at their base lay between the ebb and flood of tide, the flank of the Laurentide Mountains must have formed the coast of the Lower Silurian Sea. As has already been stated, these hills extend from Labrador to the Arctic Ocean, and we can thus trace out this ancient limit of the ocean for 3,500 miles.
>
> The thoroughly rounded form of the grains of sand composing a large portion of the deposit, and the fact that all the material other than quartz has been bruised up and washed out from so much of it, would seem to make it probable that the formation accumulated slowly, and that the Potsdam coast remained unchanged for a great length of time. The fact, however, that the formation is in some places overlapped by the succeeding deposit would seem to show that a subsidence had commenced toward the end of the epoch; and the passage, by interstratification with the succeeding rock, which is so distinct in many places, appears to indicate that the subsidence was slow and gradual. Its duration and the area affected by it must be proved by the accumulation and distribution of the succeeding formations.[1]

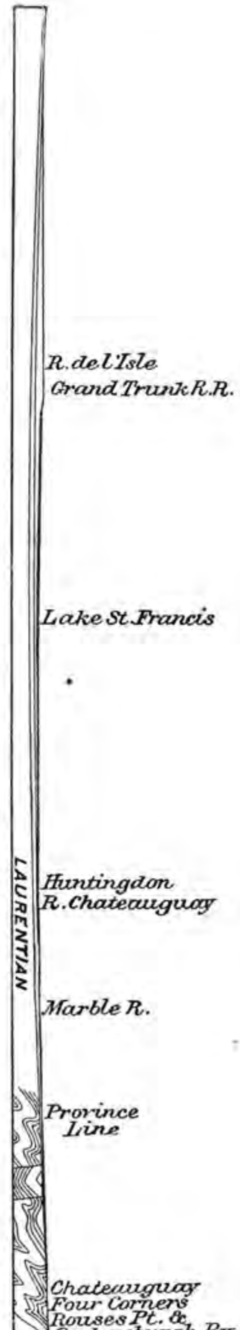


FIG. 76.—Section from Rigaud, Canada, to Chateaugay Four Corners, Franklin County, New York. The Potsdam sandstone rests unconformably upon the Laurentian gneiss and conformably subjacent to the Calciferous-Chazy formation. (After Logan.) Atlas accompanying Geology of Canada, 1865, section No. 5.

[1] Geology of Canada, 1863, pp. 108, 109.

A section extending from the north side of St. Lawrence Valley across the St. Lawrence to the Archean of the Adirondacks illustrates very clearly Sir William Logan's idea of the shallow sea in this portion of the St. Lawrence region during Cambrian time. It is shown in the accompanying figure (Fig. 76).

Other sections of this portion of the St. Lawrence Valley illustrate the shallow character of the Cambrian and Lower Silurian seas, and lead to the conclusion that this portion of the Algonkian continent had about reached its base level of erosion prior to Upper Cambrian time.

The sloping shores of the northern side of the Adirondacks are replaced upon the eastern side by more steeply inclined slopes. This is shown at Whitehall, New York, where erosion has removed the Potsdam sandstone from the inclined mountain side of Archean rocks on the west. The massive beds of Potsdam sandstone upon the opposite side of the valley to the eastward are only the upper members of the great thickness of Cambrian rocks that have been upturned a few miles to the eastward in Washington County. The deep trough in which these accumulated also extended northward through western Vermont to the Canadian border and southward into the valley of the Hudson.

Where the contacts of the Potsdam sandstone with the subjacent Archean and Algonkian rocks of the Adirondacks occur the sandstone is usually in evenly bedded layers, that rarely dip more than 10 degrees to the eastward. Often they are quite horizontal. They occur in the old bays, hollows, and indentations of the Algonkian shore line in such a manner as to leave little if any doubt in the mind of the observer that the relation of the pre-Cambrian Algonkian lands and the Cambrian deposits were the same when the sediments were being deposited as at the present day, and that the Algonkian topography has varied little since that time. On the western side of the Adirondacks, in Jefferson, St. Lawrence, and Franklin counties, the Potsdam sandstones rest upon the undulating Algonkian surface very much as described by Sir William E. Logan for the Canadian area to the north.

On the western slopes of the Green Mountains the "granular quartzite" of the Lower Cambrian rests uncomformably upon the Algonkian and Archean rocks in such a manner as to indicate that the outlines of the shore have not materially changed since Algonkian time. In many instances the Cambrian sandstones have been upturned and displaced by orographic movements during and at the close of Paleozoic time, but there is little difficulty in fixing the approximate position of the old shore line by the presence of conglomerates, sandstones, and in many instances absolute contact with the subjacent pre-Cambrian rocks of the Algonkian land.[1]

[1] See map accompanying the Taconic system of Emmons, and the use of the name Taconic in geologic nomenclature. (Am. Jour. Sci., 1888. vol. 35, Pl. III.)

The general outlines of the western border of the Appalachian Algonkian land are broadly shown upon the geological map of the United States issued by the Geological Survey in 1884. The study of the local sections and outcrops of New Jersey, Pennsylvania, Maryland, Virginia, Tennessee, Georgia, and Alabama tends to prove that the Algonkian land upon the eastern side of the Appalachian troughs was bold and precipitous, and in fact the westward facing side of a mountainous area.

Of the character of the eastern shore of the Appalachian trough south of the Adirondack region we know nothing except that in eastern Tennessee there is an approach to a shore line indicated by the mechanical sediments. It is not known where the shore line was, but the fact that in the Missouri and Texas areas there were no Lower Cambrian sediments deposited, and probably only those of the later Middle Cambrian, indicates that there was a shore line somewhere between these points and the Appalachian Mountain range east of the Appalachian trough.

ROCKY MOUNTAIN PROVINCE.

There have been two views expressed on the character of the pre-Cambrian continental surface in the Rocky Mountain region. In the first Mr. G. K. Gilbert states that the pre-Silurian stratigraphical break is as complete and universal in the West as in the Eastern States and Canada. He says:[1]

There are two general facts in regard to the geological history of the great West that deserve especial mention, for the reason that while some of the individual instances on which they depend have long been known, it is only recently that they have been announced in such number, and with such distribution as to dissipate all doubt that their meaning is general rather than local. The first is that the pre-Silurian stratigraphical break is as complete and as universal in the West as it is in the Eastern States and Canada. Its existence has been determined in Nebraska, Montana, Idaho, Wyoming, Colorado, Utah, Nevada, Texas, New Mexico, and Arizona, and its general features are everywhere the same. There is, first, a *wide* nonconformity, demonstrating the tilting and erosion of the Archean beds anterior to the deposition of the Silurian; and, second, there is always at the contact a contrast of condition as regards metamorphism, the Silurian rocks being, usually, merely indurated and the Archean invariably highly metamorphic.

These two characters of the break serve to show that it represents a vast chasm of time, a chasm the duration of which may have been greater than that of the ages which have since elapsed. A third character of the break, one that is supported by less evidence, but is negatived by none, is that the lowest of the superposed rocks are conglomerates and coarse sandstones. The lowest Paleozoic rocks are primordial and the basal portion of the Primordial is everywhere siliceous and of coarse texture. Where the Primordial is absent, and the Carboniferous rests directly on the Archean, a limestone has been observed at the contact, but this is a local phenomenon, the meaning of which is that certain Archean mountains were islands in the Silurian sea and were afterward covered or more deeply submerged by the Carboniferous sea.

[1] Geog. and Geol. Expl. and Surveys West of One hundredth Merid., 1875, Geology, vol. 3, pp. 521-522.

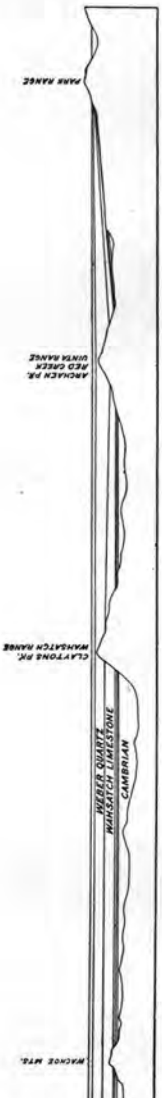


FIG. 77.—Section showing configuration of Archean bottom of the ocean in which Paleozoic sediments were deposited; also the general members of the Paleozoic series in position of conformable deposition. (After King.)

The conclusion to be drawn from the coarse fragmental nature of the lower deposits is that the water which spread them was an encroaching ocean, rising to possess land that had long been dry. The recognized interpretation of a widespread sandstone is continental submergence, or, what is the same thing, an advancing coast line, and where the formation is important in depth, as well as breadth, we must suspect at least that the shore waves sorted not merely the detritus which they themselves tore from cliffs of indurated rock, but other débris which they found already ground and which needed only redistribution. The Tonto sandstone of the Grand Cañon and its equivalent in other Territories may fairly be regarded as the coarser of the débris accumulated by subaerial agencies on the Archean continent; the continent—that is, which immediately preceded the Silurian sea, and the Tonto shale and its equivalents, as the finer and lighter part of the same débris, sorted out by primordial beach action and deposited in the stiller water that followed in the wake of the advancing shore. It would, perhaps, be out of place to controvert here the familiar presentation of eastern Paleozoic history as an emergence, beginning with the uplift of the Laurentian highlands, but it may confidently be asserted that western Paleozoic history is the reverse of this. There was a time when Archean highlands constituted islands in a Paleozoic sea, but this condition was produced, not by the emergence of these islands as the nuclei of a growing continent, but by the submergence of the surrounding area, and the consequent abolition of a continent, and, so far as we can judge of the remoteness of shores and of the depth of water, by the relative importance of calcareous and earthy soluble and insoluble deposits, the general movement of land through the entire Paleozoic age was a subsidence. Of the extent of the pre-Silurian continent we know absolutely nothing. No portion of its shore is determined, nor the position of any reservoir for the reception of its waste. The break which its existence made in the sedimentary history of this portion of the world appears to be absolute, and with its extinction as a continent and division into islands by the Primordial sea begins our acquaintance with the early limits of land and water.

The second, by Mr. Clarence King, is less general and the observations were confined to a more limited area. In speaking of the surface upon which the Paleozoic rocks were deposited north of the line of the fortieth parallel, between the Archean highlands of western Nevada and Medicine Bow range, Colorado, or between the one hundred and fifth and one hundred and twentieth meridians, he says:[1]

[1] U. S. Geol. Expl. of Fortieth parallel. Systematic Geology, 1878, vol. 1, pp. 228, 229.

Referring to Analytical Geological Map I, accompanying the Archean chapter, and observing the ideal section at the bottom of the map, the reader will perceive that the bed on which the Paleozoic series have been imposed was by no means a plain; on the contrary, it was a vast mountain system which had suffered submergence, and over which the Paleozoic sediment settled. One feature of importance is the fact that there is little or no tendency on the part of the sediments of a given horizon to follow the hill slopes, but in all cases where observed they abut directly against them as if deposited in absolute horizontality. Owing to the very great height of these Archean ranges, reaching in one instance an abrupt cliff slope of 30,000 feet, the earlier sediments, those of the Cambrian and Silurian, must have been deposited chiefly in what were the valleys of the submerged Archean mountain system. The base of the Cambrian is never seen. To the full section, as observed, there is, therefore, an unknown plus quantity to be added.

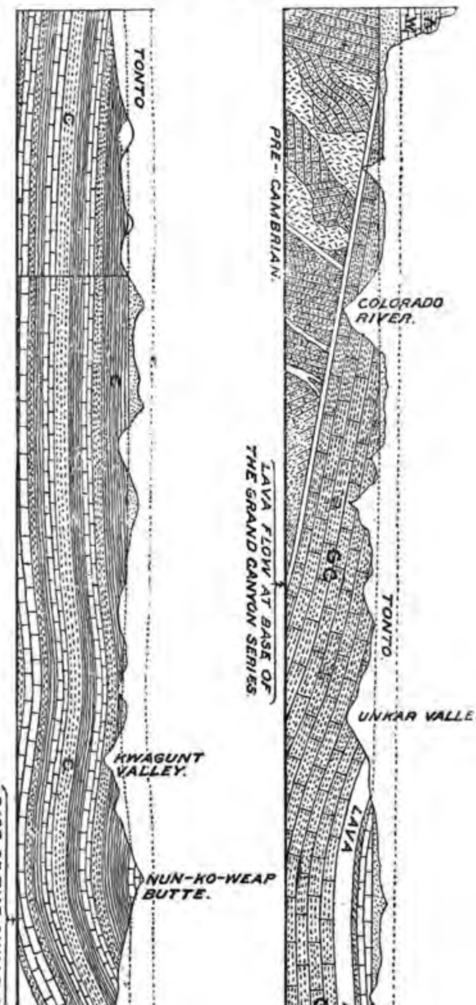


FIG. 78.—Grand Canyon Section. This section crosses the Algonkian and pre-Algonkian strata nearly at right angles to their strike and illustrates the unconformity between the Cambrian and pre-Cambrian rocks. The Cambrian (Tonto) formation has been removed by erosion on the direct line of the section, but it is shown on the sides of the canyon as indicated by the dotted line. The letters G C, and C' equal the Grand Canyon and Chuar formations, or strata referred to the Algonkian. T = Tonto formation of the Cambrian. W = Red Wall limestone of the Lower Carboniferous. A = Aubrey sandstone of the Carboniferous. The plane of the pre-Cambrian surface is shown by the lower dotted lines when the Tonto sandstone is absent.

In 1877 Mr. Clarence King expressed the view that "Archean America was made up of what was originally ocean beds lifted into the air and locally crumpled into vast mountain chains, which were eroded by torrents into true subaerial mountain peaks." He says that[1] "in pre-Cambrian time this continental area sank, leaving some of its mountain tops as islands, and the neighboring oceans flowed over it, their bottoms emerging and becoming continents." The rate of depression of the Archean continent is considered to have been more rapid upon the Atlantic side than upon the Pacific. To account for the vast volume of sediment poured into the Paleozoic ocean it is suggested that continental land areas (Atlantis and Pacifis) existed east and west of the present continental area. From the character of the sediments he concludes that the eastern side went down by gradual and successive subsidence, and that the western sank at once so as to form a profound ocean, which, from beginning to end of the vast Paleozoic age, received in its quiet depth the dust of a continent and the débris of an ocean life.[2]

In the Grand Canyon area of northern Arizona a base level of erosion appears to have been reached before the Cambrian rocks exposed on the line of the canyon section were deposited. Both the Archean and Algonkian rocks were eroded nearly to a horizontal plane, prior to the deposition of the Upper Cambrian sandstone. Here and there a harder layer of lava or quartzite forms a low ridge, but as a whole, the basal layers of the Cambrian were deposited upon a nearly level surface. This is well shown in the accompanying figure (Fig. 78).

INTERIOR CONTINENTAL PROVINCE.

After speaking of the geography at the close of the Keweenawan period, Prof. T. C. Chamberlin says:[3]

As soon as the foregoing elevation [Keweenawan] had lifted the region from the sea, arching it upward into lofty land, a fresh impetus was given to the old-time never-ending process of land-wearing and sea-filling. The rains and the agencies which they called into action softened, dissolved, and abraded the surface, and bore the resulting material down to the sea to fill its bed, and, to that extent, to lift its surface. The sea, on its part, ground away at the borders of the land, wearing back the shore line, little by little, through the lapse of ages. These general facts are certain, but for a long period following the Keweenawan elevation, during which the sea was slowly readvancing from the distance to which it had retired, and before it again reached our borders, there is, in the interior, no definite record of geological events, for the deposits are concealed. What were the special details of that long history we may never know from any evidence found in the interior of our continent.

When speaking of the geography of the Potsdam period he says:[4]

To picture the geographical circumstances that attended the commencement of the Potsdam formation, the earliest Wisconsin member of the Paleozoic series, conceive the whole or the greater portion of our State to be above the sea, and to be attached to the Archean continent lying to the northward, forming one of its southward-projecting promontories. The sea lay to the southward, and during the period gradually advanced upon the land. At a very early stage it crept up through the basin of the lower peninsula of Michigan, and entered the depression of Lake Superior. At the same time it appears to have advanced through the stratigraphical

[1] Catastrophism and Evolution. Am. Nat., 1877, vol. 11, p. 455.
[2] Op. cit., p. 456.
[3] Geological Survey of Wisconsin, 1873, vol. 1, p. 116.
[4] Ibid., p. 119.

basin lying beneath Iowa and southern Minnesota, and reached well to the northward on that side, partially surrounding the Archean heights of northern Wisconsin, forming a peninsula connected with the mainland only by an isthmus in the upper St. Croix region. This stage was apparently reached at about the middle of the period. During the latter part the sea continued its advance, reducing the peninsula and narrowing the isthmus. It is a matter of some difference of opinion whether or not by the close of the period the neck of land was entirely severed, making the peninsula an island. In the judgment of the writer the sea crossed the neck, cutting off the Archean heights and reproducing the *Island of Wisconsin*. If this view be correct the water swept entirely around the old granite highlands, submerging three-fourths or more of the State, but leaving reefs and islets formed of resistant portions of the Huronian rocks, lying off the southern shore of the main island in central Wisconsin. (See Pl. XLIV, Fig. 1.)

Prof. R. D. Irving after describing the lithological characters of the rocks that form the pre-Potsdam land surface of Wisconsin, says:[1]

The surface is one, in the main, of but gentle undulation. In the vicinity of Lake Superior it reaches an altitude of about 1,000 feet above the level of Lake Michigan; underneath the horizontal formations of the southern part of the map it stands about 500 feet below the same level, having at the present time a general southerly descent. Looked at in greater detail, however, it is seen to have numerous minor and often somewhat abrupt irregularities. The more abrupt of these have an evident genetic relation to the durability and general resisting power of the rocks which compose them. These prominences, in that portion of the ancient land surface which is still uncovered by later formations, reach at times elevations of from 100 to 600 feet above the general surface. Those that rise from beneath the Potsdam sandstone rise to about the same extent above the general level of the surface upon which that formation lies. There is one exception to this, however, in the case of the Baraboo Ranges, the present elevation of whose summits above the general Archean surface is in the neighborhood of 1,200 feet, the rock being of an unusually resistant nature.

Of the opportunities for studying the ancient pre-Cambrian surface Prof. Irving says:

It is doubtful whether anywhere in the world there are to be met with among the ancient formations more admirable reproductions of the conditions which obtain at the present time on every cliffy seashore than are found in the Baraboo region. A few days' examination of this region enables one to obtain a most vivid mental picture of the conditions which obtained at the time when the sandstone was in process of accumulation. He sees great east-and-west rocky ridges, at times with jagged edges just awash, at other times rising into smoothed and rounded rocky islets, and again buried some distance beneath the surface of the sea, and all about and against them growing the deposits of the sand washed from them by the waves.[2]

DESCRIPTION OF PLATE XLIV.

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

[1] On the classification of the early Cambrian and pre-Cambrian formations, Seventh Ann. Rept. of the U. S. Geol. Survey, 1888, p. 401.

[2] Ibid., p. 407.

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 Keweenawan series and Potsdam sandstone. (After Irving, Seventh Ann. Rep. U. S. Geological Survey, p. 413, Fig. 88.)

The pre-Cambrian land surface of the Ozark area of Missouri is beautifully illustrated by some topographical sections of the Pilot Knob district prepared by Prof. R. Pumpelly.[1] These sections show that the sandstones and magnesian limestones of the Upper Cambrian and Lower Silurian (Ordovician) were deposited in the basins and against the sides of the Archean hills and ridges of pre-Cambrian rocks.

Prof. J. C. Broadhead, in discussing the geological history of the Ozark uplift, says:[2]

> The evidence is that the sandstones and magnesian limestones (Potsdam and Calciferous) were deposited in Archean valleys of erosion, for they generally repose nearly horizontally, or with slight inclination upon the Archean.

The pre-Cambrian surface of the Adirondacks has been mentioned in connection with the remarks on the pre-Cambrian surface of the Appalachian province.

When describing the Upper Cambrian sandstones of the Black Hills of Dakota, Prof. Henry Newton states that:[3]

> We may thus, from a study of the Potsdam rocks and their relations, infer with a high degree of probability that at this early time the Black Hills were already marked out, and that they stood above the waves of the Potsdam shallow sea, probably as a long, low reef or island. This reef was undoubtedly as long as we now find the exposure of the Archean rocks, and may even have been of greater length, as we do not know the character of the unexposed Potsdam of the Hills.
>
> Again, the Archean rocks were, in Potsdam time, metamorphosed to nearly or quite the same extent as now, for the fragments composing the conglomerate are of the same character as the still unbroken strata of the metamorphic slates and schists. The slates were also tilted to their present high inclination, for upon their upturned surfaces the Potsdam rests unconformably, and if any tilting of the metamorphic rocks had taken place since the deposition of the Potsdam the evidence would be found in great breakings and fractures in the sedimentary rocks.
>
> At the beginning of the Lower Silurian term we may hence imagine the Black Hills, and possibly a much more extended region, as an island ("an island" because the conglomerate is on both sides of the present axis), a reef of schists, quartzites, slates, and granites, running northwest and southeast. Barren and desolate we may

[1] Atlas accompanying report on iron ores and coal fields, Geol. Survey of Missouri, 1873, Pl. 1a.

[2] American Geologist, vol. 3, 1889, p. 8.

[3] Geology and Resources of the Black Hills of Dakota, 1880, p. 105.

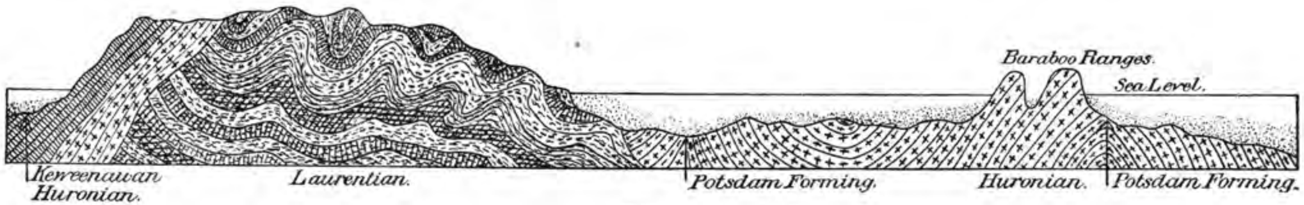


Fig. 1.

Fig. 2.

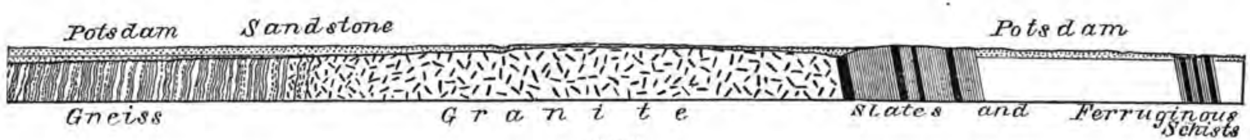


Fig. 3.

Fig. 4.

SECTION SHOWING DEPOSITION OF POTSDAM SANDSTONE IN WISCONSIN.

picture this island, for we know of no plants nor land animals that then had their existence. The only moving things that left their record were the waves that rolled over a broad and shallow sea and broke the silence by dashing against the primordial land. Slowly but surely they tore and undermined its cliffs and rolled away the fragments to form the conglomerates and sandstones of another age. The inequalities of the Archean shore became gradually filled up, and as the sea rose higher upon the land all that was not worn away at last became entirely covered by the Potsdam Sea and its sediments.

The relations of the Upper Cambrian sediments of Montana, Wyoming, and Colorado all indicate the same condition of pre-Cambrian surface as those of Wisconsin and the Black Hills, or, in other words, the advancing sea found in these areas a more or less irregular surface of mountain ridges, valleys, and plains very much like that of the present time. The outward slope of the Cambrian strata from the pre-Cambrian rocks indicates that the mountain masses have been elevated more or less on the same bases that they occupied at the beginning of Cambrian time.

In a note on the pre-Paleozoic surface of the Archean terrane of Canada Dr. A. C. Lawson sums up the evidence relating to the character of that surface as follows:[1]

Thus, wherever careful observations have been made as to the nature of the superposition of the undisturbed Paleozoic rocks upon the Archean, whether in the Lake Superior country, eastern Ontario, Quebec, or Labrador, the evidence points to the same conclusion, i. e., that the early Paleozoic rocks were laid down upon a surface which did not differ essentially from that presented by the exposed Archean surface of the present day upon which the great Canadian glacier rested, and that there is no good evidence of that surface having undergone any material reduction in level in consequence of the conditions of the glacial epoch, either by any plowing power, sometimes ascribed to glacier ice, or by the removal of the products of extensive rock decay.

CONTINENTAL FEATURES.

DANA.

Extending the range of observation from the minor details of the surface to the grander topographic features of the continent we find that Prof. J. D. Dana more definitely characterizes the continental area at the beginning of Paleozoic time than any other writer. He says:

The revolution closing the Azoic age, the *first* we distinctly observe in America, was probably nearly universal over the globe.[2]

Of the northern nucleus he says:

The earliest spot or primal area will be that of the Azoic rocks, the first in the geological series. Such an area (see Chart A A A) extends from northern New York and Canada northwest to the Arctic Ocean, lying between the line of small lakes Slave, Winnipeg, etc.,) and Hudson Bay. East and west it dips under Silurian strata (S S), but it is itself free from superincumbent beds, and therefore, even in the Silurian age, it must have been above the ocean. And ever since, although subject, like the rest of the world, to great oscillations, it has apparently held its place with wonderful stability, for it is now, as probably then, not far above the ocean's level.

[1] Bulletin, Geological Society of America, 1890, vol. 1, p. 169.
[2] On Am. Geol. Hist., Am. Jour. Sci. 2d ser., 1856, vol. 22, p. 330.

This area is central to the continent, and, what is of prominent interest, it lies parallel to the Rocky Mountains and the Pacific border, thus proving that the greater force came from that direction in Azoic times as well as when the Rocky Mountains were raised. Thus this first land, the germ or nucleus of the future continent, bears in itself evidence with respect to the direction and strength of the forces at work. The force coming from the Atlantic direction has left comparatively small traces of its action at that time. Yet it has made its mark in the Azoic, stretching through Canada to Labrador, in the dip and strike of the New York Azoic rocks in the direction of the channel of the St. Lawrence and the northwest coast of Lake Superior, and probably also in the triangular form of Hudson Bay. Against this primal area, as a standpoint, the uplifting agency operated, acting from the two directions—the Atlantic and the Pacific, and the evolution of the continent took place through the consequent vibrations of the crust, and the additions to this area thereby resulting, the ocean in the meantime pursuing its appointed functions in the plan of development by wearing exposed rocks and strewing the shores and submerged surface with sand, gravel, or clay, or else growing shells, corals, and crinoids, and thus storing up the material of strata and burying the life of successive epochs.[1]

Through these means the continent which was begun at the far North, a region then tropical but afterwards to become inhospitable, gradually expanded southward, area after area as time moved on being added to the dry land.[2]

The Appalachian range of heights, as I explained a year since, was commenced in the Silurian age, and even earlier, long before a trace of the mountains had appeared. The force from the southeast, in the dawn of the Paleozoic era, had made the Appalachian region generally shallower than the Mississippi valley beyond. The vast sandstone and shale deposits of the region bear marks in many parts of seashore action, while the limestones which were forming contemporaneously farther west indicate clearer and somewhat deeper seas; and the patch of Azoic in northern New York, lying at the northern extremity of part of the range, points to an anterior stage in the same course of history; so that in early time, long before there were mountains, the future of the continent, its low center and high borders, was foreshadowed. We can hardly doubt that the region of the Rocky Mountains was in the same condition, in the main, with that of the Appalachians. Moreover, these borders, or at least the eastern, for ages anterior to the making of the mountains, were subject to vastly greater oscillations than the interior; for the Silurian and Devonian sandstones that occur along from New York to Alabama are of great thickness, being five times as thick as the limestones and associated deposits of the same age to the west. A limestone bed, moreover, is of itself evidence of comparatively little oscillation of level during its progress.

We hence learn that in the evolution of the continental germ, after the appearance of the Azoic nucleus, there were two prominent lines of development: One along the Appalachian region, the other along the Rocky Mountain region; one, therefore, parallel with either ocean. Landward, beyond each of these developing areas, there was a great trough or channel of deeper ocean waters, separating either from the Azoic area.[3]

On the map accompanying this paper Prof. Dana illustrates his view of the nucleal V of the continent, but does not indicate the development at that time above sea level of the Appalachian and Rocky Mountain ranges. In a later paper on the Appalachian and Rocky mountains as time boundaries in geological history he[4] concludes

[1] On the Plan of Development in the Geological History of North America. Am. Jour. Sci., 2d ser., 1856, vol. 22, pp. 341, 342.

[2] Op. cit., p. 343.

[3] Op. cit., p. 344.

[4] Am. Jour. Sci., 2d ser., 1863, vol. 36, p. 227.

that the Appalachians date from the closing act in Paleozoic history, and at the introduction of Cenozoic time the mass of the Rocky Mountains began to rise above the ocean.

With the increase of information Prof. Dana gradually extended his views, and in 1875 summed them up as follows:[1]

On the map, p. 149, the striking fact is shown that the great northern V-shaped Archean area of the contment has (1) its longer arm, B B, parallel approximately to the Rocky Mountain chain and the Pacific border, and (2) its shorter, C C, parallel to the smaller Appalachian chain and the Atlantic border. Further, of the other ranges of Archean lands (1) there is one near the Atlantic border in Newfoundland, Nova Scotia, and New England; (2) another along the eastern side of the Appalachian chain; (3) two or more of great length along the Rocky Mountain chain, and (4) others, not included in the above, lie in ranges parallel to these main courses. Moreover, the Archean rocks of these regions were upturned and crystallized before the Silurian age and probably at two or more different epochs, and some, if not all, were thus early raised into ridges, standing not far below the water's surface, if not above it.

Hence, in the very inception of the continent not only was its general topography foreshadowed, but its main mountain chains appear to have been begun and its great intermediate basins to have been defined—the basin of New England and New Brunswick on the east; that between the Appalachians and the Rocky Mountains over the great interior; that of Hudson Bay between the arms of the northern V. The evolution of the grand structure lines of the continent was hence early commenced, and the system thus initiated was the system to the end. Here is one strong reason for concluding that the continents have always been continents; that, while portions may have at times been submerged some thousands of feet, the continents have never changed places with the oceans. Tracing out the development of the American continent from these Archean beginnings is one of the main purposes of geological history.

In conformity with the broad structural features, the continental area was divided off into the following regions:

1. *The Eastern Border basin or region*, east and northeast of the Green Mountain range, including New England, eastern Canada, New Brunswick, western Nova Scotia, the Gulf of St. Lawrence, and Newfoundland.

2. *The Appalachian region*, along the course of the Appalachians, through the Green Mountains, to the vicinity of Quebec.

3. *The Interior Continental basin*, between the Appalachians (with the Green Mountains, properly the northern part of them) and the Rocky Mountain chain.

4. *The Western Border basin*, west of the Rocky Mountain summit.

A great Arctic border and a Rocky Mountain region may hereafter be recognized, but the facts thus far collected do not at present make it necessary to refer separately to them.[2]

In a still more recent paper Prof. Dana says, when summing up his study:

It is of the highest interest to find, in such a review of events marking off the growth of the continent, that the grander lineaments were well defined and the grander movements initiated in its early beginning. Surely there can be no mistake

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[1] Manual of Geology, 2d edition, 1876, pp. 160, 161.

[2] Op. cit., p. 146.

in the conclusion that the continent has ever been a unit in its system and laws of development, or the wider conclusion that all the continents "have had their laws of growth, involving consequent features, as much as organic structures." (Expl. Exped., 4to; Report, p. 436, 1849.)[1]

In a subsequent paper on the Archean axis of eastern North America he describes the ranges partly or wholly Archean lying east of the Appalachian protaxial range as follows:

THE RANGES.

The ranges, partly or wholly Archean, lying to the east of the Protaxial Range are the following—numbering the protaxis I, as it is the first in the series:

II. The *New Hampshire Range*, extending from the borders of Maine and Canada through New Hampshire and Massachusetts into Connecticut, making the east side of the Connecticut Valley.

III. The *Mount Desert Range*, commencing near Chaleur Bay, on the Gulf of St. Lawrence, and continued southwestward through New Brunswick to the coast of Maine, where it includes the Mount Desert region, and thence into eastern Massachusetts between Boston and Worcester, and probably into Connecticut.

IV. The *Acadian Range*, commencing in the western part of northern Newfoundland, east of White Bay, and extending thence to St. George Bay, and Cape Ray, in the southwestern, and beyond over eastern Nova Scotia; and thence, probably, beneath the sea along the course of shallow soundings, as sustained by Prof. W. O. Crosby, to Plymouth and Cape Cod, in eastern Massachusetts.

The Archean ridge of the long northwestern arm of Newfoundland, north of the Bay of Islands, making the northern part of the so-called "Long Range," is a more western range than the preceding; it is separated from the Archean region of Labrador by the Belleisle Strait or Channel.

V. The *Central Newfoundland Range*, extending over a broad region east of the Exploits River Valley to the east side of Exploits Bay.

Besides these ranges there appear to be two other more or less complete ranges separating pairs of bays that head together, and then, the easternmost, that of Ferryland.[2]

Of the valleys or troughs occurring between these ranges he says:

The troughs into which the country is topographically divided by these ranges were the rock-making troughs or basins of Paleozoic time, and partly of Mesozoic, and were more or less independent in their geological history, especially after the Lower Silurian era. The Lower Silurian and Cambrian beds often spread from one of these troughs to another, and across the protaxis, over portions that were then submerged.[3]

He thus sums up the results of this and his previous paper:

The facts illustrate strikingly the great truth that the earth's features even to many minor details were defined in Archean time, and consequently that Archean conditions exercised a special and even detailed control over future continental growth. The extension of North America to the most eastern point of Newfoundland, and beyond it, was determined in this beginning time, and likewise that of the European continent to the Hebrides, in front of the Scandinavian Archean area.[4]

[1] Areas of continental progress in North America and the influence of the conditions of these areas on the work carried forward within them. Bulletin Geol. Soc. Am., 1889, vol. 1, p. 48.

[2] Archean Axis of Eastern Northern America. Am. Jour. Sci., 3d ser., 1890, vol. 39, pp. 379, 380.

[3] Op. cit., p. 380.

[4] Op. cit., p. 383.

Mr. G. K. Gilbert's observations on the great pre-Paleozoic stratigraphic break have been quoted (ante, p. 551). At the time of making them he did not recognize the great troughs on the eastern and western sides of the continent in which some of the sediments of late Algonkian time appear to have been deposited.

CHAMBERLIN.

When making observations upon the pre-Laurentian history of the North American continent Prof. T. C. Chamberlin described the location of the primitive land as follows:[1]

> Precisely what was the location of the primitive land we do not know, for there is as yet no clear proof that the earliest sediments which we have studied were the earliest formed, while it is almost certain that the earliest lands which we can map did not constitute the primitive continent. But it is highly probable that the earliest known sediments were near those actually first formed and hence near the first land. The tenor of geological evidence is to the effect that the land has been essentially constant in position from the beginning, and it is a well-known fact that the greater part of oceanic sediments accumulate near the land whence the material is derived.

Of the earliest known land he says:

> Now, the earliest known land in our quarter of the globe consists of a great V-shaped or U-shaped area occupying the northern part of our present continent, embracing Hudson Bay between its great arms and resting its point on the great lake region. From the latter one broad belt stretches northwesterly to the Arctic sea and another northeasterly to the coast of Labrador. South of Lake Superior there arose an island which will become to us an object of especial interest, since around it gathered the formations which at length produced the substructure of our State.
>
> There probably existed at the same time a long island parallel and adjacent to the present Atlantic coast, which became the basis of growth in the Appalachian region. Although our knowledge of the Archæan geology of the mountain belt of the West is limited, sufficient is known to warrant the statement that there were elongated areas or lines of islands along its axis that became the germs of growth of the western border lands.
>
> Within these greater ranges scattered islands or archapelagoes seem to have appeared, the remnants of which are now found in Missouri, Arkansas, Kansas, Indian Territory, Texas, and the Adirondack region of New York. The last, however, may have been a peninsula. All these areas were doubtless really more extensive than the present mapping, based on their worn remnants, indicates. Some of them may, however, be due to subsequent elevation.
>
> In a generalized view it may be said that there was a V-shaped area in the northern part of the continent, flanked on the southeast and southwest at moderate distances by linear belts, parallel respectively to the arms of the V, leaving between them a Y-shaped sea.[2]

A map entitled "Approximate map of Laurentian land in North America" accompanies these illustrations and defines the author's view of the extent of the Laurentian land areas prior to the deposition of the great intermediate series of rocks which are now classified under the Algonkian system.

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[1] Geology of Wisconsin, vol. 1, 1883, p. 61.
[2] Ibid., pp. 61-62.

My own work on the Cambrian formations and the subjacent comformable series beneath them in the Appalachian and Rocky Mountain areas has led me to consider that the prevailing view of the geographic distribution and extent of the continental area at the beginning of Paleozoic time is too restricted. If the interpretation, as represented on Pl. XLIII, be correct, the continent was larger at the beginning of the Cambrian period than during any epoch of Paleozoic time, and probably not until the development of the great fresh-water lakes of the Lower Mesozoic was there such a broad expanse of land upon the continental platform between the Atlantic and Pacific oceans. The agencies of erosion were wearing away the surface of this Algonkian continent and its outlying mountain barriers, to the eastward and westward, when the epoch of the Lower Cambrian or Olenellus zone began. The continent was not then new. On the contrary, it was approaching the base level of erosion over large portions of its surface. The present Appalachian system of mountains was outlined by a high and broad range, or system of ranges, that extended from the present site of Alabama to Canada, and subparallel ranges formed the margins of basins and straits to the east and northeast of the northern Paleo-Appalachians or the Paleo-Green Mountains, and their northern extension toward the pre-Cambrian shore-line of Labrador. The Paleo-Adirondacks joined the main portion of the continent, and the strait between them and the Paleo-Green Mountains opened to the north into the Paleo-St. Lawrence Gulf, and to the south extended far along the western side of the mountains and the eastern margin of the continental mass to the sea that carried the fauna of the Olenellus epoch around to the Paleo-Rocky Mountain trough.

On the Pacific side the eastern mass of the Paleo-Rocky Mountains rose as a broad mountain barrier upon the western side of the continental area, from the present sites of Arizona and New Mexico to Montana, where a strait or sea opened across the range to an interior sea that extended north on the eastern side of the mountains towards the Arctic Circle. To the west the primitive Sierra Nevada protected the Nevada sea, in which the life of early Cambrian time was spreading.

The continent was well outlined at the beginning of Cambrian time; and I strongly suspect, from the distribution of the Cambrian faunas upon the Atlantic coast, that ridges and barriers of the Algonkian continent rose above the sea, within the boundary of the continental plateau, that are now buried beneath the waters of the Atlantic. On the east and west of the continental area the pre-Cambrian land formed the mountain region, and over the interior a plateau existed that at the beginning of, or a little before, Upper Cambrian time was much as it is to-day. Subsequent mountain building has added to the bordering mountain ranges, but I doubt if the present ranges are as great as those of pre-Cambrian time that are now known only by more or less of their truncated bases. The Interior Continental area was outlined then and it has not changed materially since. Its foundations were built in Algonkian time on the Archean basement, and an immense period of continent growth and erosion elapsed before the first sand of Cambrian time was settled in its bed above them.

If these conclusions are correct, it is evident that the continental area and the deep seas (Atlantic and Pacific) have retained their relative positions since the beginning of Algonkian time. There is certainly no evidence to show that since the beginning of Paleozoic time the continent has ever formed the bottom of a great oceanic basin, or that the beds of the deeper seas have been elevated above the surface of the water, and this is probably true since the contours of the continental plateau were first marked off. The indications are that the oceans have grown deeper and the continents broader since the first beginning of the land areas that formed the nuclei of the continent. If this be true, the continent has grown by the extravasation and deposition of volcanic rocks and by the tendency of the earth's crust to consolidate in some areas and push the surrounding matter up into continental masses. The scope of this paper and the range of the author's studies do not permit of a discussion of the theory. The continent is considered at the inception of Cambrian time, and its history traced in a broad manner to the closing epoch of the period.

In the first section (ante, p. 532), on the deposition of sediments now forming the Cambrian group of rocks and their relation to pre-Cambrian and post-Cambrian formations, the evidence is mentioned upon which the pre-Cambrian form of the continent is outlined. On the section at the base of Pl. XLII the presence of deep troughs westward of the Appalachian Archean protaxis and the Rocky Mountain protaxis is distinctly shown; also that during the deposition of the Lower and Middle Cambrian a great plateau existed between the Appalachian and Rocky Mountain regions. The section over the interior continental plateau indicates that perhaps with one exception, that of the central Texas section, only sediments of Upper and closing Middle Cambrian age were deposited. The view that such Cambrian sediments were deposited during the transgression of the sea across the interior is supported by the fact that the rocks are largely composed of sand and mechanical sediments such as would be deposited by an advancing sea. In the deeper water areas of the Appalachian and Rocky Mountain troughs the corresponding horizon is represented by calcareous shales and limestones, with the exception of where it is in the immediate vicinity of the shore line, or within the area of currents that carried fine sediment farther out from the shore.

MIDDLE CAMBRIAN LAND.

There is little definite data for the construction of a map of the continent during Middle Cambrian time. The narrowing of the land areas that existed at the beginning of Cambrian time, and the probable presence of a barrier between the Atlantic coast and Appalachian provinces appears to be all the changes recorded. The latter is supposed to have prevented the Paradoxides fauna of the Atlantic coast province from penetrating into the Appalachian trough, either to the north in the St. Lawrence and Champlain valleys or along the line of the southern Paleo-Appalachians. The possible exception to this is in the southern limit in Alabama, where a few types of Paradoxides fauna of Newfoundland and Sweden occur in association with the characteristic Middle Cambrian fauna of the Appalachian and Rocky Mountain provinces. The presence of this fauna indicates that there was a line of communication between the North Atlantic province and the southern portion of the Appalachian trough, to the eastward of the Paleo-Appalachian barrier, during Middle Cambrian time.

Owing to the fact that the Middle Cambrian zone is differentiated from the Lower and Upper in the great Paleo-Appalachian and Paleo-Rocky Mountain troughs, and that its upper zone occurs in the Interior Continental area, a map of these provinces from existing data would show a deep contraction of the margins of the central area and a slight narrowing of the bordering ridges.

During the field season of 1891 I had the opportunity of examining sections of the Cambrian rocks in Virginia, Tennessee, Georgia, and Alabama. Special attention was given to the middle zone, as the data upon it was limited to the one fact that the Middle Cambrian fauna was known to occur in the Coosa Valley of Georgia and Alabama. At the Balcony Falls section of Virginia the Olenellus fauna was found just above the upper massive Scolithus quartzite, and the zone of the Middle Cambrian was limited to the relatively thin belt of ferriferous shales, if the discovery of the Upper Cambrian fauna in the yellowish shales just beneath the limestones proves correct.[1] No fossils were found in the Doe River and Nulichucky River sections of Tennessee, but they are interpreted by the Balcony Falls section. In each there is a great thickness of Lower Cambrian sediments, and only a few hundred feet of strata that are referred to the Middle and Upper Cambrian.

The data for the interpretation of the physical conditions of the Paleo-Appalachian trough during Middle Cambrian time was obtained in southeastern Tennessee, and northwestern Georgia. It shows that the barrier that closed the Appalachian sea to the fauna of the Atlantic coast province was a shallowing of the interior sea, and that very little, if any, deposition of sediment occurred until well into Middle Cambrian time. The Knox sandstone of Safford is well developed in the vicinity of Cleveland, Tennessee. It is superjacent to a considerable thickness of variegated shales and thin sandstones, that are capped by a massive siliceous limestone. The Olenellus fauna was found in the shales and in the base of the sandstones above the limestone. In the middle and upper portion of the sandstones the fauna is characteristic of the central zone of the Middle Cambrian fauna as it occurs in Dutchess County,

[1] For a description of the Balcony Falls section see Bull. U. S. Geological Survey, No. 81, 1891, pp. 293-298

New York, Antelope Springs, Utah, and near Pioche, Nevada. Fifty miles southward, in the Coosa Valley of Georgia and Alabama, the Rome sandstone carries the fauna characteristic of the central zone of the Middle Cambrian, but not the Olenellus fauna. A series of arenaceous, calcareous, and argillaceous shales and thinly bedded rocks, over 2,000 feet in thickness, come in beneath the sandstone that are not represented in Tennessee, and, farther north, they contain a strongly marked Middle Cambrian fauna, a portion of which is identical with that of the Paradoxides fauna of the Atlantic Basin, Newfoundland, Sweden, etc. Applying these facts to the interpretation of the physical conditions of the Appalachian province during Middle Cambrian time, the following conclusions are reached:

1. Most of the Paleo-Appalachian sea became very shallow and was practically an area of very slight or no deposition of sediments from the close of the Olenellus zone until the middle part of Middle Cambrian time.

2. In the southern portion of the sea sedimentation went on as in the Paleo-Rocky Mountain sea, and accumulated the Coosa and Hoodoo shales.

3. Toward the close of the early part of Middle Cambrian time the Paleo-Appalachian trough began to deepen and to receive deposits of sand and clays, in which the later Middle Cambrian fauna was imbedded.

4. The contir ental depression that brought about the extension of the Upper Cambrian sea over the great interior of the continent began toward the close of Middle Cambrian time, as shown by the deepening of the Paleo-Appalachian trough and the presence of the upper phase of the Middle Cambrian fauna in the basal Cambrian sandstones of the Grand Canyon district of Arizona, and of Texas and Wisconsin.

5. The deepening of the Appalachian trough ceased, except at its southern end, during a considerable portion of late Cambrian time.

6. In the Paleo-St. Lawrence region the conglomerates of Lower Cambrian limestone were formed during the movement that deepened the more southern portion of the Paleo-Appalachian trough.[1]

POST-CAMBRIAN LAND.

At the close of Cambrian time and the beginning of Lower Silurian (Ordovician) time a greater change had taken place, owing to the extension of the Upper Cambrian sea over the broad interior of the continent and the submergence of all the low ground along the line of the barrier ridges and some portions of the great northern nucleal V of the Archean continent. The distribution of the Upper Cambrian and the Lower Ordovician fauna indicate free intercommunication between all the seas with the exception of the Atlantic coast front and the interior. Here a barrier appears to have existed which prevented the life of the Atlantic basin from penetrating into the interior seas of

[1] A full discussion of this subject will be published in a memoir on the Middle Cambrian rocks and faunas.

the Paleo-St. Lawrence and Paleo-Appalachian region. Within that barrier the same types and species of marine animals range from the Paleo-St. Lawrence Valley to British Columbia along the northern front south along the Paleo-Appalachians and Paleo-Rocky mountains, and on the shores of the islands of Wisconsin, Dakota, Missouri, and Texas. It is known that the gradually sinking continent soon depressed the barrier of the Atlantic side beneath the sea, and that by middle Lower Silurian (Ordovician) time the ocean had transgressed far upon the crystalline rocks of the nucleal V and deposited the sediments of the Trenton epoch over and beyond the ancient Cambrian shore-line and overlapped far to the north in Labrador, toward Hudson Bay and among the islands of the arctic region.

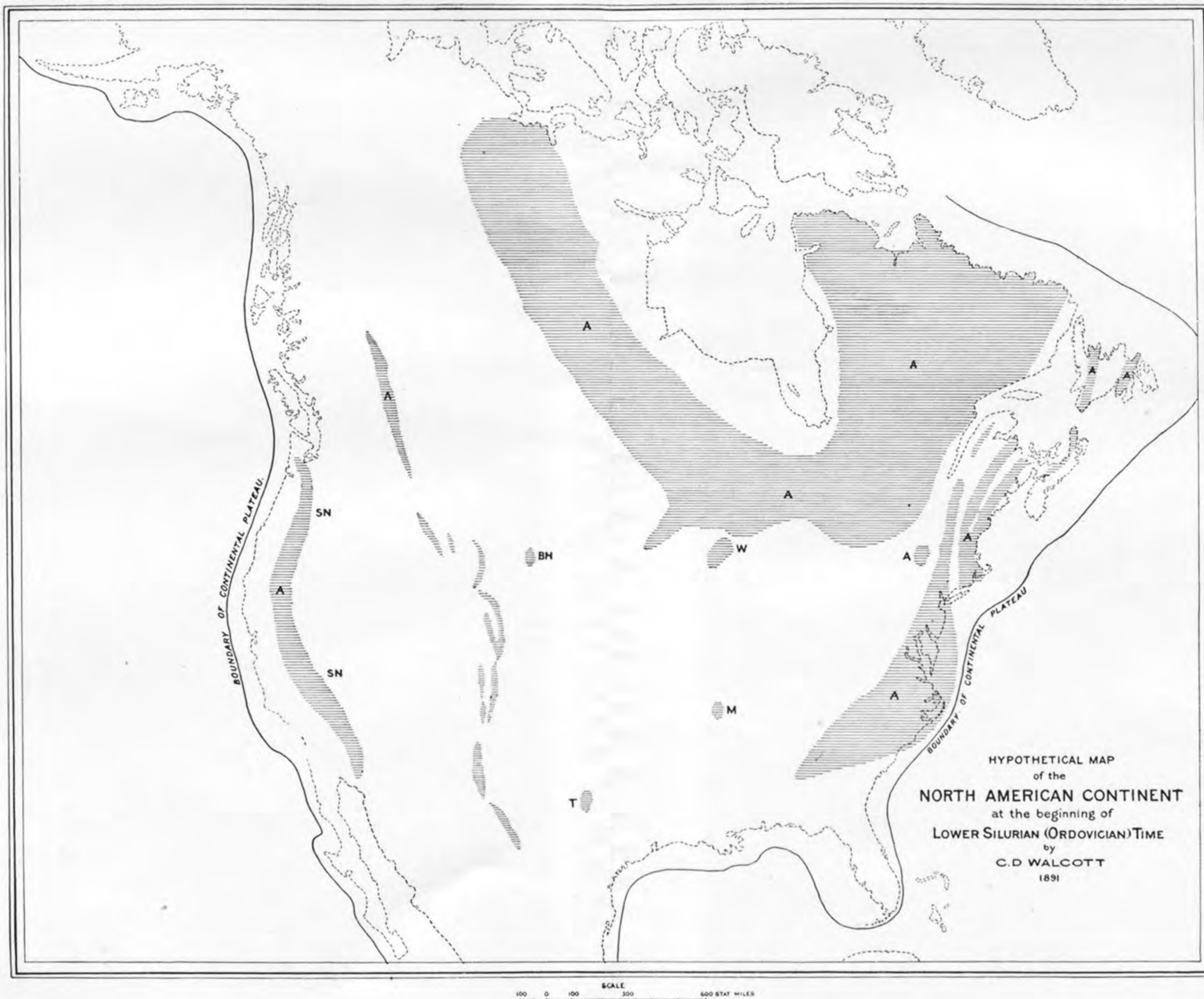
It is to be noticed that the sediments following those of the Upper Cambrian are largely calcareous. Over the areas of the Paleo-Appalachian and Paleo-Rocky Mountain seas this is almost universal, and over the broad interior continental area the closing sands of the Cambrian time are mingled with the calcareous sediments of the opening Lower Silurian (Ordovician). This fact has been so well brought out by Prof. Dana in his Manual of Geology that it is unnecessary at the present time to repeat the evidence. There is, however, the fact to be noticed that the accumulation of calcareous sediments in the Appalachian and Rocky Mountain troughs during the earlier portion of Lower Silurian (Ordovician) time, was far greater than over the Interior Continental area. This indicates a greater depression of the troughs than for the interior continental surface and lends a little support to the theory of Prof. James Hall (as expressed in the introduction of the third volume of the Paleontology of New York) that the accumulation of sediments caused the greater depression on the line of the Appalachians. With the view, however, that the troughs were formed by the contraction of the borders of the continental mass, and that the sediments accumulated to a great thickness in them owing to the favorable conditions for their deposition, the theory of Hall is not sustained.

DESCRIPTION OF PLATE XLV.

Hypothetical map of the North American continent at the beginning of Lower Silurian (Ordovician) time.

This map is based upon our present knowledge of the distribution of the sediments of the closing epoch of Cambrian time. The space with the horizontal ruling represents the supposed land areas and the white spaces within the boundary of the continental plateau the sea, or unknown land areas of which we have not any record.

The large islands are: A.=Adirondack, W.=Wisconsin, B. H.=Black Hills, M.=Missouri, and T.=Texas. The Paleo-Rocky Mountains are broken into short ranges, while the primitive Sierra Nevada (S. N.) is left unbroken. The Paleo-Appalachians and the eastern border are represented very much as on Pl. XLIII.



HYPOTHETICAL MAP
of the
NORTH AMERICAN CONTINENT
at the beginning of
LOWER SILURIAN (ORDOVICIAN) TIME
by
C. D WALCOTT
1891
BOUNDARY OF CONTINENTAL PLATEAU
BOUNDARY OF CONTINENTAL PLATEAU
A
A
A
A
A
A
A
A
A
A
SN
SN
BH
W
M
T
SCALE
100 0 100 300 600 STAT MILES

CONCLUSIONS.

1. The pre-Cambrian Algonkian continent was formed of the crystalline rocks of the Archean nuclei, and broad areas of superjacent Algonkian rocks that were more or less disturbed and extensively eroded in pre-Cambrian time. Its area was larger than at any succeeding epoch until Mesozoic time. (See Pl. XLIII, p. 546.)

2. On the east the Paleo-Appalachian system of mountains was outlined by a high and broad range, or system of ranges, that extended from the present site of Alabama to Canada, and subparallel ranges that formed the margins of seas and straits to the east and northeast of the northern Paleo-Appalachians or the Paleo-Green Mountains and their northeastern extension toward the pre-Cambrian shore line of Labrador.

3. On the Pacific side the eastern mass of the Paleo-Rocky Mountains formed a broad mountain barrier that extended from the present region of Arizona and New Mexico to Montana, and toward the Arctic circle, upon the western side of an interior continental land area. To the west the primitive Sierra Nevada protected the Nevada sea and extended far to the north.

4. The interior continental area was, at the beginning of Cambrian time, an elevated, broad, relatively level plateau between the Paleo-Appalachian sea on the east, and the Paleo-Rocky Mountain barrier on the west. (See Pl. XLIII and sections at the bottom of Pl. XLII.)

5. At the beginning of Cambrian time three principal areas of sedimentation existed: (*a*) The Atlantic coast province, including various narrow seas between the several pre-Cambrian ridges; (*b*) a narrow sea extending along the western side of the Paleo-Appalachian range from the present site of Labrador to Alabama; (*c*) a broader sea on the western side of the continent, west of the eastern Paleo-Rocky Mountain ranges that extended from the southern portion of the present site of Nevada northward into British Columbia and probably toward the Arctic circle, and south to the Paleo-Gulf of Mexico and thus connecting with the Paleo-Appalachian Sea.

6. Sedimentation probably began in the Paleo-Appalachian and Paleo-Rocky Mountain seas before Cambrian time, and it continued without any known unconformity to the close of Lower Silurian (Ordovician) time in the northern Paleo-Appalachian sea, and with relatively little interruption to the close of Paleozoic time in the Paleo-Appalachian sea south of New York, and in the Paleo-Rocky Mountain sea.

7. The Cambrian sea began to invade the great Interior Continental area in late Middle Cambrian time, and extended far to the north toward the close of the period, as indicated on Pl. XLV.

8. The depression of the continent in relation to sea level began in pre-Cambrian time and continued with a few interruptions until the close of Paleozoic time.

9. The relative positions of the continental area and the deep seas have not changed since Algonkian time.

10. The sediments of Cambrian time were accumulated to a great extent in approximately shallow seas except in portions of the Paleo-Rocky Mountain and Paleo-Appalachian seas.

11. The Lower Cambrian fauna lived in the seas of the Atlantic coast province, the Paleo-Appalachian, and the Paleo-Rocky Mountain seas.

12. The Middle Cambrian fauna of the Atlantic basin is not known to have penetrated into the Paleo-Appalachian or Paleo-Rocky Mountain seas, except in the case of a few species now found in Alabama and probably eastern New York. The portion of the fauna occupying the same relative stratigrapic position in the group is essentially the same in the Paleo-Appalachian and Paleo-Rocky Mountain sections.

13. The Upper Cambrian fauna was distributed over the broad Interior Continental area and in the Paleo-Appalachian and Paleo-Rocky Mountain seas, but it has not been recognized by the same genera and species in the Atlantic coast province, the fauna of the latter being more closely allied to that of the Upper Cambrian of the eastern side of the Atlantic basin.

THE ERUPTIVE ROCKS

OF

ELECTRIC PEAK AND SEPULCHRE MOUNTAIN, YELLOWSTONE NATIONAL PARK.

BY

JOSEPH PAXSON IDDINGS.

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THE ERUPTIVE ROCKS OF ELECTRIC PEAK AND SEPULCHRE MOUNTAIN, YELLOWSTONE NATIONAL PARK.

By Joseph Paxson Iddings.

INTRODUCTION.

For the student of igneous or eruptive rocks there is no question which excites greater interest, and the correct answer to which would be of greater importance, than that involving the relation or connection between the various forms and kinds of coarse grained rocks and the different varieties of glassy ones. Any group of observations, therefore, that bears upon this problem should be studied with the greatest care, in order that we may learn how far it contributes to our understanding of these intricate relations, which not only lie at the foundation of any system of classification of igneous rocks, but which must affect our comprehension of the real nature of the rocks themselves.

The observations recorded in the following pages appear to contribute so largely to certain phases of the problem that it is hoped they may be presented in such a manner that the reader will be able to judge whether the conclusions arrived at by the writer are sufficiently well founded.

This study forms a part of the work undertaken by the division of the U. S. Geological Survey under the charge of Mr. Arnold Hague, which has been investigating the region of the Yellowstone National Park. It constitutes a chapter of the contributions which are being made from time to time to the knowledge of this highly attractive region, where the character of the country is so diversified that the student is confronted by nearly every phase of geology, among the most prominent of which are the phenomena of volcanic action, including the distribution and character of the volcanic material, the physics and chemistry of the thermal springs, and the dynamics of erosion and glaciation—problems which are being investigated by different members of the division. The present paper deals with a group of eruptive rocks occurring at Electric Peak and Sepulchre Mountain, which has been studied with special care because of the bearing of the results upon the general petrological question already stated.

The eruptive rocks of Electric Peak and vicinity embrace a group of *intrusive* rocks that occur in the form of a stock with apophyses, breaking up through Cretaceous strata, which had already been penetrated by horizontal sheets of intrusive rocks from a neighboring center of eruption. They also include a group of *extrusive* or volcanic rocks, lying east of Electric Peak, which form the mass of Sepulchre Mountain and contain certain intruded bodies.

The object of the present paper is to describe the nature and occurrence of these intrusive and extrusive bodies and to trace the geological and lithological connections between them, and to show the development of crystallization and the resulting mineral constitution of magmas of similar chemical composition which have solidified under a variety of physical conditions.

GEOLOGICAL SKETCH OF THE REGION.

In order to obtain a clear idea of the geological relations between the various groups of eruptive rocks coming within the scope of this paper, it will be necessary to sketch briefly the leading features of the geology of the region; the more so since the connection between the intrusive and extrusive bodies must be traced across a profound fault, which has affected a large area, and has permitted subsequent erosion to expose deeply seated intruded bodies by the side of contemporaneous surface extrusions.

Electric Peak, 11,100 feet in altitude, lies on the northern boundary of the Yellowstone National Park, 10 miles from its western line. It is the highest point of that portion of the Gallatin Mountains situated within the Park limits. These mountains have been carved out of a block of sedimentary strata composed of limestones, shales, and sandstones of Paleozoic and Mesozoic age, which range from Cambrian to Cretaceous. This block, about 14 miles wide, at present occupies the trough between two great bodies of Archean rocks, and trends northwest and southeast. It has been subjected to a succession of dynamical forces, which have bent it into a general synclinal fold, the axis of which lies near the northern body of Archean, and trends northwest and southeast. They have also produced a number of smaller transverse folds and faults with a nearly north-northeast and south-southwest trend.

The general synclinal movement was accompanied by a series of intrusions of igneous rocks, which found their way between the sedimentary strata, wherever the fissile character of the beds presented planes of least resistance to the dynamical forces engaged in bending them. These intruded masses formed immense laccolites and thinner sheets, that penetrate the more fissile strata for miles, with only occasional changes of horizon.

One large body of eruptive rock is located about 4 miles southwest of Electric Peak, and appears to have been the source of a great number of the sheets, which are intercalated between the Cretaceous shales and sandstones of this mountain. As a result of the main synclinal movement the strata at Electric Peak have a general dip toward the northeast.

After the intrusion of the eruptive sheets a more local synclinal break occurred in the neighborhood of what is now Electric Peak, its axis trending northeast and southwest. The southeastern side of the fractured mass suffered the greater displacement, the strata being turned up vertically in some places. This break produced one or more large fissures and numerous smaller crevices, along which igneous rock was again forced through the shales and sandstones, in the form of a stock and dikes. The stock is located near the axis of the break, and the dikes, which are mostly vertical, branch out into the sedimentary beds for a short distance, and cut across the intruded sheets or cut between them where they had been previously turned up on end.

The igneous magmas which accompanied the convulsive movements of the ruptured strata and forced their way between them to cool as intrusive bodies, also reached the surface of the earth in places and took the form of extrusive masses. The ejected rocks were probably erupted from a number of different vents whose position was governed by the nature and extent of the fissures in the sedimentary rocks. They poured out as flows or massive eruptions and were subsequently blown to pieces and thrown into breccias and were occasionally cut by dikes. They undoubtedly formed very extensive bodies of volcanic ejectamenta which covered a large area of country.

After the intrusion of the stock and dikes just mentioned, and after the accumulation of the volcanic breccias, the region was broken by great faults. These faults trend nearly north and south and have caused great changes in the relative vertical position of the severed rocks, so that, after extensive erosion, deep-seated strata and intrusive bodies of erupted rocks are now exposed by the side of extravasated surface lavas.

The great erosion which carved the faulted blocks into the steep mountains and valleys of the Gallatin Range was followed by the eruption of the vast flows of rhyolite and less abundant basalt that form the plateau country to the south, since which time glaciation and erosion have still further modified the contour of the country.

ELECTRIC PEAK.

GEOLOGICAL DESCRIPTION.

The form and character of Electric Peak may be seen from the accompanying map and illustrations. The peak constitutes the highest point on the mountain ridge that stretches from Cinnabar Mountain to Mount Holmes. It is not an isolated mass, but is the most prominent portion of a range of mountains which present a continuous series of sedimentary strata. For the purposes of the present paper it will not be necessary to explain more of its geology than may be included in the statement that the mass of the mountain from the streams which bound it on the south and west is made up of Cretaceous shales and sandstones, the lower portion being mostly black shale with occasional beds of sandstone, the upper portion being mostly sandstone with occasional beds of shale. The south and west slopes of the mountain are largely shale, and the summit and the top of the northeast spur are sandstone. These beds pass uninterruptedly into the broad ridge, which is north of the peak, and are well exposed on the south face of the spur that lies on the north side of the deep gulch northeast of Electric Peak. The south face of this spur and the pitch of the strata are shown on the right-hand side of the panorama of the mountain taken from Sepulchre Mountain. (Pl. XLVI.)

The southeast spur is formed by the upturned beds east of the synclinal already mentioned. At its extreme southern end the upper portion of the Carboniferous rocks is exposed, together with the Jura-Trias. The black shales have been metamorphosed in the vicinity of the main body of intrusive rocks, and have been indurated to such an extent that they have withstood erosion sufficiently to form the pyramidal mass of the southeast spur, which is to the left of the gulch in the center of Pl. XLVI.

On the south and west erosion has cut down 3,000 feet below the summit of the mountain, while on the east and northeast it has cut 4,000 and 5,000 feet below the highest point. Two deep gulches penetrate the very heart of the mass and lay bare its structure. Along the eastern base of the mountain the deeply cut drainage channel of Reese Creek marks very nearly the line of faulting that separates the rocks of Electric Peak from those of Sepulchre Mountain. The fault line passes across the slope just west of the main creek and up the south branch of the creek to the divide near Gardiner River.

The character of the western half of the mountain is very different from that of the eastern, which comprises the eastern summit with the northeast and southeast spurs. The western and southern slopes are quite uniformly steep or precipitous exposures of slightly tilted strata with intercalated sheets of intrusive rocks, or long talus slopes of small fragments. The eastern summit and spurs, on the other hand, are irregular in form and present a serrated mass of crags and pinnacles with precipitous faces of rock hundreds of feet in height. The southern portion of the southeast spur, however, is more uniformly eroded to smooth slopes. The northeastern spur is especially rugged, and bristles with rocky points and needles. These features appear in Pl. XLVI.

This difference of character results from the change in the geological structure of the mountain. The shales and sandstones in the eastern portion have been highly indurated and altered, and, with the vertical dikes and stocks that traverse them, have withstood erosion much better than the unaltered strata to the west, and have presented a much more heterogeneous body, which has yielded very irregularly.

ELECTRIC PEAK, FROM SEPULCHRE MOUNTAIN.

The deep east gulch has cut an amphitheater at the base of the peak, which rises nearly 1,500 feet vertically above the débris in the head of the gulch. The walls of this gulch are shown in the panorama (Pl. XLVII) and its general position in the previous view. The gulch crosses the synclinal break and the main stock of igneous rock, but the great accumulation of angular débris, which fills the head of the gulch, obscures the bottom rocks. The central body or stock of intrusive rocks is located on the northeast spur of the mountain, where it has broken up into the upper sandstones. It outcrops in a great number of exposures which cover the southern slope of the spur from an altitude of 9,000 to 10,000 feet. A large branch stock runs up the crest of this ridge, forming the line of dark colored pinnacles shown on the right-hand side of the illustrations. It thins out before reaching the summit of the mountain. The southwestern end of the main stock is exposed in the south wall of the amphitheater already mentioned, left-hand end of the view (Pl. XLVII). It appears as a high wedge of crystalline rock reaching to within a few hundred feet of the top of the cliff, which is the north face of the pyramidal southeast spur. The crest of this spur, from an altitude of about 10,000 feet up to the summit of the peak, is serrated by numerous narrow gulches and rocky points formed by the weathering and erosion of a great number of narrow dikes and upturned intrusive sheets. The dikes are nearly vertical and are specially abundant along that part of the spur lying between the wedge of crystalline rock and the break in the sedimentary strata. They are less numerous as the summit of the peak is approached, and do not appear to occur farther to the northwest. They do not occur along the east base of the southeast spur, but extend southward across the upper slopes of the spur in parallel walls that rise above the shales. They are hardly to be distinguished from the upturned sheets, which, however, usually exhibit signs of crushing and displacement. They are very prominent where the shales are but slightly metamorphosed and are easily eroded. Toward the more indurated portion of the spur they are less noticeable and do not rise above the surface of the surrounding rocks. They become more numerous and larger toward the north as the area of metamorphism is approached.

The dikes appear to radiate from a center, situated on the northeast spur, where the main stock is located, and are confined to a range of about 45° from south to southwest. They are not more than a mile and a half long.

GEOLOGICAL MAP.

The geological map, Pl. LIII, exhibits the chief features of the geology in as simple a manner as possible. Owing to the small scale of the map and the necessarily limited time devoted to the study of the region, it is not possible to give more than a general idea of the geological structure of Electric Peak. Only a small number of the intruded sheets of igneous rocks can be represented and their thickness has to be exaggerated. Thus ten sheets are represented instead of fifty, and they are drawn 50 to 150 feet thick, while in actual fact they are from 4 to 30 feet thick. Moreover, the sheets are continuous, following the bedding of the strata for long distances, and breaking up toward the north and east into higher layers which they follow in turn; occasionally the sheets intersect one another. On the map, however, they are not drawn continuously, but are interrupted, as there are not sufficient data to carry any one sheet a very long distance. The same is true of the dikes, which are more numerous and narrower than they are represented on the map.

The sedimentary rocks are colored according to the period in which they were deposited, that is, as Carboniferous, Jura-Trias, and Cretacous, without attempting to express any further subdivisions. The large accumulations of morainal débris in the east and northeast gulches are represented. They are made up of large angular blocks of the sedimentary and eruptive rocks in which the gulches are located.

That portion of the map which represents the structure of Sepulchre Mountain will be understood when the geology of this locality is described.

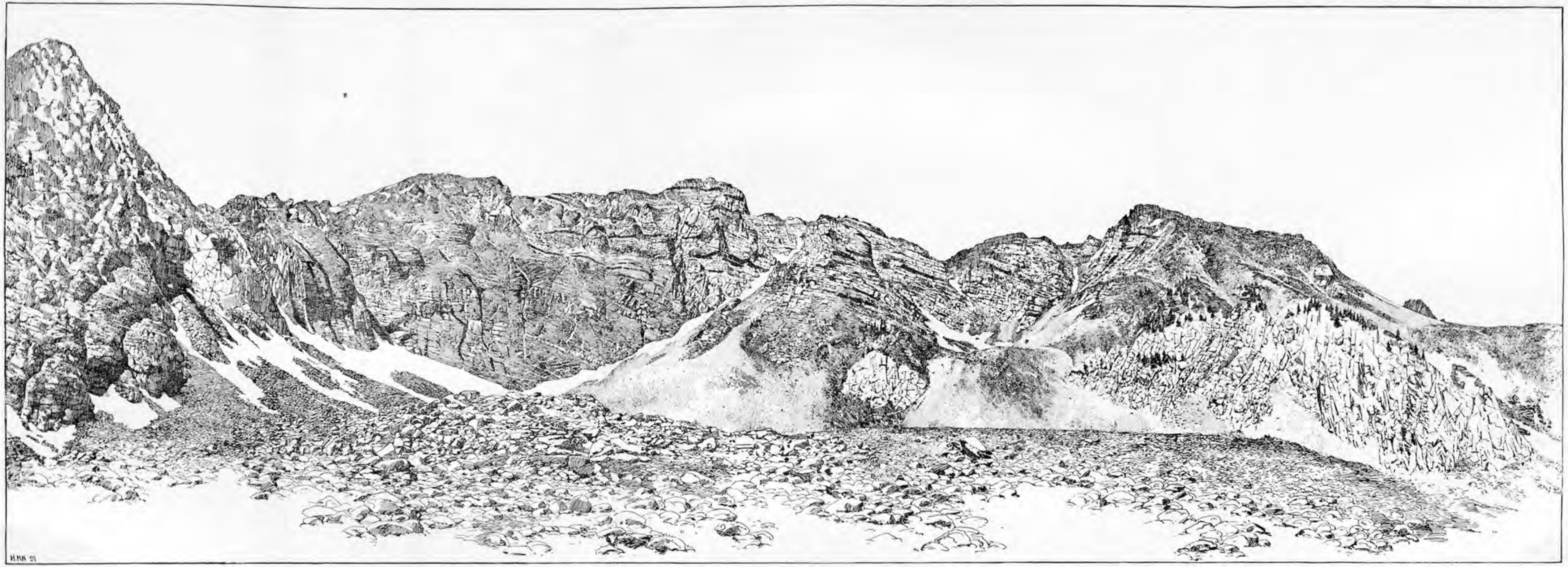
THE ERUPTIVE ROCKS OF ELECTRIC PEAK.

The igneous rocks that form the intruded sheets, and the subsequent stock and dikes, comprise a number of varieties, having quite an extended range both of composition and of structure. They include modifications of diorite and porphyrite, the extreme forms approaching granite and quartz-porphyry.

Before entering upon the description of these rocks it will be necessary to explain at some length the writer's use of the terms *porphyrite* and *porphyry* in order to avoid a possible misunderstanding.

USE OF THE TERMS PORPHYRITE AND PORPHYRY.

The term *porphyrite* is used throughout this paper for certain structural forms of rocks whose essential minerals include the lime-soda-feldspars, while the term *porphyry* is used for the corresponding structural forms of rocks characterized by the alkali-feldspars. This is the same usage as that adopted by Prof. Rosenbusch in his "Mikroskopische Physiographie der massigen Gesteine." Stuttgart, 1886, p. 301. In limiting the usage of these terms to certain structual forms of igneous rocks the writer wishes to call attention to the freedom of the terms from any implication of the age of the rocks. In this respect Prof. Rosenbusch appears to have fallen into a seeming inconsistency, since he subsequently confines the terms *porphyrite* and *porphyry* to the paleovolcanic equivalents of the neovolcanic andesites, dacites, rhyolites, etc. This action can be consistent only on the assumption that the ancient and modern volcanic rocks in all cases differ from one another in structure, a supposition which is contrary to our present experience. With every step in the advancement of our knowledge of the geolog-



HEAD OF EAST GULCH OF ELECTRIC PEAK.

ical occurrence of igneous rocks it becomes more and more evident that the magmas which were erupted in Paleozoic times crystallized into rocks which differed in no essential respect from those of recent date, though in the former instances they have more frequently suffered from decomposition and other modes of alteration. The apparent greater preponderance of certain forms of rocks in the earlier periods of the earth's history has been correctly referred to the effect of great denudation during long ages, and the consequent exposure of those portions of the solidified magmas that were situated at greater distances from the surface of the earth. Hence the apparent connection between the structure of these rocks and their geological age. In proving the absence of this supposed connection the use of an age qualification in the definition and classification of igneous rocks has been eliminated, while the distinctions due to their structure remain unchanged. The coarse grained forms of rocks that are characterized by labradorite, augite, and hypersthene, or by labradorite, hornblende, and biotite are none the less gabbros or diorites because they have crystallized in Tertiary times or lie incased in basaltic breccias. Neither should we give up the terms *andesite* or *rhyolite* because lavas of their composition and texture occur in older geological ages. For similar reasons, then, we should continue to use the terms *porphyrite* and *porphyry*, limiting them to certain structural forms, for which they were in most cases originally employed. In the present paper they are applied to medium grained porphyritic rocks that occupy an intermediate position between the coarsely granular diorites and gabbros, and the microlitic or glassy andesites. This, we think, corresponds the most closely to their earliest usage.

It is to be further remarked that the terms *porphyrite* and *porphyry* are applied to rocks without reference to their state of preservation, though, of course, their best types are perfectly fresh, unaltered rocks. There are abundant instances in which igneous rocks of recent date exist in a perfectly fresh and unaltered condition, without evidence of any change having taken place within them since they crystallized from a molten state, except occasional surface weathering. Such a set of rocks are those described in this paper. They present all degrees of microstructure, from the finest to the coarsest; the medium grained forms are inseparably connected with the glassy lavas on the one hand and with the coarsely granular rocks on the other. Their crystallization is not the devitrification of previously solidified glass, but is the crystallization of a heated fluid magma. It is in this sense *primary*. It is a fair presumption that the majority of magmas that have crystallized into an association of silicate minerals retain their original structural character for a very great length of time, geologically speaking, unless subjected to dynamical or chemical processes which rearrange their mineral constituents more or less completely. Where this has taken place there are usually evidences of the fact, either within the rock itself or in those surrounding it. Instances of the devitrification of solidified glasses are abundant and have been ably studied and interpreted, especially by the English petrographers. It seems to the writer, however, that the utmost caution should be exercised in treating such altered rock bodies, since it may not be possible in most cases to discover exactly what was the primary condition of the rock before alteration set in, and a primary crystalline structure may be mistaken for a secondary one. The writer is not aware from personal experience, that the two can be distinguished in most cases even. Differences between the two, however, are to be expected, and both should be carefully studied together. It is certain that very many structures common to glassy rocks, such as lithophysæ and other crystalline cavities, must be highly modified by any process of secondary alteration. In many cases the altered forms of igneous rocks can be distinguished from their primary, fresh condition. It is to the unaltered forms of the medium grained porphyritic rocks that the terms *porphyrite* and *porphyry* have been applied in this paper, which appears to the writer to be their legitimate use. He would, therefore, urge those who have restricted the term porphyrite to altered andesite to restore it to its original application in order that the porphyries or porphyrites of petrography may correspond to the porphyries of more general usage.

SHEET ROCKS.

The rocks occurring as intrusive sheets present a series of fine grained holocrystalline forms of porphyrite and a variety of diabase. They are all more or less porphyritic, but vary somewhat in habit from coarsely porphyritic to those in which the porphyritic structure is scarcely noticeable. In color they range from dark to light gray, which may be bluish, greenish, or brownish, according to the freshness or degree of alteration of the rock.

In the upturned strata of the southeast spur the sheets vary in thickness from 4 feet to 20 or 30 feet, and the rocks forming them often exhibit characters which indicate that what are now two vertical sides of the bodies were originally top and bottom surfaces of nearly horizontal sheets. Thus the two sides are often quite different. In one instance what was the bottom of the sheet is much darker colored than the body of the rock, which exhibits a strongly marked flow structure, while the side which was formerly the top surface bears large spherical nodules ranging from several inches to 10 inches in diameter. A still more striking difference between the two sides of an upturned sheet is found in a 30-foot sheet of augite-porphyrite or diabase, which occurs on the lower slope of the southeast spur and on the south side of the large east gulch. The rock is dense, massive, and greenish; near the east contact, which was originally the bottom of the sheet, it is very fissile and crumbles upon weathering, giving rise to a narrow gulch. Immediately at the contact with the shale it is dense and much altered, with a purplish tinge of color. A layer of the sheet 4 or 5 feet thick near the bottom contact is full of large porphyritical augites. The remainder of the body to the western contact or upper surface does not contain them, but exhibits small feldspar phenocrysts and is more massive, and weathers quite differently from the coarsely porphyritic portion of the body. The presence of a broad band of rock carrying all the large phenocrysts and situated on one side of a vertical sheet of eruptive rock, could scarcely be accounted for if the body had been intruded vertically, unless it was assumed that there had been two intrusions of different magmas. But when it is found that the body was originally a nearly horizontal sheet, the presence of a layer near the bottom containing all of the large crystals of augite, while exceptional, is nevertheless in accord with the observations of Charles Darwin[1] upon the basaltic flows of the Galapagos Islands, and of Clarence King[2] upon the lava streams of Hawaii. Both of these observers mention instances in which the larger crystals had fallen to the bottom of small basalt flows, leaving the upper parts quite free from them. In these cases the magmas must have been very liquid.

The greater part of the sheet rocks that occur in the eastern part of Electric Peak and come within the present discussion are somewhat decomposed. This appears to be due to the dislocation and shattering which they have undergone at the time of the upturning of the strata containing them. On the southeast spur they usually exhibit slickensides and distinct evidences of crushing in conjunction with that of the shales in which they lie, the shales frequently showing a crumpled "cone-in-cone" structure near their contact with the sheet rocks. The latter have in this way been rendered more susceptible to the decomposing action of the atmosphere. In some instances the substance of the ferromagnesian silicates has been destroyed, leaving only the original form of the minerals recognizable. In general, however, the decomposition has not destroyed the feldspars nor materially affected the microstructure of the rock.

As the fresher and more extensive occurrences of these intrusive sheets will be fully described at another time, it is not necessary to enter into a detailed account of them in this paper. Considered mineralogically they comprise:

(*a*) Rocks whose essential minerals are lime-soda feldspar and pyroxene, with no hornblende.

(*b*) Rocks with lime-soda feldspar and pyroxene and some hornblende. These embrace a few doubtful occurrences which may be upturned sheets or vertical dikes.

(*c*) Rocks with lime-soda feldspar and hornblende with little or no biotite, and no pyroxene.

(*d*) Rocks like (*c*) with more biotite.

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[1] Volcanic Islands, London, 1851, p. 117.

[2] U. S. Geol. Expl. of the Fortieth Parallel, vol. 1, Systematic Geology, p. 715.

(*e*) Rocks with lime-soda feldspar, biotite, and hornblende, the biotite being in excess of the hornblende.

(*f*) Rocks like (*e*) with some quartz phenocrysts.

These variations in mineral composition are accompanied by changes in the character and amount of the feldspars. Toward the end of the series, in the order given, the feldspars become less and less basic, and more abundant, and are associated with an increasing amount of quartz, which appears microscopically in the groundmass of the rock. The ferromagnesian silicates necessarily diminish in amount from the hornblende end of the series toward the mica end.

The microscopical characters of the minerals in these rocks are similar to those of the dike rocks of like grain, which will be described later on. The groundmass has the same microstructure as that of the dike rocks, and varies in the degree of crystallization from microcryptocrystalline to microcrystalline.

By far the greater number of the sheets in Electric Peak are of hornblende-mica-porphyrite, without pyroxene or porphyritical quartz. Only two occurrences carry small quartz phenocrysts. The pyroxene-bearing varieties form an insignificant part of the group.

The sheet rocks having been intruded between the sedimentary strata prior to their steep upturning and to the vertical fracturing which admitted the material forming the dikes and main stock, it appears that the magma or magmas which took the form of sheets were characterized for the most part by phenocrysts of hornblende and biotite, and that on the one hand they pass into varieties bearing porphyritical quartz, and on the other hand they grade into forms bearing pyroxene. Hence they present varieties of rock which occur again as later eruptions in the dikes and stock.

DIKE AND STOCK ROCKS.

As already mentioned the igneous rocks occurring in the stock and its apophyses and in the dikes form a group of diorites and porphyrites of variable composition and structure. The greater number of the porphyrites and diorites are not separable, except in a general way, as they are connected by intermediate structural varieties. In general, the coarse grained and granular rocks, the diorites, are confined to the main stock and the larger apophyses, while the porphyritic finer grained rocks, the porphyrites, occur in the dikes and small apophyses and along the sides of the stock, in places, in contact with the sedimentary rocks.

The main body of the stock is diorite. It varies in structure and composition, the variations being rapid in some places and very irregular. There is ample evidence that a series of eruptions followed one another through this conduit or fissure. The nature of this evidence will appear when the rocks composing the stock are described in detail. A study of the porphyrites occurring as dikes and contact facies of the stock reveals the fact that most of them differ from the main body of diorite in the character of their porphyritical minerals, or those older minerals which were present in the magma at the time of its eruption.

Most of the porphyrites are characterized by the presence of idiomorphic hornblende and biotite, and by the absence of pyroxene. In some varieties of the diorite there is evidence of an early crystallization of brown hornblende, and of pyroxene, but none of biotite. In most of the diorite, however, there is no evidence of any development of phenocrysts.

If we consider what would be the course of events when a synclinal fracturing of sedimentary strata, as in the case of Electric Peak, permitted a series of molten magmas to be forced through the resulting fissures, we see that the first magma would penetrate all the small crevices connected with the larger fissures and fill them with its material, which would solidify rapidly as narrow dikes. The magma occupying the large fissures would remain molten much longer, consolidation setting in on the sides and in the narrower portions. A subsequent eruption would force the molten portion out and replace it by other material. It would also fill up any new crevices or fissures made at the time of its outbreak. But their number would probably be much smaller than that of the crevices accompanying the first great upheaval or dislocation of the strata. Hence the number of dikes of the same magma as that constituting the later eruptions would be smaller. The magma which eventually closed the conduit would be represented by but few dikes, unless the final outbreak had been accompanied by extensive fracturing and dislocation. At Electric Peak the last intrusion of magma was not a violent one, which indicates that the dynamical forces were gradually dying out in this vicinity. The latest magma to rise in this conduit was that of the quartz-diorite-porphyrite which broke through the middle of the diorite stock and filled six or eight narrow crevices stretching toward the southwest.

The rocks about to be described constitute a very complex group, since they are portions of a series of magmas that have followed one another with more or less interruption through the same conduit on their way to the surface of the earth, and have consolidated under different physical conditions. Their relations to one another are so intimate and their variations in composition and structure so gradual and so extensive that it is almost impossible to discover any simple method of presenting the facts regarding them. It will be necessary to treat them collectively, owing to their number, and also to consider them in different groupings and from different points of view.

For convenience of petrographical description and because the greatest number of similar varieties of rocks will be brought together, they will be treated in the following groups:

I. The greater number of dike rocks and some of the contact facies of the stock, that are older than the main body of the stock.

II. The main body of the stock, with most of its contact facies, and most of the rocks that have broken up through it, and some apophyses that appear to be contemporaneous with it.

III. The quartz-mica-diorite-porphyrite which has broken up through the main body of the stock, and has produced a few dikes.

Porphyrites.—The porphyrites forming the dikes, which are from 1 or 2 feet in width to 25 feet, have a generally uniform habit. They are dense, fine grained rocks, filled with a multitude of small feldspars and ferromagnesian silicates, mostly hornblende and biotite, which gives them a uniformly speckled appearance, with occasional spots of white feldspar or of black ferromagnesian silicates. The general habit is modified by a variation in the color of the rock, due to the relative abundance of the dark and light phenocrysts, and to the nature and amount of the groundmass. The color of the rocks varies from dark greenish and purplish gray to light gray of different tints. In the region of the metamorphosed sandstones some of the dike rocks have been bleached to white. The quartzose dike rocks will be described in connection with the quartz-mica-diorite-porphyrite in Group III (p. 617.)

In the field it is observed that some are very fresh and compact, others decomposed and disintegrated. They become rusted and weathered in much the same manner as the metamorphosed strata containing them, and are crossed by the same system of joints. For this reason they can not be recognized at a distance on the face of the cliff at the head of the east gulch.

When they are studied in thin sections under the microscope, they are found to consist of a holocrystalline groundmass, with abundant phenocrysts of lime-soda-feldspar and hornblende, generally with biotite and occasionally with pyroxene. Mineralogically considered, they constitute a series of varieties of porphyrite with a variable percentage of hornblende, biotite, and pyroxene, without any one variety being particularly predominant. They may be arranged in the following subdivisions according to the relative amounts of the various ferromagnesian phenocrysts:

TABLE I.—*Mineral variation of the porphyrites at Electric Peak.*

Subdivisions.	Biotite.	Hornblende.	Pyroxene.
a	much.	some.	
b	much.	much.	
c	some.	much.	
d	little.	much.	
e		much.	
f		much.	some.
g		much.	much.
h		some.	much.
i			much.

Besides the porphyritical biotite which crystallized previous to the eruption of the rocks, there is some that was evidently crystallized at the time of their final consolidation. The latter occurs in shreds and irregularly shaped individuals.

The microscopical character of the different minerals is much the same throughout the series, and no particular specimen will be described as the type rock, for the variations throughout the series are gradual, and no single variety should be selected to represent the remainder. The variations affect the relative proportions of the minerals composing the rocks and their microstructure. A gradual modification of the species of the plagioclase feldspars may be detected by their optical properties, but a corresponding range of changes within the isomorphic series of the hornblendes, pyroxenes, or biotites is not recognizable, if it is present. The variation in mineral constitution affects the microstructure of the groundmass, an increase of quartz being accompanied by an approach to a granular structure.

In describing the porphyrites which belong to the nine subdivisions just given, it must be borne in mind that for each mineralogical variety there is a range of structural forms which depend on the crystalline development of the rock. In order to give an idea of these different varieties of porphyrite the general features of each will be described first, and afterwards the characteristics of the essential minerals.

(*a*) This variety, which is characterized by abundant phenocrysts of biotite, some of hornblende, and no pyroxene, constitutes a narrow dike, whose width varies from 10 inches to 10 feet. Specimens from its sides and the middle, at a place where it is 8 feet wide, show that the groundmass of the rock, near its contact with the inclosing rocks, is fine grained, being composed of irregular patches about $0{\cdot}04^{mm}$ in diameter. The patches are clouded with minute particles, which are partly shreds of mica and partly lath-shaped feldspar.

In the center of the dike the groundmass is made up of very irregular patches, from $0{\cdot}09^{mm}$ to $0{\cdot}43^{mm}$ in diameter. They are filled with lath-shaped feldspar microlites and minute gas cavities and carry microscopic hornblende and biotite. The patches are quartz, which has crystallized as the last mineral, and acts as a cement for those which preceded it. Its true nature is recognizable in still coarser grained forms of similar rocks, where it can be tested optically. The quartz forming a single patch has one orientation and behaves as an optically uniform individual, but the minerals inclosed in each patch of quartz have no uniform orientation. The structure is the same as the poicilitic structure of certain coarse grained rocks. It may therefore be called *micropoicilitic*, and is to be distinguished from micropegmatitic structure by the fact that in the latter case groups of the inclosed minerals have the same orientation throughout each group.

Through the groundmass are scattered abundant phenocrysts of lime-soda-feldspar from 1 to 2^{mm} long and smaller crystals of hornblende and biotite. The relative proportion of the hornblende and biotite is not constant, the biotite being in excess of the hornblende in some specimens of the rock and equal to or even less than the hornblende in others. The biotite preponderates in those specimens from this dike with the fewest ferromagnesian silicates. As the amount of the dark colored minerals increases the hornblendes increase. There is a little magnetite, apatite, and zircon.

(*b*) This is represented by a 4-foot dike just west of the summit of Electric Peak. It is fine grained, with the same micropoicilitic structure, the patches 0·05 mm in diameter. The rock is not entirely fresh, and the phenocrystic plagioclases and micas are somewhat altered, but the hornblendes are not so much decomposed.

(*c*) is represented by a 2-foot dike on the southeast spur. The groundmass is very fine grained, with a slightly micropoicilitic structure which is not well marked, and merges into one in which the lath-shaped feldspar microlites become more prominent. The hornblende is considerably in excess of the biotite.

(*d*) is represented by a 3-foot dike on the northeast spur, which is dark colored at the center, but along the contact with the metamorphosed sandstone is light colored, with fewer and more prominent phenocrysts. The groundmass is a fine grained aggregation of lath-shaped feldspars and irregular grains; there is much iron oxide; phenocrysts of hornblende and plagioclase are abundant; biotite is scarce.

(*e*) is represented by a narrow dike a quarter of a mile west of the summit of Electric Peak. The groundmass is very fine grained, composed chiefly of lath-shaped feldspars about 0·04 mm long, with some irregular grains, and considerable chlorite resulting from the partial decomposition of the hornblende. The phenocrysts of hornblende and feldspar are small; there is no mica.

In the foregoing varieties pyroxene is entirely absent, and the chief variations are in the relative proportion of mica and hornblende, and in the microstructure of the groundmass. The micropoicilitic structure appears in those fine grained rocks which have a certain amount of quartz. It is replaced by a "felt-like" structure in the more basic varieties of nearly the same degree of crystallization.

(*f*) is represented by a 10-foot dike on the southeast spur. The groundmass is fine grained, composed almost entirely of lath-shaped and rectangular plagioclases, about 0·07 mm long, with some irregular grains and microscopic hornblendes and shreds of biotite. There is but little iron oxide. The porphyritical plagioclases and hornblendes are abundant. There was probably a small amount of phenocrystic pyroxene, which has been altered to fibrous green amphibole. Biotite is present in shreds, but not as phenocrysts. It may have been formed during the final crystallization of the magma, but part of it appears to be secondary, due to the subsequent alterations of the rock.

(*g*) is represented by a contact facies of the main stock. The rock resembles the other varieties of porphyrite in its general habit and structure. The groundmass is fine grained and is made up of lath-shaped, rectangular, and irregularly formed plagioclases, about 0·15mm long, besides some quartz, with microscopical hornblendes and biotites. The phenocrysts are hornblende and plagioclase in abundance, and much pyroxene which has been completely uralitized. There are no phenocrysts of biotite. Iron oxide, probably magnetite, is abundant. Apatite and zircon, if present, are rare. The development of the porphyritical hornblendes is particularly interesting and is described on page 593.

(*h*) is represented by a much coarser grained variety, occurring as a dike, 10 to 15 feet wide, on the southeast spur. It is, however, but slightly porphyritic, consisting of a mass of lath-shaped plagioclases, $0{\cdot}4^{mm}$ to $0{\cdot}7^{mm}$ long, with very rarely a larger individual, 1^{mm} long. Between these is a very small amount of cementing material, composed of irregular grains of feldspar and quartz and ferromagnesian silicates, amphibole, and mica. There is much uralitized pyroxene and a small amount of primary hornblende, with some biotite. The latter appears to belong to the period of final crystallization of the magma and is possibly due in part to subsequent alteration. The largest idiomorphic minerals are the altered pyroxenes, so that the rock undoubtedly belongs to a magma which carried numerous pyroxenes and some hornblende at the time of its eruption.

(*i*) is represented by a 4-foot dike on the northeast spur. It is distinctly porphyritic; the groundmass of the central portion of the dike rock is fine grained, composed of lath-shaped plagioclase about $0{\cdot}1^{mm}$ long, and irregular grains of feldspar, with very little quartz. It also contains shreds of biotite and microscopic amphibole, with some iron oxide. The groundmass of the rock from the side of the dike is finer grained, with the same general structure, but with no mica or amphibole; there is, however, much colorless monoclinic pyroxene in irregular grains, whose primary nature is questionable. The rock bears abundant phenocrysts of plagioclase and pyroxene, but none of hornblende or biotite. In the center of the dike the pyroxene has been completely altered to uralite, which is also scattered through the groundmass. Near the contact of the dike rock with the metamorphosed strata the pyroxene is an almost colorless monoclinic species resembling that which has resulted from an alteration of hornblende in other varieties of porphyrite from this region, to be described later on. It does not resemble the primary porphyritical pyroxenes which occur in the unaltered varieties of these igneous rocks.

Besides the porphyrites just described there is a more quartzose variety, found in several places, not far from the main stock. It has reached a somewhat higher degree of crystallization and exhibits mineralogical characters peculiar to the diorite of the stock, which will be fully described in that connection. There are also dikes or veins of coarser grained rocks cutting the body of the stock and passing into more massive portions of the same, which will not be considered with the finer grained dike rocks.

As already remarked, the microscopical characters of the minerals constituting these porphyrites are very nearly the same in all of the varieties.

Feldspar.—All the feldspars, so far as can be determined optically, are species of the lime-soda feldspar series. All of the porphyritical individuals are idiomorphic and exhibit the characteristic polysynthetic twinning according to the albite and pericline laws. Many of them are also twinned according to the Carlsbad law. The forms of their sections are lath-shaped, rectangular, and tabular, the general form of the crystals being tabular parallel to the clinopinacoid. They possess a fine zonal structure with varying optical orientation. From their optical behavior they appear to range from labradorite to oligoclase, the former occurring in the more basic porphyrites, rich in hornblende or pyroxene, the latter predominating in the more acid varieties, rich in phenocrystic biotite. The feldspars contain few primary inclusions, which are in some instances glass, in others microscopic grains of the other minerals. They are much richer in secondary inclusions, largely gas cavities, or needles of secondary amphibole.

The lath-shaped feldspars of the groundmass are also lime-soda feldspars, but the specific character of the irregularly shaped feldspar grains is not recognizable; they crystallized with the quartz at the time of the final consolidation of the magma.

The feldspars are more distinctly idiomorphic than the hornblendes, and are occasionally inclosed in large hornblendes; more rarely small hornblendes are inclosed in the feldspars.

Hornblende.—The primary, phenocrystic hornblende is more or less idiomorphic, but not always; occasionally its outlines are extremely irregular. It usually has crystallographic boundaries in the prism zone, consisting of the fundamental prism, ∞P, and the clinopinacoid, $\infty P \grave{\infty}$, the terminal planes, when present, being $P \grave{\infty}$ or P. Twinning parallel to the orthopinacoid is frequently observed.

The color varies from brown to green, through various tones of reddish brown, greenish brown, and light brown, brownish green, and olive gray, sometimes with a tint of red, which approaches a violet gray. The olive gray to violet gray tones are characteristic of much of the hornblende of the porphyrites occurring in the dikes and intrusive sheets; it is the component color transmitted parallel to the positive optic axis, $\mathfrak{c}$, in many cases. The other components in the same hornblendes are olive brown, parallel to $\mathfrak{b}$, and light brown, parallel to $\mathfrak{a}$. The absorption is $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$. The color is not always distributed uniformly through the individual crystals. It sometimes occurs in irregular patches, the darker color being generally in the central part of the crystal. It is evident that this regular distribution is sometimes due to the original crystallization of the hornblende, and at others has been occasioned by secondary influences, which tend to bleach out the color. A zonal distribution of the color is seldom observed.

The hornblendes throughout the series of porphyrites just described have very nearly the same tones of color in different sections, but as the basic end of the series is approached the colors grow slightly darker and the brown tones are stronger, approaching chestnut brown.

There are no characteristic inclusions. Iron oxide is frequently inclosed in the hornblende, and less often feldspar and apatite. When it is associated with porphyritical biotite the latter is often inclosed by the hornblende, and appears to be an older crystallization. In some cases the hornblende bears numerous patches of biotite, indicating that they have crystallized together. Where the hornblende is partly altered it sometimes contains biotite in shreds and irregular aggregates that are undoubtedly secondary.

The hornblendes of the dike rocks exhibit various degrees of alteration and decomposition, from those that are entirely fresh to those completely altered. The change is usually into chlorite, accompanied by epidote in irregular grains, which occasionally possesses a strong pleochroism, from colorless to yellow and deep garnet red; calcite and quartz are also developed. In some instances the compact hornblende is altered to light green "reedy" amphibole, usually accompanied by chloritization.

In the fine grained porphyrites the outlines of the phenocrystic hornblendes are sharply defined, as though the act of their crystallization had received a sudden check, but in the coarser grained porphyrites their outlines are often very irregular. Here the hornblende crystals have grown against feldspars and other minerals, according to circumstances, and are only partially idiomorphic.

In the variety described under (*g*), from a contact facies of the stock rock, the crystallization of the brown hornblende has varied greatly with different individual crystals within the area of one thin section of the rock. With some of the porphyritical hornblendes it has ceased suddenly, leaving them sharply outlined by crystal faces. With others it has carried the hornblende substance against crystals of feldspar and produced a rough surface. The margin of others is crowded with comparatively large grains of magnetite and is also rough. Some of the hornblendes have an irregular zone of magnetite and small feldspars, outside of which the hornblende substance is free from inclusions, but of very irregular form. In a few cases the crystallization of the brown hornblende has extended into the period of the final consolidation of the groundmass, and the resulting hornblende individual incloses within its extremely irregular outline the various constituent minerals of the groundmass. The color of these hornblendes is greenish brown and reddish brown, sometimes in irregular alternating zones, generally with the reddish brown color at the margin of the crystal. One large, ill-shaped individual, of very pure substance, free from cleavage cracks, has an irregular outline made up of small crystal faces, with some projecting forms like attached crystals of the same substance. The margin is a redder brown than the central part of the individual. Besides the primary brown and the greenish brown hornblende, there is a great amount of secondary green, reedy amphibole, resulting from the alteration of the pyroxene. It not only occupies the spaces of the original pyroxenes, but fills the groundmass of the rock with small needles. The primary brown hornblendes exhibit no signs of secondary alteration.

Biotite.—The porphyritical biotite occurs in six-sided plates and thicker crystals, occasionally twinned parallel to the basal plane. It is dark reddish brown, with characteristically strong absorption. Optically it appears uniaxial. Its substance is quite pure, with occasional inclusions of apatite and zircon; magnetite grains are scarce. In some instances it is partially bleached, and the light colored spots often contain bundles of rutile needles lying at right angles and also parallel to the edges of the basal plates. In the highly decomposed porphyrites it is completely altered to chlorite and epidote, sometimes with calcite and quartz.

The biotite of final consolidation, which occurs as a component of the groundmass and does not belong to the same period of crystallization as the porphyritical biotite, has the same optical characters, and can be distinguished only by its mode of occurrence.

Pyroxene.—The primary phenocrystic pyroxenes of the few pyroxenic dike rocks embraced in this grouping are recognizable only by their form, as they have all been uralitized.

Iron oxide.—In the absence of direct chemical tests and of characteristic crystal forms the exact nature of the iron oxide occurring in these porphyrites can not be determined. The chemical analyses of the rocks shows the presence of a variable percentage of titanic acid.

Apatite.—This mineral is more abundant in the porphyrites rich in phenocrystic biotite than in those free from it. It is colorless in most cases, but in the rock described under (*a*) it occurs in comparatively large gray crystals with slight pleochroism.

Zircon.—Zircon occurs in very small doubly terminated prisms. It is closely associated with the phenocrystic biotite, and is more abundant in the more siliceous porphyrites.

Secondary pyroxene.—The porphyrites in the metamorphosed sandstones are in some instances perfectly white. The feldspars are fresh and brilliant, as are also the small crystals of biotite scattered through the rock. In thin sections they are found to resemble the other porphyrites in general structure; their feldspars are very fresh, and bear numerous glass inclusions. The biotites are unaltered, but what from their crystal forms were evidently once hornblendes are now colorless augite. The hornblendes were originally very abundant, and the porphyrite belonged to the variety rich in hornblende, with a small amount of biotite and with no primary pyroxene. There are no porphyritical individuals exhibiting the crystal form of pyroxene. The augite substance which now replaces hornblende is sometimes compact, and exhibits cleavage characteristic of pyroxene. Cross sections in such cases have the crystal form of hornblende, bounded by the prism faces, making an angle of about 124°, together with the clinopinacoid, and exhibit a perfect prismatic cleavage of about 90° corresponding to the prismatic cleavage of augite, so oriented that the plane of symmetry in the augite coincides with that in the original hornblende. There is also a less perfect pinacoidal cleavage. The substance of the augite is almost colorless, with numerous gas cavities in some instances. It is highly refracting and highly doubly refracting, and possesses a high extinction angle.

More frequently the augite is not compact, but is made up of small individuals with more or less parallel orientation; these individuals are not acicular but rather shortened prisms having an irregular form. The same augite substance occurs in irregularly shaped grains and patches through the groundmass in some cases.

Within the compact fresh feldspar a few small crystals of brown hornblende still remain unaltered. In some occurrences the hornblende phenocrysts are but partially changed to augite, which is scattered in microscopical grains and patches through the groundmass. These grains are sometimes crowded around an aggregation of colorless augite. In one instance the augite is confined to the space originally occupied by the hornblende. The specimens of porphyrite exhibiting this form of pseudomorphism are mostly from near the contact with the sedimentary strata and in the regions of contact metamorphism; one, however, is from a narrow dike of whitened porphyrite on the southeast spur, at a place where the strata are not so greatly metamorphosed.

The occurrence of secondary augite after primary hornblende is uncommon, the writer not having noticed any mention of it by others; it appears to correspond crystallographically to that of secondary hornblende after primary augite, though the two processes of alteration are reversed, and the causes producing them are undoubtedly different. What the causes may have been in this particular instance is not evident.

II. THE STOCK ROCKS AND APOPHYSES.

The diorite forming the body of the main stock, which is 1,500 feet across its widest exposure, presents a crystalline mass of variable grain. A great part of it is coarsely crystalline, and is composed of clusters of feldspars and ferromagnesian silicates that range from 5 millimeters to 2 millimeters in diameter, and smaller. The coarsest grain is shown in Fig. 1, Pl. XLVIII, photographed natural size from No. 201. The apparent grain of the rock is larger than it actually is, for the constituent minerals are not intermingled uniformly but irregularly, so that from two to a dozen crystals of feldspar are clustered together, and two or more of the dark colored minerals; this irregularity, however, recurs so regularly through the mass that the general effect is that of uniformity. The true size of the grain of these forms of the diorite, judged from the size of the feldspars, is from 2 millimeters to 1 millimeter. A medium grained form is shown in Fig. 2, Pl. XLVIII, natural size, No. 197. It constitutes a large portion of the diorite mass. The grain of the rock sinks to fine grained, and to microcrystalline in some instances. The variation in the grain of the rock is in some places gradual, in others rapid. As the rock becomes finer grained it grows darker colored; the finest grained portions are dark gray. In numerous instances the gradual transition of this dark colored, fine grained form was traced through increasing size of grain to light colored, coarse grained diorite, and in the immediate vicinity of such transitions the two extreme forms are also found in juxtaposition, with a sharp line of demarcation between them, or the dark, fine grained form is cut by narrow dikes or veins of the coarse grained form. Along the contact there are in places many fragments of different forms of the diorite, dark and light, fine grained and coarse, which appear to have been broken from older portions of solidified diorite by later magmas, which also became diorite.

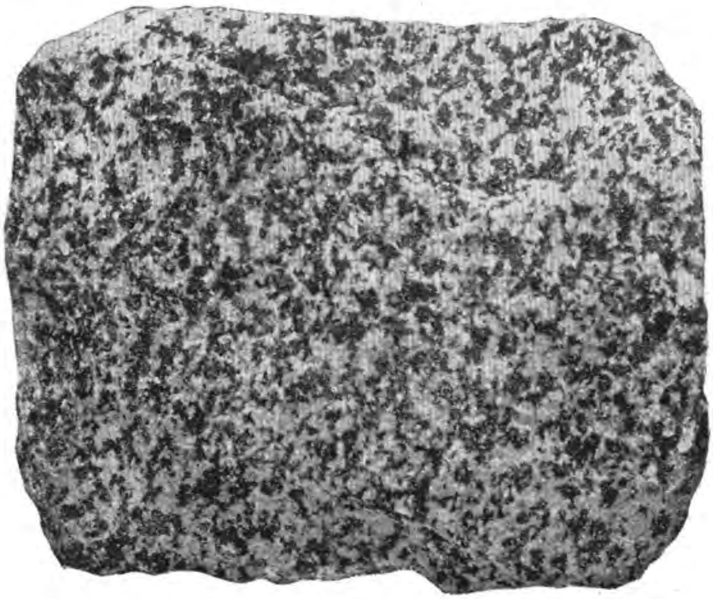
The mineral composition of the diorite is not uniform throughout the body of the stock, which may be easily recognized in the field. Portions of it are richer in the ferromagnesian silicates than the average, in which the proportions of the dark colored minerals to the light colored is about one to one. In places the light colored minerals preponderate. Parts of the body are noticeably richer in mica than the main mass, which appears, macroscopically, to be composed of lime-soda-feldspar, hornblende and biotite; the lighter colored varieties exhibit quartz, and the finest grained forms show only small porphyritical feldspars and pyroxenes. In general, there is an absence of porphyritic structure, the whole effect being evenly granular.

The component minerals of the diorites are hypersthene, augite, hornblende, biotite, lime-soda feldspar, orthoclase, and quartz. They are not all present in each variety of the diorite, however, for these varieties range from rocks with pyroxene and biotite to others with hornblende and biotite and still others with biotite alone as the ferromagnesian mineral. This range of mineral variation is shown in Table II, in which (*a*), (*b*), etc., represent different mineralogical modifications of the rocks.

TABLE II.—*Mineral variation of the diorites and their facies at Electric Peak.*

	Pyroxene.	Hornblende.	Biotite.	Labradorite.	Oligoclase.	Orthoclase..	Quartz.
(*a*)	much	....	little	much	some	....	little
(*b*)	much	much	some	much	some	....	little
(*c*)	little	much	much	some	some	little	some
(*d*)	....	much	much	some	some	little	much
(*e*)	....	some	much	little	much	little	much
(*f*)	....	little	much	....	much	little	much
(*g*)	....	....	much	....	much	some	much

The main body of the diorite is cut by dikes or veins of equally coarse grained, lighter colored diorite, which sometimes approaches granite in character and in one instance is a fine-grained granite (Fig. 1, Pl. XLIX). In places the diorite is traversed by small seams of feldspathic material, which often pass into larger seams with more hornblende and biotite, and finally into veins having the composition and structure of quartzose diorite.



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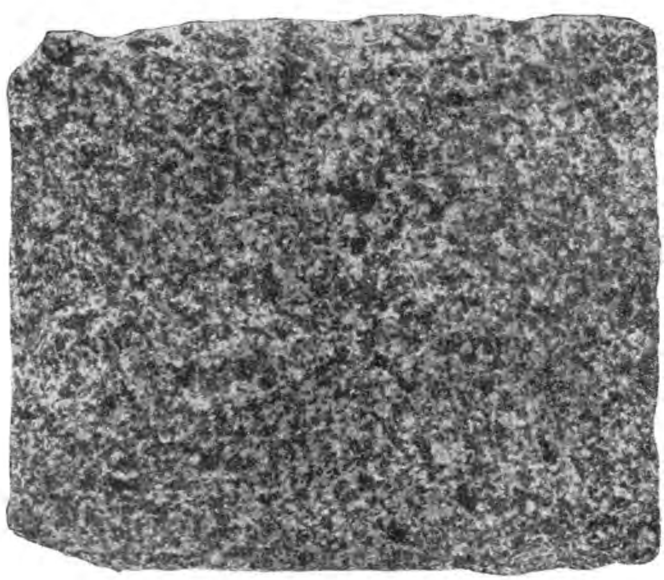

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FIG. 1. DIORITE (COARSE GRAIN). FIG. 2. DIORITE (MEDIUM GRAIN).

Such narrow seams of feldspathic material appear to be the extremities of the larger cracks in the earlier solidified magmas into which the fluid portion of the subsequently intruded magma or magmas was forced; that is, they are distinctly eruptive in their origin, and not of a secondary nature. That portion of the magma which is the last to crystallize, namely, the feldspathic, furnishes the material that penetrates the extremely narrow cracks at the ends of the crevices, and the material in the intermediate portion of the crevice between the extremities and broader parts partakes more and more of the composition and character of the intrudedr ock. The microstructure of such seams is not that of the rock from which they spring, for the liquid portion of the magma will be gradually separated from the crystals suspended in it through the greatly increased internal resistance between the particles of the fluid consequent on its flow through such narrow passages.

Some parts of the diorite bear numerous small masses of coarsely crystallized rock, usually consisting largely of hornblende. They exhibit a variety of structures and appear to be segregations of early crystallization.

As already mentioned, there are contact facies of the stock which exhibit characters that ally them to the porphyrites. Such forms grade into the coarse grained diorites and appear to be portions of the mass that have been cooled rapidly in consequence of their contact with the inclosing rocks. On either side of the central portion of the stock and on the east side of the south end of it, the contact form of the diorite does not differ greatly from the main mass; it is somewhat finer grained, but not much. This indicates that the magma out of which this part of the diorite was formed was not chilled to any great extent by the surrounding rocks, and the inference is that the surrounding rocks were heated when this part of the magma came in contact with them. The occurrence of contact varieties of the rocks that range from fine grained prophyritic forms to coarse grained ones proves that the temperature of the rocks with which they came in contact varied greatly. Some were comparatively cold, others highly heated. If a series of eruptions followed one another closely enough to prevent the heat of one eruption from being entirely dissipated before the next one followed it, the surrounding rocks would be kept heated for a long period, and the last eruption of a series with regular intervals would pass through a hotter conduit than the earlier eruptions had passed through.

In describing the microscopical character of the stock rocks it will be convenient to separate them into three subgroups, according to some phases of their mineralogical composition indicated in Table II, as follows:

II (*a*) Varieties in which the amount of the dark colored minerals approximately equals that of the light colored minerals.

II (*b*) Varieties in which the amount of the light colored minerals exceeds that the dark colored minerals, and in which the quartz is not excessive.

II (*c*) Like II (*b*) but with much quartz.

By dark colored minerals are meant the ferromagnesian minerals and by light colored minerals are meant the feldspars and quartz.

This grouping brings together varieties with structures similar in some respects, though not necessarily of the same degree of crystallization; that is, size of grain. It also brings together rocks of approximately the same chemical composition; but the groups will be found to grade into one another chemically, mineralogically, and structurally, and do not represent any natural divisions of the rocks in the field, except in a general way. It brings together rocks which have different constituent minerals, the differences being among the species of the ferromagnesian silicates.

II (*a*) *Varieties in which the amount of the dark colored minerals approximately equals that of the light colored minerals.*—This group includes most of the main body of the stock rocks and is the most basic of the three groups. It embraces a closely allied series of varieties which vary structurally, mineralogically, and chemically within certain limits.

The specimens on which the microscopical study of this group has been based number thirty-two. They fall into a series of twenty-seven different degrees of coarseness of grain, of which it can only be said that each degree from fine to coarse is coarser than the preceding one. There has been no attempt made to establish a scale of uniform degrees.

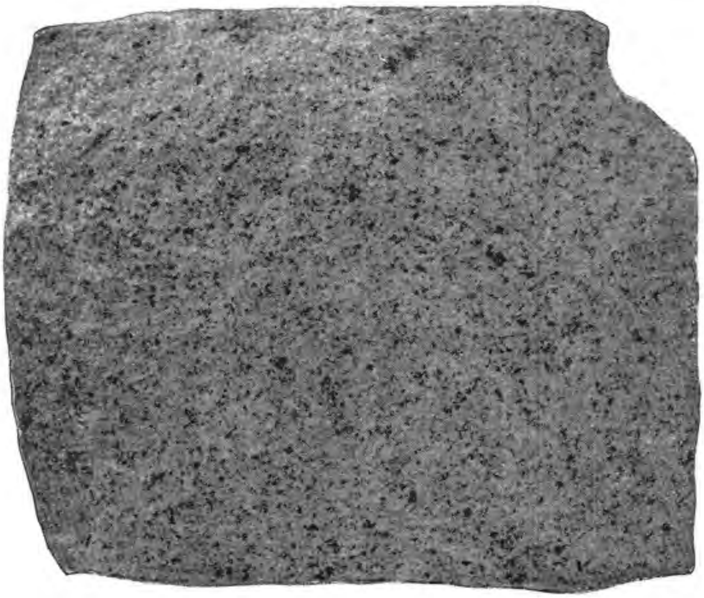
Tables have been prepared to express as concisely as possible the various mineralogical, structural, and chemical features of the rock varieties under discussion. They will appear on a subsequent page and will be referred to frequently.

At the coarse grained end of the series, Table VIII, column II (*a*), p. 625, are the diorites which occur in the most massive exposures on the northeast spur and have reached the highest development of crystallization. Their structure is hypidiomorphic granular; that is to say, the component minerals have their proper crystallographic form to some extent, but a large part of them have irregular shapes, occasioned by the interference of adjacent crystals during their crystallization.

The component minerals are lime-soda feldspars, hornblende, augite, hypersthene, biotite, and quartz, with numerous grains of iron ore, which appears to be magnetite.

The feldspars are more nearly idiomorphic than the other constituents, but are not strictly so. They are mostly rectangular to lath-shaped. Their outlines are not sharp, crystallographic boundaries, but are more or less irregular ones, controlled by the growing together of neighboring feldspars. Their outlines are also affected in most instances by the juxtaposition of the other constituents of the rock.

The quartz forms irregular cementing grains, wholly allotriomorphic, and is evenly scattered through the rock in small amount.



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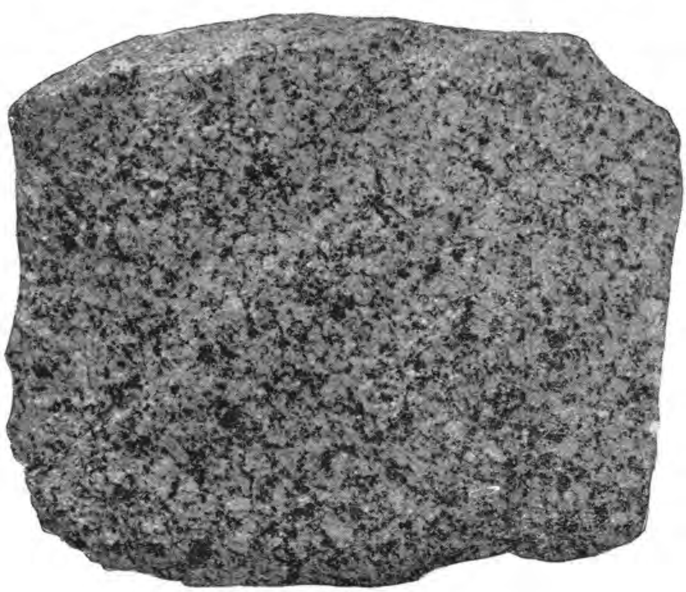

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FIG. 1. GRANITE (FINE GRAIN). FIG. 2. QUARTZ-MICA-DIORITE PORPHYRITE.

The hornblende, pyroxene, and biotite exhibit no crystal boundaries, with some exceptions, and penetrate one another in the most intricate manner.

The iron ore, from its crystal form, appears to be magnetite. It is irregularly scattered through the ferromagnesian silicates and is occasionly observed in the feldspars and quartz.

Apatite occurs in short, stout crystals, not very well formed, and colorless.

Zircon is rare.

The diorites representing the seven highest grades of crystallization in Table VIII, column II (*a*), correspond in structure to the description just given. They vary, however, in the relative abundance of hornblende, pyroxene, biotite, and quartz, as is indicated in the Table V. In the coarsest form the feldspars average from $2{\cdot}5^{mm}$ to 1^{mm} long, and the quartz grains about $0{\cdot}25^{mm}$ in diameter. In the seventh degree from the coarsest end, the feldspars average from $1{\cdot}25^{mm}$ to $0{\cdot}5^{mm}$ and the quartz grains about $0{\cdot}12^{mm}$.

As the grain of the rocks becomes smaller there is a greater development of idiomorphic forms, especially of the hornblende and biotite. Since all the other minerals are generally idiomorphic with respect to quartz, that is, are bounded by their proper crystal planes when adjoining quartz, the number of idiomorphic individuals of hornblende and biotite increase with the amount of quartz in the rocks.

Without any apparent interruption in the gradual variations in structure accompanying the diminution in the size of the grain, the structure of the thirty-third degree differs from that of the forty-fifth in that the number of partially idiomorphic individuals is very much greater. The feldspars are partly idiomorphic, partly allotriomorphic, some being rectangular, others broader and irregular in form like the quartz. Hornblende and biotite frequently exhibit their crystal form. Pyroxene is a prominent constituent, but is surrounded more or less by idiomorphic hornblende. The average length of the feldspars is $0{\cdot}46^{mm}$.

At grade 26 the grain is reduced to about half of that at 33, and averages about $0{\cdot}23^{mm}$, but there is more inequality between the feldspars, a porphyritic structure becoming more pronounced. Macroscopically, however, this variety of the rock has a uniformly granular habit.

The variety representing the twenty-third grade is composed of a mass of lath-shaped or rectangular feldspars and more irregular individuals of feldspar with some quartz. These average $0{\cdot}17^{mm}$ in length and carry many larger crystals of feldspar, besides much hornblende, pyroxene, and biotite, in very nearly equal proportions.

The next grade, 22, is considerably finer grained and has a somewhat different structure. It is still more porphyritic, the larger crystals of feldspar grading down into smaller ones, until they reach a diameter of about $0{\cdot}08^{mm}$. The smaller grains of feldspar are mingled with those of quartz, and in the finer grained forms of this variety of the stock-rock give the groundmass its peculiar mottled appearance. The variety representing grade 22 bears much pyroxene and considerable mica, with less hornblende; magnetite is abundant in small grains or crystals.

Grade 14 is represented by a much finer grained form of rock with marked porphyritic structure. The groundmass is a holocrystalline aggregation of grains of feldspar and quartz, whose outline is poorly defined; it is filled with microscopic pyroxenes and magnetite grains. The phenocrysts are lime-soda feldspar, hypersthene, augite, with some irregular patches of biotite. There is no hornblende. The porphyritical pyroxenes range from $0{\cdot}5^{mm}$ to $0{\cdot}25^{mm}$ approximately.

The varieties representing the five grades, from 17 to 13 inclusive, have very much the same structure and composition, and might be classed as holocrystalline *pyroxene-porphyrites*. They belong to the main body of the stock rocks and form with them one geological body, the fine grained variety grading by imperceptible transitions into the coarse grained. They also have nearly the same chemical composition.

This group of rocks, therefore, presents a continuous series of varieties, that range from fine grained hypersthene-porphyrite with small phenocrysts to coarse grained hornblende-mica-diorite with a variable percentage of pyroxene.

The essential character of the minerals constituting the different varieties under consideration are much the same throughout the series, and since the variations in their microscopical character are intimately connected with the general structure of the rock in each case, and have an important bearing on the question of the development of crystallization in the rock, it seems advisable to describe the microscopical characters of the various minerals with reference to these variations. For this reason the detail description will begin with the minerals as they occur in the finest grained forms, although these forms are not the most characteristic of the main body of the stock. Such a method of treatment is admissible when it is considered that the different varieties included in this grouping have in some instances been collected from one continuous rock mass within short distances of one another, and were intended to illustrate the actual transition of the fine grained forms into the coarse grained. Thus, specimens Nos. 172, 173, 174, 175, 183, and 191, were collected from a continuous exposure of massive rock which exhibited a gradual transition of grain. They occurred about 1 foot apart in the order given, the extremes being 5 feet apart. The grain of the rock changes rapidly from No. 175 to No. 183. Specimen No. 170 is from the same body of rock as Nos. 172, 173, etc. Specimens Nos. 181, 182, 185, 188, and 193 are also from one continuous mass of rock exhibiting a gradual change of grain. They all occurred along a line not more than 4 feet long. The mass from which they were taken was continuous with that from which No. 171 was collected, and was within a few feet of it. These two series were collected within a hundred yards of one another and appeared to be portions of the same mass. They range from the thirty-fifth to the thirteenth grade of crystallization (Table VIII).

Microscopical characters of the feldspars.—In the finest grained form of pyroxene-porphyrite, No. 170, the porphyritical feldspars that lie scattered through the holocrystalline groundmass are sharply idiomorphic. They are lath-shaped and rectangular, some having less regular outlines. They all exhibit polysynthetic twinning and high angles of extinction which indicate that many individuals belong to labradorite. They vary greatly in regard to inclusions: many are nearly free from all kinds of inclusions, others are so filled with them that the feldspar substance is subordinate to that of the foreign minerals. These are mostly pyroxene in rounded grains and prisms, and magnetite, which are also abundant in the groundmass. In some instances the section of a feldspar appears darker than the surrounding groundmass, for the pyroxene and magnetite grains are smaller and more abundant in the former. Some of these impure feldspars exhibit low extinction angles and interference colors, but others appear to be of the same species as the feldspars free from inclusions. Zonal structure is well marked optically, and occasionally controls the arrangement of the inclusions. Some feldspars bear colorless glass inclusions, but they are not very numerous.

Where the feldspar and pyroxene phenocrysts are clustered together, the latter are surrounded by the former, and the crystal form of the pyroxene is interfered with by the feldspars, proving that the pyroxenes began to crystallize before the feldspars, but did not finish before the feldspars commenced. These surrounding feldspars have variable amounts of inclusions.

The feldspars in the next variety, No. 171, have much the same characters as those just described. The inclusions in the different feldspars vary from almost none to great numbers evenly distributed through the crystal. In some they are confined to the margin, in others to the center of the individual. Some feldspars contain swarms of minute dots and short needles or rods apparently opaque. The needles are arranged in a number of sets of parallel lines, which do not appear to bear any fixed relation to the axes of the crystals, for they pass through twin lamellæ without change of direction. They are sometimes more abundant in one lamella than another and usually form irregularly shaped clouds, which exhibit no connection with cracks or cleavage planes in the feldspars. They appear to be primary. These minute dots and needles occur with the other inclusions—magnetite grains, pyroxene, apatite, and glass.

In the next three grades of the rock specimens, Nos. 172, 173, and 174, the feldspars are like those described, but their crystallographic outline is less sharply defined. In grade 22, No. 175, the porphyritical feldspars have a narrow marginal zone of purer feldspar substance. It has much fewer inclusions, sometimes being free from them.

It exhibits the same twinning as the inner feldspar, but has a lower angle of extinction, which indicates that the outer zone is composed of a more alkaline lime-soda feldspar than the central portion. The inner feldspar has a sharp idiomorphic form, while the outer zone is allotriomorphic, having crystallized against other individuals in the groundmass. The zones around the large and small feldspars are of about the same width and are apparently synchronous. In the groundmass there are small, rectangular, unstriated feldspars scattered through larger individuals of quartz. There are only a few grains of pyroxene in the groundmass; magnetite is quite abundant in grains which are smaller than in the finer grained varieties of the rock.

In the same rock, 1 foot from the last specimen, the grain is considerably coarser and is grade 29, No. 183. Here the feldspars are larger, the central portion has the same kinds of inclusions as the feldspars just described, with the addition of a little hornblende in rounded grains and biotite in minute plates. The marginal zones are broader and of very pure substance. The feldspar and quartz of the groundmass is in larger grains. At the distance of another foot the rock is grade 33, and the character of the feldspars is about the same as in those forms of the rock just described.

In the varieties embraced in the series Nos. 181, 183, 185, 188, and 193 the phenocrystic feldspars have the same characters and inclusions as those just mentioned. The central core carries more or less inclusions of magnetite, pyroxene, biotite, hornblende, and apatite; the outer zone is of pure feldspar substance. As the coarser grained form, No. 193, grade 35, is approached the number of these kinds of inclusions in the feldspars diminishes and their size increases. The swarms of black dots and needles occur in various feldspar individuals throughout these grades. The feldspars in the other forms of the rock represented in the table between grades 13 and 35 have the same characteristics as those in the series described. It is observed that the number of individulized inclusions decreases as the rock is coarser and that the swarms of dots and needles increase. In the coarser grained forms biotite and hornblende occur with the pyroxene and magnetite as inclusions in the larger feldspars. In many of the feldspars there are colorless rectangular inclusions, with a black dot near one end, which are oriented parallel to the vertical axis of the crystals. In most cases they behave like isotropic substances, but occasionally appear to be doubly refracting. The black dots do not appear to be spherical and the nature of the inclusions is doubtful; they suggest glass inclusions, but are indeterminable.

In the still coarser grained forms the feldspars are larger, the presence of a central core with a margin of more alkaline feldspar is still recognizable in most individuals though not in all. Inclusions of the ferromagnesian silicates are less abundant, but those of opaque dots and needles are more so; in some cases giving a brown tint to the feldspar. They are confined, almost exclusively, to the inner feldspar, which sometimes exhibits fine zonal structure. The twin lamellæ are much broader than in the small porphyritical feldspars of the fine grained forms. In some individuals there are many thin lamellæ twinned according to the albite and pericline laws. None of the outlines are idiomorphic. As the grain of the groundmass becomes very coarse it is evident that among the irregular grains of feldspar, most of which are striated, there are some of orthoclase. These never exhibit an approach to idiomorphism and share with the quartz a completely allotriomorphic habit. These two minerals were undoubtedly the last to crystallize out of the magma.

The large feldspars of the coarsest grained form of the rocks are about three times as large as the porphyritical feldspars in grade 13. In the coarse grained forms they have the characteristic inclusions and twinning of labradorite, as it occurs in many gabbros and norites. In most of the sections the feldspars are extremely fresh and unaltered, in a few they are partly clouded in the central portion.

The *quartz* occurs in allotriomorphic grains with the most irregular outline; it fills the interspaces between the other minerals. In the finer grained varieties of the rock its substance is extremely pure, and free from characteristic inclusions. There are almost no gas inclusions; minute crystals of apatite with occasional grains of other minerals are often inclosed by it. In the coarser grained varieties the quartz carries more gas inclusions, often in dihexahedral shapes; fluid inclusions are less numerous; the relative amount of fluid in the cavities varies considerably; in rare instance the bubble is in motion. The abundance and size of the gas cavities increases with the coarseness of the grain of the rock.

The *pyroxenes* in these rocks are hypersthene and augite, the relative amounts of which are variable. The hypersthene is distinctly pleochroic in thin sections; the colors are green || $\mathfrak{c}$, yellow || $\mathfrak{a}$, and light red || $\mathfrak{b}$. Very rarely there is zonal difference in the color of the hypersthene; this is noticed on strongly colored individuals. The form of the phenocrysts in the finest grained rocks is in part idiomorphic, some of the crystals being sharply defined; the outline of others is rough in the prism zone, and fringed at the terminations by the projection of microscopic crystals of pyroxene. The greater number are quite irregularly shaped, and exhibit no crystal outlines. In the well formed crystals the pinacoids are large and the prism faces small. Cleavage is not well developed, and is often absent from longitudinal sections; a prismatic cleavage is most always observed in cross sections. Occasionally there is a cleavage or parting parallel to the brachypinacoid. The augite is light green in thin sections and is not pleochroic. Its forms are similar to those of hypersthene, but the cleavage is more pronounced and is always present in longitudinal sections. It is occasionally twinned parallel to the orthopinacoid. It is distinguished from hypersthene by its optical characters. The two species are often easily confused when the hypersthene sections are not distinctly pleochroic. Their general habit, their form, substance and inclusions, and their behavior toward the other minerals associated with them, are so much alike that they may be described together as the pyroxenes.

In the few instances where decomposition has affected the rocks under investigation the hypersthene has yielded before the augite. Most of the rocks, however, are remarkably fresh and exhibit no signs of decomposition. The substance of both the phenocrystic hypersthene and augite is mostly very pure and free from characteristic inclusions. Some of the large pyroxenes bear numerous irregular colorless inclusions, with no bubbles, and of an indeterminable nature, besides grains of magnetite. In the fine grained varieties of the rock the microscopic pyroxenes bear numerous grains of magnetite and rounded grains of the colorless indeterminable mineral. These microscopic pyroxenes, which fill the groundmass of the varieties of the rock, are mostly rounded, but are also idiomorphic. They appear to be in part hypersthene and in part augite. They have attached themselves with parallel orientation to some of the porphyritical pyroxenes, producing very irregular outlines. In other cases, the growth of the large individuals has continued into the period of crystallization of the microscopic ones, for they have added to their purer substance a margin of pyroxene material filled with the same minute inclusions that occur in the microscopic individuals. This is true of both the hypersthene and augite.

Where individuals of the two species have grown in conjunction the hypersthene is evidently the older, being inclosed by augite. The two are sometimes intergrown, indicating that their crystallization was in large part synchronous. The character of the intergrowths of these two mineral species is especially important because of its bearing on the intercrystallization of other minerals in these rocks. The hypersthene generally occupies the central place, and is often entirely surrounded by the augite, but quite as frequently the augite only partially surrounds the hypersthene, and occasionally the two penetrate one another irregularly and intimately. In the cases where the hypersthene is surrounded by augite, the hypersthene possesses no crystallographic form or outline, but is irregularly rounded or rough and jagged (Pl. L, Fig. 1). The augite material is in direct contact with the irregular surface of the hypersthene, and forms a single augite individual, oriented parallel to the inclosed hypersthene. There is often no physical line of demarcation between the two substances, except that produced by a change of color when present, and by the different optical effects between crossed nicols. When the section of the two minerals exhibits nearly the same color for both, the presence of an intergrowth may easily be overlooked in ordinary light. The cleavage fractures and cracks often traverse the two minerals without noticeable change of direction, and behave as though the compound individual were a simple one. In places where the plane of contact between the two minerals is inclined to the axis of the microscope (line of vision) the colors of the two blend into one another, as do also their interference colors between crossed nicols.

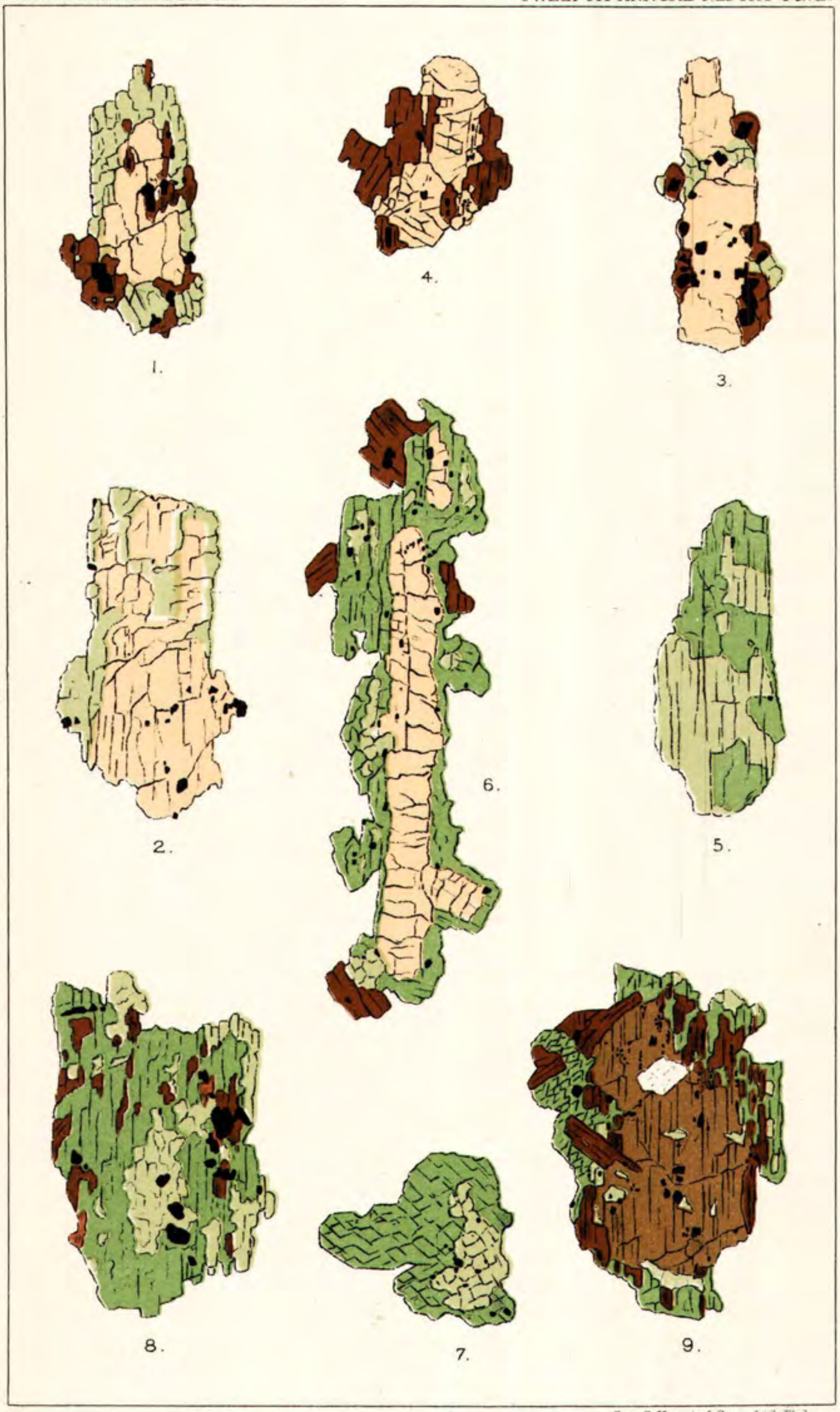
In one instance a group of pyroxenes and feldspars have crystallized in conjunction. The hypersthene and augite exhibit almost the same color, the pleochroism of the hypersthene being almost imperceptible. In the illustrations on Pls. L and LI, the colors given to the various minerals are in a measure conventional. They are those characteristic of the minerals under certain conditions, and have been used in this way in order to avoid a multiplicity of colors or tones, or the necessity of reproducing the colors exhibited in polarized light. In the intergrowth just mentioned a large, irregularly outlined pyroxene appears in ordinary light to be a homogeneous individual, traversed by irregular cracks and imperfect cleavage planes. Between crossed nicols it resolves itself into an intergrowth of hypersthene and augite, whose substances interlock irregularly, as shown in the illustration. (Pl. L, Fig. 2.) There is nothing in the section, viewed in ordinary light, to indicate where the hypersthene substance ends and the augite begins. They have evidently crystallized at the same time and have interlocked crystals.

The pyroxenes inclose comparatively large grains and crystals of magnetite, with which biotite is intimately associated. In the coarser grained varieties of the rocks the pyroxenes exhibit the same optical characters as those in the fine grained, which indicates that their chemical composition is nearly constant. Their form becomes more and more irregular and their size larger, but they are fewer in number and become less prominent as a constituent of the rock.

The *biotite* is in irregularly shaped patches, usually composed of one individual. In many cases it surrounds the magnetite completely, especially when lying in the groundmass. But where they are connected with the large pyroxenes the biotite often occurs on the side of the magnetite farthest from the center of the pyroxene and extends to the outside of the latter, as shown in the illustration (Pl. L, Figs. 1 and 3), indicating that it began to crystallize about the time the attached magnetite was being inclosed in the pyroxene, and continued after the pyroxene's growth ceased, as it grows larger toward the outside of the pyroxene crystal and is often found surrounding the latter. The surface of contact between the pyroxene and biotite is very irregular and indicates that they interfered with each other's growth. The crystallization of the biotite appears to antedate that of the microscopic pyroxenes of the groundmass, but not wholly, for the biotite occasionally incloses grains of pyroxene. Its growth was interfered with by the feldspars of the groundmass, which it sometimes incloses in rounded grains. Biotite and pyroxene occur intergrown in the same irregular manner as that observed between hypersthene and augite, but the crystallographic orientation is not so uniform. The biotite is the outside mineral. The irregularity of the boundary between the two minerals is shown in the accompanying illustration (Pl. L, Fig. 4) from No. 174. As the rock becomes coarser grained the biotite is better developed, that is, it is in larger patches and is more abundant. There is only a little biotite in the finest grained variety of the rock, grade 13. The character of the biotite is constant throughout this group of rock varieties. It is dark brown, with strong absorption and an almost uniaxial optical character. Its form is allotriomorphic and very irregular; the size of the individuals increases with the grain of the rock. It has no characteristic inclusions.

Hornblende appears as an essential constituent of the rock as it becomes coarser grained. At grade 22, No. 175, the hypersthene and augite individuals are surrounded more or less completely by compact brownish green hornblende, which also occurs to some extent in independent individuals. In other and coarser grained varieties of the rock, where it maintains the same relation to the pyroxenes, it sometimes exhibits sharply defined, idiomorphic forms. Cross sections are bounded by the prism faces making an angle of 124°, and by the clinopinacoid as a small plane, with the orthopinacoid strongly developed. The characteristic prismatic cleavage is always present in cross sections, but does not always appear in longitudinal sections. Terminal planes are also observed in some instances. But the great majority of individuals are allotriomorphic, and have very irregular outlines of the same character as those of the pyroxenes in the finer grained varieties of the rock. They are in no case acicular or columnar, but are always compact. The pleochroism is brownish green parallel to $\mathfrak{c}$ and $\mathfrak{b}$, and light brown parallel to $\mathfrak{a}$; $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$. There are no characteristic inclusions, but magnetite and biotite are often included in great amount.

The hornblende has crystallized around the augite and hypersthene in the same manner as that in which the augite surrounds the hypersthene. It is observed immediately surrounding either of the pyroxenes singly, or both together. In most cases the growths are parallelly oriented, but the pyroxene is frequently inclosed by the hornblende in various orientations. The line of demarcation between the two is as indefinite and as irregular as that between the hypersthene and augite. The pyroxene is very irregularly bounded and the union of the hornblende and pyroxene substances is often so perfect that the color and optical characters alone distinguish the different individuals. In longitudinal sections the cleavage is frequently continuous through both minerals, but in cross sections and inclined sections the cleavage is no longer parallel. It also happens occasionally that the pyroxene possesses irregular fractures which do not penetrate the hornblende. There is no uniform relation between the position or amount of hornblende and those of the inclosed pyroxene. The hornblende may form a narrow or broad border around the pyroxene or may surround only a part of the pyroxene, or they may occur independently of each other; all these



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INTERGROWTHS OF MINERALS IN DIORITE.

different relations are observed in the same thin section. The irregularity is shown in the illustrations. Pl. L, Fig. 5, represents an intergrowth of augite and green hornblende, and Fig. 6 represents an irregular growth of green hornblende around hypersthene. The hornblende incloses some grains of augite and magnetite, and has four individuals of biotite attached to it. The primary nature of the hornblende is unquestionable; cross sections exhibiting the intergrowth are observed in great numbers and in all cases where the outline is bounded by crystal faces it exhibits the characteristic forms of hornblende, as in Pl. L, Fig. 7. The hornblende does not penetrate the pyroxene in acicular needles; the junction between them is often sharp-edged and well defined by the color. Where the plane of junction is inclined to the line of vision, the two minerals wedge out in the section and their colors appear to shade into each other.

The hornblende not only surrounds the pyroxene in the manner just described, but in many cases intermingles with it in parallel orientation, presenting an intergrowth of the two minerals which corresponds exactly to the intergrowth of hypersthene and augite already described. This is oftener observed in the coarser grained varieties of the rocks than in the finer grained, but occurs in the latter also. Such an intergrowth is represented in the illustration, Pl. L, Fig. 8, taken from the coarsest grained variety, No. 202. The outline between the hornblende and augite is distinct; the shapes of the augite within the hornblende are very irregular, but the augite on the outer edge has its crystal form and appears to have continued its growth after the hornblende had ceased. They have evidently crystallized contemporaneously. The relative amount of hornblende and pyroxene varies in the different modifications of the rock studied. In some the hornblende greatly preponderates over the pyroxene, which occurs scattered through the hornblende individuals. This relation is expressed approximately in Table V.

Biotite and magnetite occur in the same connection with the hornblende as with the pyroxene in the finer grained varieties. Magnetite is scattered through the hornblende very irregularly, being abundant in some cases and absent in others. Biotite is often intergrown with the hornblende and pyroxene groups, and also incloses them in many cases, and occurs in isolated individuals with irregular shapes. The greater part of its growth seems to have been later than that of the hornblende.

A dark brown variety of hornblende occurs in some of the rocks of this group. Its relations to the other minerals are of great interest in connection with the question regarding the magmas involved in this complicated series of eruptions. It is chestnut brown to greenish brown, and resembles in this respect most of the porphyritical hornblende in the andesites of Sepulchre Mountain. It occurs in irregularly shaped individuals intergrown with the other minerals in such a manner as to indicate their nearly contemporaneous growth. In many cases it is evident that it is distinctly different from the brownish green hornblende. This is brought out by such groups as that represented by Fig. 9, Pl. L.

As in the illustration, the dark brown hornblende generally forms the central body of the mineral group, but sometimes incloses small individuals of feldspars, augite, and hypersthene with magnetite. Biotite is included near the margin of the brown hornblende, but is more abundant in the green hornblende which surrounds the brown hornblende. It frequently occurs in this association and indicates that in these instances the crystallization of the biotite set in after that of the brown hornblende and before that of the green, though its crystallization in many cases appears to set in after that of the green hornblende.

There are instances where the distinction between the dark brown and the green hornblendes is not so definite and is not separated by the commencement of the crystallization of a third mineral. In these cases the form of the brown hornblende is exceedingly irregular; the boundary between the two is sometimes sharp edged, but often is indeterminable, and the two shade into each other. There is usually no approach to a zonal arrangement of the colors, and their distribution is as irregular as the outward form of the individual or as that of the intergrown minerals already described. The general absence of zonal structure in the hornblende and pyroxenes of this group of rocks is noteworthy and will be discussed subsequently. It appears to some extent in the distinctly porphyritic modifications of the rock. In the contact facies of the diorite, already described, No. 139, the idiomorphic form of the hornblende is accompanied by a zonal distribution of the color. The reddish brown color occurs at the center and also along the margin of brownish green hornblendes and appears to be the result of primary crystallization. In the same way the brown hornblende in the coarse grained diorites appears to belong to a phase of the hornblende crystallization distinct from that of the brownish green hornblende.

Magnetite occurs in well developed crystals and irregular grains, which contain more or less titanic oxide as shown by the chemical analyses. In the porphyritic varieties of the rock, magnetite appears in large porphyritical grains and in a multitude of minute grains in the groundmass, evidently the product of two generations. As the rock becomes coarser grained the individuals of magnetite are larger and fewer in number. In the coarsest grained varieties they are much fewer in number and appear to belong to one generation.

Apatite is not observed in the finest grained varieties of the rock, but is first noticed in the twenty-third grade, No. 176, where it occurs in microscopically minute crystals, sharply idiomorphic. As the grain of the rock increases they appear as larger and larger crystals, but fewer in number. Their size and amount are not perfectly regular throughout the different varieties of rock included in this group, so that there is no definite relation between the size of the apatite and the grain of the rock, but the variation in size and amount is very noticeable in a general way. They attain their largest development in No. 201, where they reach 0·45 ^{mm}. In this rock their form is irregular, with no crystal outlines.

Zircon is scarce. It is not noticed in the finest grained varieties of the rock. It first appears in very small crystals and in the coarser grained rocks it is in larger crystals. Thus both the zircon and apatite in this group of rocks appear to vary in size with the grain of the rock; that is to say, their crystallization was influenced by the conditions which controlled the degree of crystallization of the whole rock.

Recapitulation.—Some of the variations in the microscopical habit of the minerals composing this group of rocks may be briefly recapitulated as follows:

The idiomorphic feldspars and the zonal portion of the allotriomorphic ones increase in size with the grain of the rock. Their twin lamellæ become broader; the number of inclusions of ferromagnesian silicates and magnetite diminish, and the abundance of minute dots and needles increases with the grain of the rock. The feldspar, forming irregular grains in the groundmass of the porphyrites, crystallizes as a border around the idiomorphic individuals in the coarser grained varieties; is allotriomorphic and more alkaline. Orthoclase is recognizable in the coarsest grained varieties.

Quartz occurs only in allotriomorphic individuals, which are nearly contemporaneous with the orthoclase. The gas and fluid inclusions increase in number and in size with the size of the quartzes and the grain of the rock.

Hypersthene and augite occur in idiomorphic and allotriomorphic individuals in the porphyrite; are much more irregularly shaped in the coarser grained varieties of the rock and are in larger individuals.

Primary brownish green hornblende occurs in the same manner, and dark brown hornblende appears as an independent crystallization, but is not always present.

Biotite occurs almost wholly in allotriomorphic forms.

The ferromagnesian silicates occur isolated to some extent, but are generally intergrown in the most intimate manner. There is an apparent order in the time when they started to crystallize, but they have evidently grown synchronously to a large extent. This is more noticeable in the coarser grained varieties of the rock, where all of the minerals exhibit mutual interference with those near them in the order of crystallization. Where the extremes of this order are in conjunction the older mineral has its idiomorphic form.

Magnetite occurs in two generations in the porphyrites; the evidences of a second generation cease as the rock becomes coarse grained, and the size of the individuals increases and their number diminishes.

Apatite occurs in abundant minute idiomorphic crystals in the finer grained varieties, and is in much fewer, larger, poorly shaped individuals in the coarse grained varieties.

Zircon is more noticeable in the coarser grained rocks, and is in larger crystals.

INTERGROWTH OF HORNBLENDE AND PYROXENE IN GLASSY ROCKS.

It is important to emphasize the primary nature of the hornblende found intergrown with the augite and hypersthene in the diorite just described. Similar intergrowths are mentioned by Prof. Rosenbusch as of common occurrence in those diorites in which all of these minerals are developed.[1] Its resemblance to certain paramorphic changes of pyroxene to compact hornblende in other coarse grained rocks described by George H. Williams,[2] G. W. Hawes,[3] R. D. Irving, and C. R. Van Hise,[4] may in some minds cast a doubt on its primary nature in the rocks under investigation. It is to be remarked that Prof. Williams in his paper observes with regard to the cases described by the other investigators mentioned, "In neither of these instances, however, are the proofs of paramorphism adduced entirely convincing." In his own paper he rests his case on the very irregular boundary between the pyroxene and hornblende, on the fact that the hornblende penetrates the pyroxene in the form of "the most delicate possible tongues and shreds," extending "in every direction, though they seem to be most developed in the direction of its cleavage." And, further, on the apparent gradual transition of one mineral into the other optically.

With regard to the last observation it is self-evident that thin edged portions of minerals with similar indices of refraction, which wedge out against one another within the space of a rock section, appear to pass into one another by insensible gradations of color. This can be observed in the case of inclined contacts between hypersthene and feldspar in which case there is no suspicion of an actual transition of substance or intermediate stage of chemical character. There is no direct evidence brought forward in the paper cited to show by the crystal outline of the mineral that the original form was that of a pyroxene, as in the case of uralite. The whole argument seems to the writer to hang on the fact that the hornblende penetrates the pyroxene in tongues and shreds, in which respect it resembles the paramorphism of pyroxene to uralite. From the writer's acquaintance with instances of undoubtedly primary intergrowths of hornblende with other minerals, the last-mentioned argument for the paramorphism of compact hornblende from pyroxene does not seem to him to be sufficient. Because of the doubt which may have been cast upon the primary nature of certain intergrowths of hornblende and pyroxene it has seemed advisable to recall to those who have studied glassy volcanic rocks, and to present to those unfamiliar with them, some of the numerous instances of the nearly contemporaneous crystallization of hornblende and pyroxene, which are identical with those observed in the diorite at Electric Peak. Their occurrence in perfectly

[1] Mikroskopische Physiographie der Massigen Gesteine. Stuttgart, 1887, p. 119–120.

[2] On the Paramorphosis of pyroxene to hornblende in rocks. Am. Jour. Sci., Oct., 1884, vol. 28, p. 259–268.

[3] Mineralogy and Lithology of New Hampshire, pp. 57–206; Pl. VII, fig. 1.

[4] Geology of Wisconsin, 1880; vol. 3, p. 170. Am. Jour. Sci., July, 1883; vol. 26, p. 29. Geology of Wisconsin, 1882; vol. 4, p. 662.

fresh, glassy, and often pumiceous surface lavas makes it evident that the two minerals have crystallized out of a molten magma at very nearly the same time, and are not the result of metamorphism subsequent to the consolidation of the rock.

In the glassy hornblende-pyroxene-andesites of Sepulchre Mountain there are instances of the conjoint growth of hypersthene, augite, and brown hornblende. The pyroxene and hornblende are occasionally grown together with an irregular line of demarcation between them. The hornblende partly surrounds the pyroxene and appears to be the younger mineral. In one instance a large individual of brown hornblende is surrounded by a border of augite crystals in nearly parallel orientation. The outline of the inclosed hornblende is irregular, but exhibits no evidence of resorption and bears no magnetite. The other hornblendes are idiomorphic.

In some of the other hornblende-pyroxene-andesites from this region red porphyritical hornblende is found to include pyroxene in irregularly shaped grains and in different orientations, showing that in these cases the hornblende crystallized after the pyroxene commenced to crystallize.

The most striking examples of these intergrowths that have come to the writer's notice and that furnish good subjects for illustration are found in pumiceous glassy andesites from different parts of North and Central America.

In a very glassy andesite from Santa Clara Canyon, New Mexico, described in a recent bulletin of the Survey,[1] there is a fine instance of the inclosure of hypersthene by dark brown hornblende, Fig. 4, Pl. LI. The substance of the hypersthene is very pure and resembles that of the idiomorphic hypersthenes scattered through the colorless glass. The form of the inclosed hypersthene is very irregular. The inclosing hornblende has crystallized directly upon the hypersthene and forms a border round it. The outline of the hornblende is only partly idiomorphic, as it has grown against other individuals of hornblende in different orientations. The inclosing hornblende is the same as the idiomorphic hornblende scattered through the glass, and contains a great number of crystals of magnetite.

In a glassy hornblende-andesite from the mouth of Silver Creek, Utah,[2] the dark brown porphyritical hornblendes inclose irregular grains of pyroxene. One individual is especially interesting, as it incloses both augite and hypersthene. The irregular shapes of the inclosed pyroxenes are shown in Fig. 5, Pl. LI. This is very similar to what is observed in the diorites at Electric Peak, except that the hornblende is dark brown instead of brownish green. Excellent examples of the same thing are found in an andesite from Skellig Ridge, Elk Head Mountains, Colorado.[3] The groundmass of this rock is filled with small pyroxenes and

[1] On a group of volcanic rocks from the Tewan Mountains, New Mexico, and on the occurrence of primary quartz in certain basalts. J. P. Iddings, Bull. U. S. Geol. Surv., No. 66, 1890.

[2] Collection of the Fortieth Parallel Survey, No. 319 (20645).

[3] Ibid., No. 323 (20487).

brown hornblendes, and the hornblende frequently incloses the pyroxene, as in Fig. 6, Pl. LI. In this instance the hornblende surrounds the augite.

In a glassy hornblende-pyroxene-andesite from Lassen Peak, California,[1] the intensely red hornblende occasionally surrounds the pyroxene. This is shown in cross section in Fig. 7, Pl. LI.

The same thing is observed in the pumiceous, glassy dacite from the same locality.[2] Irregularly shaped pyroxene forms the center of dark greenish brown hornblende, which is distinctly idiomorphic, and has the prism ∞P, and both pinacoids, $\infty P\acute{\infty}$, $\infty P\grave{\infty}$; this is shown in Fig. 8, Pl. LI. Another instance of the intergrowth of pyroxene and dark greenish brown hornblende from the same dacite is illustrated in Fig. 9, Pl. LI. The pyroxene in this case is hypersthene. The character of the intergrowth is exactly the same as of those in the diorite at Electric Peak. Such intergrowths are not rare occurrences in this glassy rock, and are not confined to the pyroxene and hornblende. Irregular individuals of olivine surrounded by the same kind of hornblende are frequently met with. Olivine surrounded by reddish brown hornblende also occurs in a hornblende-pyroxene-andesite from Mount Ranier, Washington.[3] The same association of accessory olivine and inclosing hornblende is found in a pumiceous glassy hornblende-pyroxene-andesite from Salvador, Central America.[4] Intergrowths of hornblende and pyroxene occur in these rocks also.

In this connection it may be well to call attention to an exceptional intergrowth that will illustrate how intimately minerals of altogether different composition and habit may crystallize. It is the mutual penetration of hypersthene and plagioclase which form a porphyritical group in a glassy hornblende-pyroxene-andesite from Mount Hood, Oregon.[5] The two minerals are perfectly fresh and so oriented that the striations of the plagioclase are parallel to the vertical crystallographic axis of the hypersthene (Fig. 10, Pl. LI). The feldspar carries a great amount of fine glass inclusions, in which there is occasionally a minute crystal of magnetite. The hypersthene carries a few irregularly shaped inclusions, which may be glass, but do not contain spherical gas bubbles. It incloses numerous grains of magnetite and colorless prisms of apatite, which are also scattered through the feldspar. The difference between the association of the inclusions in each mineral is very noticeable. The minerals evidently crystallized out of the same glassy magma in which were scattered magnetite and apatite. The feldspar inclosed a great deal of the glass in sharply defined cavities, and also inclosed less apatite and magnetite. The hypersthene inclosed a much greater amount of magnetite and apatite and a much smaller amount of glass,

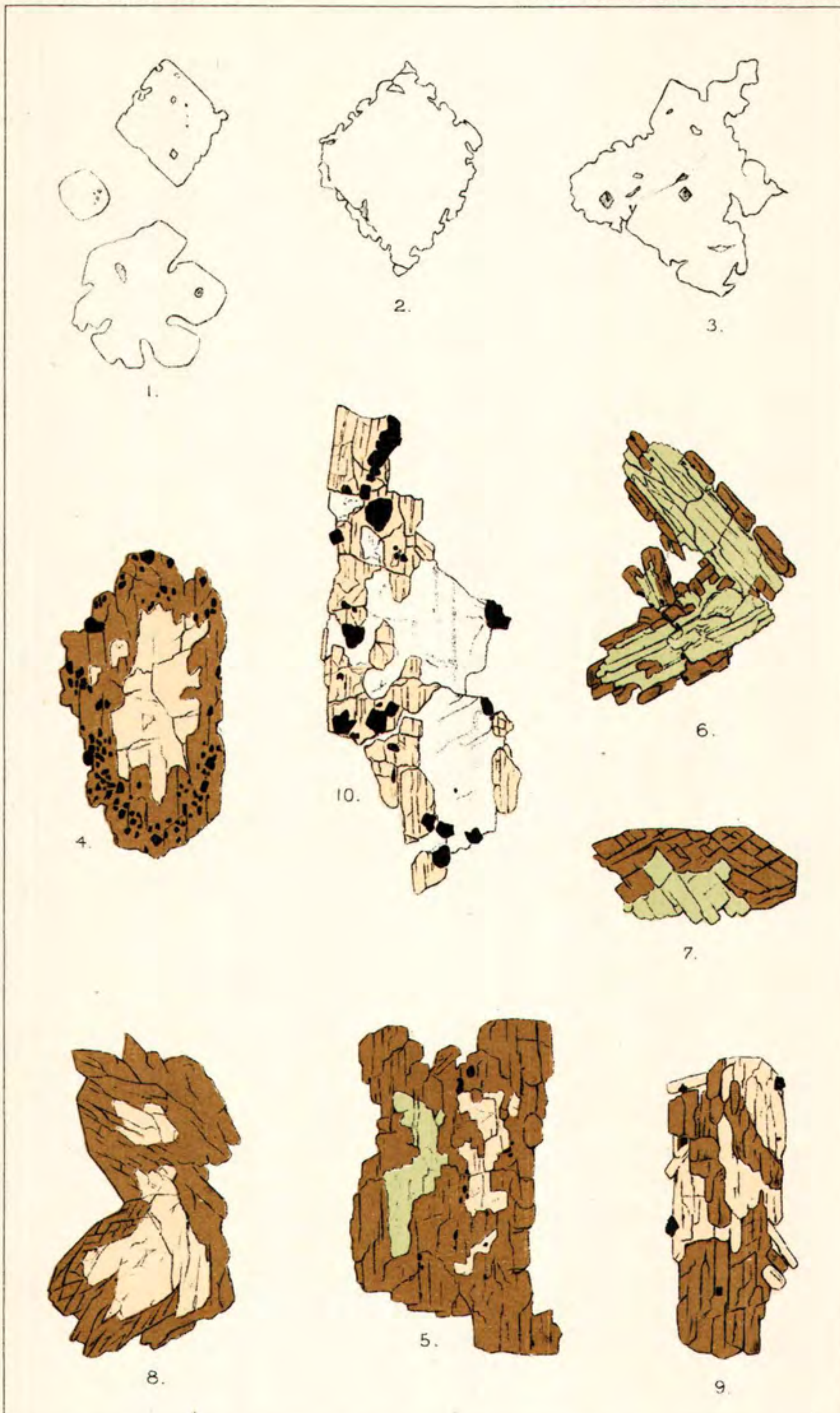
[1] Collection of the Fortieth Parallel Survey, No. 989 (22940).

[2] Ibid., No. 994 (22946).

[3] Ibid., No. 1067 (23043).

[4] Volcanic Rocks of the Republic of Salvador, Central America. By Arnold Hague and J. P. Iddings. Am. Jour. Sci., July, 1886., vol. 32, pp. 26-31.

[5] Collection of the Fortieth Parallel Survey, No. 1044 (23017).



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INTERGROWTHS OF MINERALS IN GLASSY ROCKS.
AND QUARTZ PHENOCRYSTS.

which is scarcely recognizable as such. The boundary lines between the plagioclase and hypersthene are irregular and in places distinct. Where the two minerals wedge out against each other in the section there is no line of demarkation between them, and the color of the hypersthene fades out gradually.

From the cases of conjoint crystallization of various rock-making minerals in pumiceous glassy lavas, which are of very widespread occurrence, and from the similar intercrystallization of these minerals in the holocrystalline stock rock at Electric Peak, where the various phases of intergrowth can be studied and its primary nature established, it is apparent that caution should be used in referring other instances of parallel intergrowth in coarsely granular rocks to paramorphic actions. It would seem as though the presence of idiomorphic outlines would be necessary to determine the primary or secondary nature of the mineral in doubt where the rock exhibited no signs of secondary alteration. In cases where augite is surrounded by or appears to pass into compact hornblende, and neither mineral exhibits its characteristic crystal outline in any part of the rock under investigation and the rock is unaltered, the primary or secondary nature of either mineral may be questioned; for each mineral may be the result of the primary crystallization of the once molten magma, from which either of the two minerals may separate before the other, or either may be the result of the alteration of the other, since the change of compact hornblende to compact augite occurs in the rocks already described. It is probable, however, that the study of a series of varieties of the rock in any case would determine whether the intergrowth of the two minerals in a particular case is the result of primary crystallization from a molten magma, or of paramorphic action subsequent to the consolidation of the magma.

Alteration products.—Among the secondary minerals that are found in some of the rock sections from Electric Peak is uralite. Its derivation from original pyroxene is evident from the outline of the cross sections. It is usually accompanied by other signs of alteration in the rock, and is distinguishable from the primary brownish green hornblende. In some sections there is secondary acicular amphibole, light green and generally in confused aggregates. Besides these are chlorite, epidote, quartz, and calcite in the usual association. But as already observed, most of the thin sections exhibit no signs of decomposition. As the processes of decomposition are like those commonly observed in other rocks they need no special comment.

II (*b*). *Varieties of the stock rocks in which the amount of the light colored minerals (feldspar and quartz) exceeds that of the dark colored minerals (ferromagnesian silicates) and in which the quartz is not excessive.*—This group presents a more feldspathic facies of the diorite, and includes varieties that occur as lighter colored portions of the main mass without any apparent relation to its form, others that appear to be contact facies of the stock, and some that occur as dikes or veins in the main mass of diorite.

They are not grouped according to their mode of occurrence, but on mineralogical and microstructural grounds. They agree in having a preponderance of feldspar, with considerable quartz, and a range of ferromagnesian silicates that connects them with the diorites of Group II (*a*). They resemble the main body of diorite in general habit, but are lighter colored. The finer grained varieties approach the dike rocks in microscopical characters, and are probably intimately related to them geologically.

The hornblende, pyroxene, and biotite have the same characteristics as those in the main body of diorites, and require no further comment. They exhibit the same relationship to one another when found together. But since the rocks brought within this group are not from the same geological body, there is a greater variation in the relative proportion of the ferromagnesian silicates, as will be seen in Tables V and VI. The feldspars are more alkaline than those in the main body of diorite and have a somewhat different habit. The quartz also plays a slightly different rôle. Owing to the difference in microstructure it is not possible to compare the grain of these varieties directly with the grain of the less feldspathic diorites. But they can be correlated approximately. The coarsest grained variety, No. 215, of this group, grade 39, is from a light colored vein 1 foot wide, cutting the darker colored diorite. It is composed of broad plagioclase feldspars from 1^{mm} to 2^{mm} long, with numerous small and irregularly shaped quartz grains, located along the line of junction of the feldspars; green and brown hornblende and biotite are present in very irregularly shaped individuals, besides some magnetite and apatite. The hornblende is in part phenocrystic.

The feldspar has distinct zonal structure and polysynthetic twinning. The extinction angles are not very high and may belong to oligoclase or andesine. There are no characteristic inclusions. The quartz contains numerous fluid inclusions.

When the grain of the rock becomes smaller, as in the next three grades, Nos. 214, 213, and 212, the feldspars stand out more prominently as phenocrysts; they are more nearly idiomorphic and there is a greater amount of small grains of feldspar and quartz. The greater part of the ferromagnesian silicates is found intergrown with these small grains of feldspar and quartz, and appears to be later than the crystallization of the large feldspars. There are some porphyritical hornblendes which appear to belong to an earlier period of crystallization than those just mentioned. Small augites occur in No. 212, independent of the hornblende. The next specimen in the table is clearly a more feldspathic and quartzose facies of the main diorite. It exhibits the same structure, and the pyroxene and hornblende are intergrown in the same manner as in that rock. The next specimen in this series, No. 210, is considerably finer grained, being about grade 27. It is from a contact with the sedimentary rocks. The microstructure is like that of the coarser grained varieties, except that the large feldspars and hornblendes are distinctly idiomorphic, and the amount of granular material about equals that of the phenocrysts. There is an approach to idiomorphism on the part of some of the individuals of the groundmass, more frequently the feldspars. Occasionally the same quartzes have a rudely idiomorphic form, and yield sections that indicate their occurrence in dihexahedral pyramids without the facies in the prism zone. The outlines of these sections are not sharply crystallographic, but are indented by the interference of adjacent and smaller feldspar grains. These quartzes carry fluid inclusions and individualized inclusions which sometimes have the shape of glass inclusions but appear to be feldspar. A slightly different groundmass structure is developed in a light colored apophysis of the stock, No. 209, grade 21. It is distinctly porphyritic, with abundant feldspars and numerous brown hornblendes. The groundmass in places exhibits a micropegmatitic structure.

The finest grained variety of contact facies in this group is No. 207, from near the sedimentary rocks. It has a fine grained groundmass similar to that of the last contact facies mentioned, No. 210, but is about grade 20. The porphyritical feldspars and hornblendes are not so abundant, and the latter are surrounded by shreds of biotite which appear to be nearly contemporaneous with the crystallization of the groundmass.

In this group have been placed two specimens: One, No. 208, from a dike on the southeast spur of Electric Peak, and the other, No. 206, from the talus directly below the first one. They resemble the varieties just described in the structure of the groundmass and in the occurrence of the biotite as a product of the final crystallization of the magma. They are slightly decomposed. From the same talus slope were collected two varieties, Nos. 204 and 205, which are very similar to those just mentioned, but are fresher. It is not known whether they are contact facies of the stock rock or dikes. A still finer grained variety, No. 203, occurs in small dikes near the stock on the northeast spur. The groundmass is a finely granular mixture of quartz and feldspar, with phenocrystic plagioclases and hornblende, and irregular patches of biotite.

II (*c*). *Varieties in which the amount of the light colored minerals (feldspar and quartz) exceeds that of the dark colored minerals (ferromagnesian silicates) and in which the quartz is abundant.*—This group presents very quartzose as well as feldspathic varieties of the diorite, which approach granite in composition and structure. They are mostly coarse grained dikes or veins that cut the main body of diorite and range from grade 35 to 40, Table VII. With them are placed the rocks from several narrow dikes in the sedimentary strata, which appear to be quartzose apophyses from the pyroxene-bearing magmas.

The rocks of this group are very similar to those of Group II (*b*), but are richer in quartz and the majority of the feldspars appear to be more alkaline; they have lower extinction angles and lower double refraction, and do not exhibit so great a number of twin lamellæ as the plagioclases of the dark colored diorite. Zonal structure is pronounced and the individuals are oftener equidimensional.

In the coarsest grained varieties they are allotriomorphic. There are a number of different species of feldspars present in these rocks, and their relative proportions vary. Occasionally there are those with abundant twin lamellæ, high double refraction and extinction angles, which are more nearly idiomorphic and rectangular. These appear to belong to the labradorite series. In some varieties of the rock there is considerable unstriated, allotriomorphic feldspar, without zonal structure, and with a distinct cleavage, that also bears thin lamellæ of another feldspar as inclusions parallel to the vertical axis, which is undoubtedly orthoclase. It is very abundant in No. 222, which is, in fact, a fine grained granite. It is shown in Pl. XLIX, Fig. 1, natural size. This occurs as a large body in the diorite, probably in the form of a dike or vein; it was not found in place, but as large slabs among those of diorite at the base of the high mass of diorite needles on the northeast spur of Electric Peak. The other varieties are more properly quartz-diorites.

In the coarsest varieties of this group the ferromagnesian silicates are biotite and hornblende, with no pyroxene. The biotite is in excess of the hornblende.

II (c'). The remaining rocks in this group are from narrow apophyses in the immediate vicinity of the main stock. They are rich in quartz, but carry more basic plagioclases and a variable amount of augite, besides biotite and hornblende. They appear to be quartzose facies of the pyroxene-diorite of the main stock and may be contemporaneous offshoots from it. No such variety of rock has yet been found cutting the main mass of the diorite.

The microstructure of Nos. 220 and 221 is somewhat finer grained than that of Nos. 222, 223, and 224; the relative amounts and the size of the quartz and feldspar are about the same. In No. 221 the biotite is largely in excess of the augite which occurs in small crystals and grains. Hornblende is entirely absent. In No. 220 there is very little pyroxene, more hornblende and still more biotite.

A much finer grained variety, No. 219, from the same locality is grade 25; it is distinctly porphyritic. The groundmass is composed of small grains of quartz and feldspar, through which are scattered abundant plagioclases with irregular outlines, high extinction angles and the dust-like inclusions that characterize the labradorites of the coarse grained diorite. There are large porphyritical hornblendes and considerable biotite with a small amount of pyroxene inclosed in the hornblende.

A very fine grained variety, Nos. 216, 217, and 218, about grades 19 and 24, resembles No. 221 in mineral composition. The ferromagnesian silicates are biotite and some augite. The groundmass is composed of small grains of quartz and feldspar. The distinguishing feature of the groundmass of the fine grained varieties of these quartzose rocks is the granular structure; that of the less quartzose ones is the aggregation of lath-shaped feldspars.

III. QUARTZ-MICA-DIORITE-PORPHYRITE.

The last magma to break through the conduit of Electric Peak was that of the quartz-mica-diorite-porphyrite. It forms a broad stock cutting up through the body of the diorite, wedging out to the north, and sending a number of narrow dikes into the sedimentary strata to the southwest. The rock is light gray to white, with abundant small phenocrysts of feldspar, quartz, and biotite. Its habit is similar to that of the other porphyrites, and is produced by the great number of small phenocrysts. The groundmass is scarcely recognizable as such macroscopically, except in the finest grained varieties. The rock appears to be evenly granular in hand specimens. The coarsest grained varieties are from the stock, the finest grained from the narrow dikes on the southeast spur of Electric Peak. The varieties are arranged in Table VIII, column III, according to their grade of crystallization.

Besides biotite there is a little hornblende, which is a prominent constituent of one modification of the rock, shown in Fig. 2, Pl. XLIX, but is almost entirely wanting in the greater portion of the rock. It occurs as small inclusions in some of the large feldspars. In most of the specimens collected the biotite is partly chloritized and the feldspars are more or less altered.

The rock is intermediate, between quartz-diorite-porphyrite and granite-porphyry. It varies slightly in mineral composition as well as in chemical composition, and the extremes would be classed under these two heads.

The finest grained varieties which occur in the narrow dikes consist of a microcrystalline groundmass of irregular grains, whose exact nature can not be determined optically, but which are undoubtedly quartz and feldspar, as these minerals make up the groundmass of the coarser grained varieties. Through this groundmass are scattered phenocrysts of feldspar and quartz, with biotite and occasionally hornblende. The feldspar is mostly plagioclase, with polysynthetic twinning, and appears to belong to the oligoclase series. A few individuals exhibit no striations and may be orthoclase. Their form is distinctly idiomorphic when the grain of the groundmass is extremely fine, but where this is somewhat larger the outline of the feldspar section is not so sharp.

The porphyritical quartz is in smaller individuals than the feldspar. Most of them exhibit straight edged crystallographic outlines, that belong to dihexahedral pyramids, possibly with small prism faces. Others are rounded more or less completely. Straight edged and rounded grains occur indiscriminately through the rock and in the same rock section. (Pl. LI, Fig. 1.) Some individuals exhibit irregular outlines occasioned by bays or pockets of the groundmass penetrating the quartz substance. These pockets are extremely abundant around some individuals and are entirely absent from others. They occur both in straight edged and rounded individuals. They are often associated with numerous microcrystalline inclusions that are located along the margin of the quartzes. From their mode of occurrence in otherwise idiomorphic quartzes it seems probable that in these instances they are forms of original inclusions and not the result of a corrosive action of the magma on the idiomorphic quartzes. There are also microcrystalline dihexahedral inclusions within the quartzes, and gas and fluid inclusions.

In the finest grained varieties of this rock the outline of the quartz individuals is sharply defined against the groundmass, but in the slightly coarser grained varieties this is not the case with all of the individuals. Some have rough surfaces which are evidently produced by the substance of the porphyritical quartz extending irregularly into the groundmass. In some cases there is a narrow border of groundmass around the quartz, part of which extinguishes light in unison with the porphyritical quartz. The quartz in this border of groundmass is evidently oriented parallel to the large quartz grain.

The biotite in these varieties of the rock is almost completely decomposed to chlorite with some epidote and rutile needles. The rock contains a few grains of magnetite and crystals of apatite.

The quartz-mica-diorite-porphyrite occurring in the stock is much coarser grained than that just described from the narrow dikes. It is much richer in phenocrysts, which are larger and so crowded together that there is very little groundmass between them. The coarsest grained variety is about grade 35. The feldspars have the same characters as those just described. The quartz is particularly interesting; some individuals are quite large, and the sections of these are usually sharp edged; they are partly rounded, partly crystallographically bounded, the two forms occurring together in the same thin section. The greater number of quartzes are irregularly outlined, with an approach to a dihexahedral shape, which is less noticeable as the groundmass becomes coarser grained. The inclusions are the same as in the quartzes of the finest grained varieties. These inclusions are sometimes arranged in a zone which marks a central core of idiomorphic quartz, the outer portion of the individual being less regularly defined and extending into the surrounding groundmass a short distance. In the coarsest grained varieties the forms of most of the quartzes are very irregular and allotriomorphic, the nature of their inclusions being about the same. A few are somewhat idiomorphic. The small grains of quartz in the groundmass are wholly allotriomorphic. The variation in the quartzes is illustrated by Figs. 2 and 3, Pl. LI, the former occurring in a medium grained variety, No. 231, grade 21, and the latter in the coarsest grained form, No. 238, grade 35. The quartz individual represented by Fig. 3 exhibits only a slight approach to a dihexahedral shape. It is drawn with its principal axis, c, in the vertical position, which may be recognized in the drawing by the position of several dihexahedral inclusions.

It is evident that in this rock the porphyritical quartzes were the last of the phenocrysts to crystallize and that their crystallization in the coarser grained varieties continued into the period of the crystallization of the groundmass with no marked evidence of interruption.

GENERAL CONSIDERATION OF THE MINERAL AND CHEMICAL COMPOSITION OF THE INTRUSIVE ROCKS; THEIR VARIABILITY AND OVERLAPPING, AND THE ABSENCE OF DEFINITE TYPES.

Mineral composition.—The accompanying tables are designed to express some of the variations that exist in the rocks under investigation. They are, of course, approximate determinations in every case, and represent the judgment of the writer. It is probable that another observer might differ, in particular instances, as to the position of a rock in any of the columns, but this difference would not be very material and would not affect the general result.

In considering the group of dike rocks described under Group I and the dikes of Group III the most essential variation is among the phenocrystic minerals and in the accompanying groundmass structures, the variations in the grain of the groundmass being of secondary importance. They have, therefore, been arranged in Table III according to the variable ferromagnesian phenocrysts they contain, no account being taken of the feldspars since their variation is much less marked and not easily recognized. It is to be remembered that they are present in all of the rocks, and are more basic in the basic rocks than in the acidic.

In Table III no account is taken of the degree of crystallization. This is expressed in Table IV, where the same rocks are correlated as closely as possible according to the grain of the groundmass, the finest grained being at the top and the coarsest at the bottom of the table.

TABLE III.—*Mineral variation in the dike rocks of Electric Peak.*

Mineral groups.	Specimen numbers.	Phenocrysts other than feldspar.			
		Pyroxene.	Hornblende.	Biotite.	Quartz.
d_1	136	much.			
	137	much.			
d_2	138	much.	some.		
d_3	139	much.	much.		
d_4	140	some.	much.		
	141	some.	much.		
d_5	142		much.		
	143		much.		
d_6	144		much.	little.	
	145		much.	little.	
	146		much.	little.	
	147		much.	little.	
	148		much.	little.	
	149		much.	little.	
d_7	150		much.	some.	
	151		much.	some.	
	152		much.	some.	
d_8	153		much.	much.	
	154		much.	much.	
	155		much.	much.	
	156		much.	much.	
	157		much.	much.	
	158		much.	much.	
d_9	160		some.	much.	
	161		some.	much.	
	159		little.	much.	
d_{10}	162		little.	much.	little.
d_{11}	163		little.	much.	much.
	164		little.	much.	much.
	165		little.	much.	much.
	166		little.	much.	much.
	167		little.	much.	much.
	168		little.	much.	much.
	169		little.	much.	much.

From Table III it is seen that the dike rocks vary in mineral composition from acidic rocks with much porphyritical quartz and biotite and very little hornblende, through intermediate rocks with much porphyritical biotite and hornblende, to basic rocks with pyroxene and little or no porphyritical hornblende and biotite, but which are more coarsely crystalline than the more acid rocks and contain some biotite which appears to belong to the period of final consolidation and to be related to the biotite in the diorites. The gradual nature of the transition from one extreme to the other is apparent.

The impossibility and impracticability of considering certain rocks as definite types with which to compare other rocks in the region is also evident when it is observed that the mineralogical variation takes place within certain limits in one rock body (specimens Nos. 159, 160, 161, 154, and 151 are from the same dike); and that what appears to be a mineralogical facies of one particular rock body is the characteristic combination of another, and its facies is something different. Field observation shows that in this locality the greater number of dikes are composed of rocks carrying variable percentages of porphyritical hornblende and biotite, and that the other varieties are less numerous. In another region other varieties predominate. The chemical variations which are indicated by the silica percentages range from 57·12 in subdivision d_3 to 61·85 in d_7, and probably reach 69·00 in d_{11}. They indicate the correspondence between the mineralogical and chemical variations for this group of rocks.

TABLE IV.—*Grades of crystallization of the dike rocks of Electric Peak.*

Grades of crystallization.	Mineralogical grouping indicated in Table III.										
	d_1	d_2	d_3	d_4	d_5	d_6	d_7	d_8	d_9	d_{10}	d_{11}
6											163
7						144					164, 165
8					142						166, 167
9						145, 146				162	168, 169
10						147	150				
11						148, 149			159, 160		
12					143			153, 154	161		
13								155			
14							151, 152	156, 157			
16			139					158			
19	136			140, 141							
20	137										
25		138									

Table IV expresses the range in degree of crystallization of the groundmass of these rocks, which are arranged in columns corresponding to the mineralogical grouping of Table III. It is to be remarked that the specimens were collected from different sized dikes and from different parts of the dikes, so that the variations in grain can not be compared very closely with the mineral composition. But when the size of the dikes in each case is taken into consideration it becomes even more evident than from the table that the coarseness of grain bears a very considerable relation to the chemical composition of the rock. The variation in grain between the sides and center of a dike and between dikes of different widths, for rocks of nearly the same composition, is not so great as the variation between rocks of different composition where the size of the dikes in which they occur is somewhat similar. Thus, specimen No. 137 is from the center of a 4-foot dike, and No. 136 from the contact wall of the same, and specimen No. 151 is from the center of an 8-foot dike, and Nos. 161 and 154 from the contact walls of the same; Nos. 168 and 169 are from 4-foot dikes, and No. 167 from a 2-foot dike. They all occur at nearly the same altitude, but it is possible that the pyroxene-bearing rock, No. 137, may have been intruded in rocks which were more heated at the time of its intrusion and so have acquired its decree of crystallization through slower cooling, but this is not so likely to have happened in the case of rock No. 138, which is in the same part of the mountain as No. 139, but is in a dike 10 feet wide and is very much coarser grained than No. 137. (See Table VI.)

The groundmass of the rock with porphyritical quartz and biotite, No. 169, is made up of minute grains of quartz and feldspar about $0{\cdot}015^{mm}$ in diameter, while the groundmass of pyroxene-bearing variety, No. 137, is made up of lath-shaped and irregularly shaped feldspar about $0{\cdot}10^{mm}$ to $0{\cdot}14^{mm}$ in length, and the groundmass of No. 138 is composed of lath-shaped feldspars $0{\cdot}5^{mm}$ to $0{\cdot}7^{mm}$ in length.

The character of the groundmass changes from an even granular structure in the acidic rocks, through one made up of irregular grains and lath-shaped feldspars in the intermediate rocks, to an aggregation of lath-shaped feldspars with almost no irregular grains in the basic varieties.

The tendency of basic rocks to crystallize more completely and with larger groundmass crystals than acidic rocks is constantly observed among the effusive rocks, such as basalts, andesites, and rhyolites. The same law appears to obtain among the intrusive rocks. It is of course necessary to compare rocks that appear to have crystallized under very nearly the same physical conditions.

The rocks of Group II have been described in greater detail on account of their number and importance and have been subdivided into three subgroups, II (a), II (b), II (c), page 597. The tables presenting the results of this part of the work have a different form and are arranged separately for each subdivision. They are Tables V, VI, and VII.

TABLE V.—*Mineralogical variation among the diorites of Group II (a).*

Specimen number.	Percentage of silica.	Amount of quartz.				Relative amount of pyroxene and hornblende.					Relative amount of pyroxene, hornblende, and biotite.			
		Little.	Moderate.	Considerable.	Much.	*p*.	*p*>*h*.	*p*=*h*.	*p*<*h*.	*h*.	(*ph*).	(*ph*)>*b*.	(*ph*)=*b*.	(*ph*)<*b*.
170		170				170					170			
171	57·38		171			171						171		
172			172			172						172		
173			173			173						173		
174			174			174						174		
175			175				175					175		
176	61·22	176						176				176		
177	58·05	177					177					177		
178	56·33	178					178					178		
179				179				179					179	
180	58·10		180					180					180	
181				181				181				181		
182				182				182				182		
183				183					183			183		
184				184					184				184	
185	58·11			185					185			185		
186	58·87		186					186					186	
187			187						187			187		
188				188					188			188		
189	55·64		189					189					189	
190			190						190			190		
191				191					191				191	
192				192					192				192	
193				193					193			193		
194				194						*194			194	
195				195					195			195		
196		196							196			196		
197	56·28		197					197				197		
198		198							198				198	
199	53·72	199								*199		199		
200	55·23	200						200					200	
201			201						201			201		
202			202					202				202		

* The hornblende in these rocks is in part secondary, pyroxene may have been present originally.

TABLE VI.—*Mineralogical variation among the diorites of Group II (b).*

Specimen number.	Percentage of silica.	Amount of quartz.				Relative amount of pyroxene and hornblende.					Relative amount of pyroxene, hornblende, and biotite.			
		Little.	Moderate.	Considerable.	Much.	*p*.	*p*>*h*.	*p*=*h*.	*p*<*h*.	*h*.	(*ph*).	(*ph*)>*b*.	(*ph*)=*b*.	(*ph*)<*b*.
203				203						203		203		
204				204						204		204		
205	65·60			205					205			205		
206			206							206			206	
207	65·94			207						207		207		
208				208						208			208	
209	63·78			209						209		209		
210				210						210		210		
211	64·07		211					*211					211	
212				212			†212						212	
213	65·11			213					213				213	
214			214						214			214		
215	64·85			215						215		215		

* This rock belongs with 192, resembles it in structure and character, but is higher in silica and feldspar.
† An exceptional variety, from talus.

TABLE VII.—*Mineralogical variation among the diorites of Group II (c).*

Specimen number.	Percentage of silica.	Amount of quartz.				Relative amount of pyroxene and hornblende.					Relative amount of pyroxene, hornblende, and biotite.			
		Little.	Moderate.	Considerable.	Much.	p.	$p>h$.	$p=h$.	$p<h$.	h.	(ph).	$(ph)>b$.	$(ph)=b$.	$(ph)<b$.
216					216	*216							216	
217					217	217								217
218					218	218								218
219	65·48				219				219			219		
220	65·80				220				220					220
221					221	221								221
222					222					222				222
223	67·54				223					223				223
224					224				224					224
225					225					225				225
226					226					226				226
227	66·05				227					227			227	

* The first six rocks in this group are closely related to the main mass of the diorite of Group II (*a*).

Table V presents those varieties of the stock rocks in which the amount of the ferromagnesian silicates about equals that of the feldspar and quartz combined. There is no distinction made as to whether the crystals occur as phenocrysts or not. They are arranged in a series according to their degree of crystallization, the finest grained being at the top, the value of the degrees of crystallization having been already explained (p. 599). The silica percentage is given in all cases where it has been determined. In the table an attempt is made to express the relative amounts of the quartz, of the hornblende and pyroxene, and of the biotite and hornblende and pyroxene. The relative amount of feldspar is not expressed. In a general way it varies inversely as the amount of quartz for this subgroup. The columns under the different divisions of the table express certain relations of the minerals approximately. Under the divisions of quartz, the terms "little," "moderate," "considerable," "much," are only used as comparative terms applicable to this group of rocks throughout its three subdivisions, II (*a*), II (*b*), II (*c*), and have no reference to the relative amount of quartz which might be found in another suite of rocks. Consequently what would be considered "much" quartz in these rocks might only be a moderate amount for another series.

Under the division which shows the relative amounts of pyroxene and hornblende in each rock, the first column, "p," indicates that there is pyroxene and no hornblende; the next column, that the pyroxene is in excess of the hornblende; the third, that they are equal, and so on. The relative amounts of pyroxene or of hornblende in any two varieties of the rock is not indicated directly. It can be ascertained roughly by considering that in this subgroup the sum of the pyroxene, hornblende, and biotite is nearly constant.

In the next division of the table the amount of the biotite is compared with that of the pyroxene and hornblende combined, in the manner already explained for the previous division.

The first fact brought out by a study of this table is the variability of the quartz percentage, which does not appear to hold a very definite relation to the silica percentage, as in the case of Nos. 185 and 186. But it is observed in studying the thin sections that the quartz is not so noticeable in the fine grained varieties as in the coarse grained ones, and may therefore be either overlooked or possibly not so strongly developed. Thus the coarse grained varieties with little quartz are lower in silica than the fine grained varieties with little quartz. (Compare Nos. 199 and 200 with Nos. 176, 177, and 178.) It is, of course, evident that in rocks with variable percentages of the essential minerals which are all silicates there can be no rigid relation between the proportion of any one of these minerals and the silica percentage of the rock within the narrow range of chemical variation that occurs in this group. In it the silica does not vary 7 per cent, and the amount of the other chemical constituents are the controlling chemical factors. This will be discussed more fully when the chemical composition of the rocks is considered.

The most regular variation is in the relative proportions of pyroxene and hornblende. There is a definite increase in the amount of hornblende and decrease in that of pyroxene as the rock becomes coarser grained. This is specially noticeable in those specimens forming series from one spot, Nos. 172, 173, 174, 175, 183, and 191, and Nos. 181, 182, 185, 188, and 193. The variation in the relative amount of biotite is not so marked, but there is a slight increase from the fine grained to the coarse grained end of the series.

The irregularities in the variations of the different minerals could be better understood if the chemical composition of all of the different varieties of the rocks were known, but such an investigation is not practicable. The rocks of this subgroup may be classed among the pyroxene-diorites and quartz-pyroxene-diorites. They carry considerable biotite, and pass into quartz-mica-diorite at one end of the series and into pyroxene-porphyrite at the other.

Tables VI and VII include those varieties of rock in which the amount of feldspar and quartz together exceeds that of the ferromagnesian silicates, and Table VII includes those varieties particularly rich in quartz.

The silica percentage is considerably higher in these rocks than in those of the previous subgroup. The quartz is more uniform, and on the whole is higher. It is very considerably higher in Subgroup II (*c*). Pyroxene is absent from most of the varieties, but occurs in small amounts without hornblende in a few instances already noticed. Biotite is more variable in Subgroup II (*b*) than in II (*c*), where it is the predominant ferromagnesian silicate.

The relation of quartz, biotite, hornblende, and pyroxene to the chemical composition of the different varieties of this series of rocks is not so definite as in the case of the group of dike rocks. In general, quartz and biotite are more abundant in the more acidic varieties of the coarse grained rocks, but they both appear in the basic varieties when they are coarsely crystalline. The relations of horneblende and pyroxene to the chemical composition of rocks is not elucidated in any way by the study of this group of rocks. It is evident, however, that in the case of the intrusive rocks of this region hornblende is developed to a greater extent in the basic rocks as they are coarser grained, and that pyroxene is more abundant in the finer grained forms than in the coarser.

The mineral composition of the quartz-mica-diorite-porphyrite, Group III, is very uniform, and needs no tabulation. It contains very much quartz, abundant biotite, and almost no hornblende; the greater part of the rock is more siliceous than the main body of the diorite, and reaches 69·24 per cent of silica, but a facies of it, which is richer in hornblende than the body of the rock, has only 65·97 per cent of silica.

TABLE VIII.—*Grades of crystallization of the dike and stock rocks of Electric Peak.*

Grade.	I.	II (*a*).	II (*b*).	II (*c*).	III.
	d_{1-10}.	s_1.	s_2.	s_3.	s_4 and d_{11}.
6	....	....	....	....	163
7	144	....	....	....	164, 165
8	142	....	....	....	166, 167
9	{ 143 { 145, 146	....	....	....	168, 169
10	147, 150	....	....	....	....
11	{ 148, 149 { 159, 160	....	....	....	....
12	{ 143, 153 { 154, 161	....	....	....	....
13	155	170	....	....	....
14	{ 151, 152 { 156, 157	171	....	....	....
15	....	172	....	....	....
16	139, 158	173	....	....	....
17	....	174	203	....	....
18	....	....	204, 205	....	....
19	{ 136 { 140, 141	....	206	216, 217	....
20	137	....	207, 208	....	228, 229
21	....	....	209	....	230, 231
22	....	175	....	....	232, 233
23	....	176	....	....	234, 235
24	....	177, 178	....	218	236
25	138	....	....	219	237
26	....	179, 180	....	....	....
27	....	181	210	....	....
28	....	182	....	....	....
29	....	183	....	....	....
30	....	184, 185	....	....	....
31	....	186, 187	....	....	....
32	....	188	....	....	....
33	....	{ 189 { 190, 191	....	....	....
34	....	192	211	....	....
35	....	193	212	220	238
36	....	....	213	221	....
37	....	194	....	{ 222 { 223, 224	....
38	....	195	214	....	....
39	....	196	215	....	....
40	....	197	....	{ 225 { 226, 227	....
41	....	198	....	....	....
42	....	199	....	....	....
43	....	200	....	....	....
44	....	201	....	....	....
45	....	202	....	....	....

Table VIII expresses the relative degree of crystallization of all the intrusive rocks collected from the stock and dikes of Electric Peak. They are arranged in the groups already described. The breaks in the different columns do not signify breaks in the gradation of crystallization in the rock bodies in the field, but simply that the specimens collected are not from all the different structural phases of the different rocks. However, the clustering of the numbers in particular parts of the scale indicates the prevailing grain of the rocks as they are exposed at the present time.

It is not possible to draw a line of demarcation anywhere in the scale based on the degree of crystallization between rocks that occur in narrow dikes and those that form parts of much larger bodies. A relation between the degree of crystallization and the size of the rock body does not at first appear when all of these occurrences are considered together. The very important influence of several other factors, however, becomes apparent. One is the chemical character of the magma, the more basic magmas tending to crystallize coarser than more siliceous ones under similar physical conditions. Another factor is the previous temperature of the rocks into which the molten magmas were injected, and the consequent differences in the rate of cooling which the molten magmas experience. There may also be other factors which influence the crystallization in certain cases, but they are not evident in the occurrences at Electric Peak. In this locality the chief factor influencing the crystallization appears to have been the temperature of the inclosing rocks at the time of the different intrusions. The next most influential factor appears to have been the chemical character of the magma itself, and the third the size of the intruded mass. In another region the relative importance of these factors may be different.

Chemical composition.—The chemical composition of the intrusive rocks at Electric Peak is shown by the analyses in Table IX. Nos. 197, 171, 177, 215, 213, 205, 233, 227, 223, and 230 were made by Mr. J. E. Whitfield; Nos. 176 and 211 were made by Mr. W. H. Melville. All are from rocks occurring in the stock and its immediate apophyses. They represent the composition of various forms of the diorite and diorite-porphyrite. The first four analyses, Nos. 197, 171, 177, and 176, are from the main body of the stock, and belong to Subgroup II (*a*). The next four analyses, Nos. 211, 215, 213, and 205, are from facies of the main body of the diorite and from one of the lighter colored veins or dikes which traverse it. They belong to Subgroup II (*b*). Two more facies of the main stock are represented by analyses Nos. 227 and 223. They are quite siliceous, and belong to Subgroup II (*c*). Analyses Nos. 233 and 230 are from the large body of quartz-mica-diorite-porphyrite, the first being a basic facies of it, and the second corresponding more nearly to the general character of the body of the rock.

TABLE IX.—*Chemical analyses of intrusive rocks from Electric Peak.*

Specimen No.	197	171	177	176	211	215	213	205	233	227	223	230
SiO_2	56.28	57.38	58.05	61.22	64.07	64.85	65.11	65.60	65.97	66.05	67.54	69.24
TiO_2	.84	trace	1.05	.61	.45	.91	.71	.75	.42	.34	.80	.65
Al_2O_3	14.23	16.86	18.00	16.14	15.82	16.57	16.21	17.61	16.53	16.96	17.02	15.30
Fe_2O_3	4.69	2.49	2.49	3.01	3.40	2.10	1.06	.95	2.59	2.59	2.97	1.72
FeO	4.05	5.17	4.56	2.58	1.44	2.15	3.19	2.76	1.72	1.38	.34	.69
NiO	......	......	......	.09	.05	......	......	......	......	......	......	......
MnO	.16	trace	none	trace	trace	none	none	none	none	none	trace	trace
CaO	7.94	7.32	6.17	5.46	4.43	4.01	3.97	3.72	3.37	3.37	2.94	2.98
MgO	6.37	5.51	3.55	4.21	3.39	2.14	2.57	1.49	2.11	2.08	1.51	.95
Li_2O	.01	.39	none	......	......	none	.04	.03	.09	none	.03	none
Na_2O	2.98	3.33	3.64	4.48	4.06	3.71	4.00	4.36	3.41	4.20	4.62	4.46
K_2O	1.23	1.45	2.18	1.87	2.27	3.10	2.51	2,36	2.67	2.53	2.28	2.52
P_2O_5	.40	trace	.17	.25	.18	.14	.02	.16	trace	trace	trace	trace
SO_3	trace	.21	.07	......	......	trace	trace	trace	.13	.03	.26	.27
Cl	.17	.17	trace	......	......	none	none	none	.09	trace	.15	trace
H_2O	.93	.42	.86	.44	.52	.35	.94	.59	1.23	.69	.55	1.30
	100.28	100.70	100.79	100.36	100.08	100.03	100.33	100.38	100.33	100.22	101.01	100.08
Less O for Cl	.04	.04	......	......	......	......	......	......	.02	......	.03	......
	100.24	100.66							100.31		100.98	

TABLE X.—*Silica percentages of the rocks from Electric Peak.*

Sheet rocks.	Dike and stock rocks.					SiO_2.
	I.	II(*a*).	II(*b*).	II(*c*).	III.	
......	......	53.72	......	......	......	53.72
......	......	55.23	......	......	......	55.23
......	......	55.64	......	......	......	55.64
......	......	56.28	......	......	......	56.28
......	......	56.33	......	......	......	56.33
......	57.12	......	......	......	......	57.12
......	......	57.38	......	......	......	57.38
......	......	58.05	......	......	......	58.05
......	......	58.10	......	......	......	58.10
......	......	58.11	......	......	......	58.11
58.49	......	......	......	......	......	58.49
......	......	58.87	......	......	......	58.87
59.64	......	......	......	......	......	59.64
......	60.54	......	......	......	......	60.54
......	......	60.56	......	......	......	60.56
......	60.89	......	......	......	......	60.89
61.50	......	......	......	......	......	61.50
......	61.85	......	......	......	......	61.85
......	......	......	63.01	......	......	63.01
......	......	......	63.78	......	......	63.78
......	......	......	64.85	......	......	64.85
......	......	......	65.11	......	......	65.11
......	......	......	......	65.48	......	65.48
......	......	......	65.60	......	......	65.60
......	......	......	......	65.80	......	65.80
......	......	......	65.94	......	......	65.94
......	......	......	......	......	65.97	65.97
......	......	......	......	66.05	......	66.05
......	......	......	......	67.54	......	67.54
......	......	......	......	......	69.24	69.24

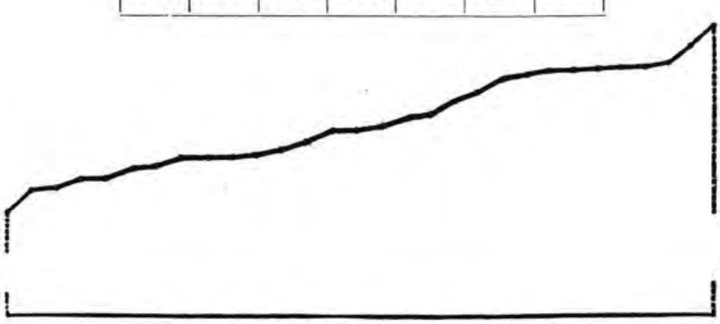


FIG. 79.—Variation of silica percentages.

The silica percentages of a number of varieties of these rocks were determined and are given in Table X, together with those from the complete analyses. In a measure they supplement these analyses and demonstrate what is evident from the microscopical study of the thin sections, namely: That the diorites and porphyrites pass through all possible gradations from one extreme to the other. The character of this transition is shown by the diagram, Fig. 79, in which each determination is given the same weight, the series is arranged according to the increase of silica, and the silica percentages are plotted as ordinates.

In Table X the percentages are all placed in the extreme right-hand column, and also in separate columns corresponding to the groups described in the first part of the paper. From this it is seen that the main body of the diorite varies from 53·72 to 60·56 per cent of silica, and in certain contact facies reaches 67·54 per cent. The dikes of later rocks related to the diorite and cutting the main body of the stock range from 63·78 to 69·24 per cent.

In the various bodies of magma that have followed one another through the conduit at Electric Peak, there is a variation in chemical composition in each, the different series of changes overlapping one another. Thus the average chemical composition of each subgroup of varieties shifts somewhat, and is more basic for one than another. But the end varieties of each subgroup overlap, so that the most basic modification of the more acidic group is more basic than the most acidic end of the more basic group which immediately preceded it.

Since the rocks of Group I belong to outlying dikes of the main stock and are contemporaneous with it, their silica percentages may be placed in the proper subgroup of the stock rocks, making subgroups II (*a*) and II (*b*) practically continuous. It appears from Table X that the succession of magmas which came up through the vertical fissures was from a basic one to more and more acidic ones, and that the previous intrusions which formed the sheet rocks were of a magma of medium chemical composition.

The variations of the other chemical constituents of these rocks are best comprehended by comparing their molecular proportions. This has been done graphically in the accompanying diagram, Fig. 80, in which the molecular proportions of the principal oxides are plotted as ordinates, those of the silica being taken as abscissas. The origin of abscissas is located some distance to the left.

The first impression derived from the diagram is that of the irregularity of the variations in all the oxides besides silica, especially in the magnesia. Moreover, these variations appear to be independent of one another. But this apparent independence disappears on closer study. The most striking evidence of connection between the molecular proportions exists in the case of the two oxides of iron; the ferrous and ferric oxides are noticeably inversely proportional to each other, an increase of ferrous oxide being accompanied by a decrease of ferric oxide. The total amount of iron varies irregularly, decreasing from the basic to the acidic end of the series. While each of the iron oxides is quite independent of the magnesia, it is found upon reducing all the iron to the ferrous state that there is the greatest accord between the iron and magnesia, both varying in like directions and to nearly the same extent. The magnesia drops rapidly at first, and is very erratic in the more siliceous end of the series, where it becomes very low.

The most regular variation is in the lime, which decreases steadily from the basic to the acidic end of the series. It exhibits little or no connection with the other constituents. The molecular proportion of

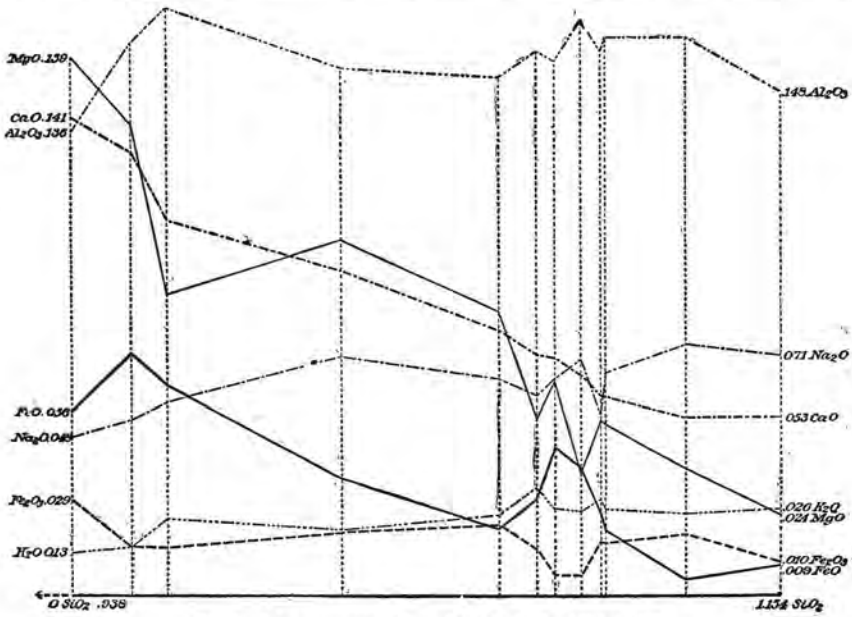


FIG. 80.—Molecular variation of the rocks at Electric Peak.

the alumina, though quite irregular between certain limits, maintains a uniformly high position, and is much greater than any one of the other constituents except silica. At the extreme basic end of the scale, however, it is equaled by both the magnesia and lime. The alkalies are most like the alumina in their variations, and remain very nearly uniform, increasing somewhat toward the acidic end of the series. The soda molecules are more than twice as numerous as those of potash, which is one of the most noticeable characteristics of the rocks of this region. In the basic end of the series the alkalies vary together in the same direction, while in the more siliceous end they vary in opposite directions. There is a marked accordance between the soda and alumina, both varying in the same direction, with one exception, though not to the same extent. There is a more strongly marked discordance between the alumina and magnesia, which, with one exception, vary in opposite directions.

These irregular variations take place not only among allied varieties of rocks, but even in different parts of one and the same rock body. They correspond to variations in the proportions of the essential minerals. Since the essential minerals of this group of rocks are, the feldspars, pyroxenes, amphiboles, mica, quartz, and magnetite, one or more of which may be absent from a particular form of the rock; and since there is a number of complex molecules into which any one of these oxide molecules enters, it is evident that the variations among the oxide molecules must be mutually dependent. Thus, while most of the alumina enters into the feldspars, a portion of it enters into the ferromagnesian silicates. The alkalies are mostly found in the feldspars, but a little of the soda takes part in the augites and hornblendes, and considerable of the potash in the biotites. The lime is an important factor in both these groups of minerals; it is most abundant in the plagioclases and diminishes as the feldspars become more alkaline; it abounds in augite and to a less extent in hornblende, and is almost absent from hypersthene and biotite. The iron and magnesian molecules, however, have no part in the composition of the feldspars, and are confined to the ferromagnesian minerals. Besides the more complex minerals there are the simple oxides, magnetite and quartz. They act as compensators to regulate the exhaustion of the oxide molecules in the magma.

These considerations render more comprehensible the variations expressed in the diagram, Fig. 80. The inverse relation between the alumina and magnesia corresponds to variations in the molecules of feldspars and of the ferromagnesian silicates; an increase of the former being accompanied by a decrease of the latter.

The independently uniform variation in the lime molecules is consistent with the fact that they enter so largely into both the feldspars and ferromagnesian silicates. Their steady diminution from the basic to the acidic end of the series is in accord with the decrease in the amount of augite and hornblende, and the increase in the alkali feldspars, which is indicated by the increase of soda and potash molecules.

The reciprocal relation between the ferrous and ferric oxides indicates the variable oxidation of preexisting molecules, which were probably ferrous oxide; and, since the hornblende and biotite are the silicate minerals carrying the greatest percentage of ferric iron, the variation in the oxidation of the iron is naturally in accord very largely with the amount of these minerals in the rock. This is most significant from its bearing on the question of the development of hornblende and biotite in the coarser grained forms of these rocks, and from its possible connection with the work of mineralizing agents.

If we were acquainted with the exact chemical composition of each of the essential minerals in these rocks, we could obtain a more precise notion of the interdependence of the component molecules of the magma, since we know the order in which these minerals began to crystallize in the granular rocks. But the essential minerals in the diorites are so intimately intergrown that it would be an extremely difficult, if not an impossible, matter to separate them mechanically for chemical analysis. It is possible, however, to arrive at some general conclusions by considering the approximate composition of the minerals, which may be derived from the analyses of similar occurrences.

Since the essential minerals of the diorites are magnetite, hypersthene, augite, hornblende, biotite, labradorite, oligoclase, orthoclase, and quartz, they may be placed in two series; one, including those bearing iron and magnesia; the other, being free from both. The terms labradorite and oligoclase include all the varieties of the lime-soda feldspars within the limits of these species in the Tschermak sense.

When arranged in the order in which they began to crystallize, the first series becomes magnetite, hypersthene, augite, hornblende, and biotite; the second series is labradorite, oligoclase, orthoclase and quartz. Assuming the chemical composition of these minerals to be within the limits of similar varieties in other localities, which is of course only a rough approximation, and comparing their molecular proportions, we obtain the data presented in Table XI, very small quantities of different oxides having been omitted.

TABLE XI.—*Molecular proportions in the essential minerals of the diorite.*

	Molecular proportions.							
	SiO_2	Fe_2O_3	FeO	MgO	CaO	Al_2O_3	Na_2O	K_2O
Magnetite		43	43					
Hypersthene	86–83		29	52				
Augite	83–78	(*)	7–14	30–37	32–39	3–6		
Hornblende	78–66	3–6	9–15	32–37	16–21	10–13		(*)
Biotite	66–58	3–12	(*)	22–60		10–18	(*)	7–10
Labradorite	88				21	31	7	
Oligoclase	103				9	23	13	(*)
Orthoclase	106					17	(†)	18
Quartz	166							
Magnetite		43	43					
Hypersthene	86–83		29	52				
Augite	83–78	(*)	7–14	30–37	32–39	3–6		
Labradorite	88				21	31	7	
Hornblende	78–66	3–6	9–15	32–37	16–21	10–13		(*)
Biotite	66–58	3–12	(*)	22–60		10–18	(*)	7–10
Oligoclase	103				9	23	13	
Orthoclase	106					17	(†)	18
Quartz	166							

* Occasionally in small amounts. † Variable, often in considerable amounts

It will be seen from this table that the order of crystallization of the ferromagnesian silicates is according to a decreasing percentage of silica; while for the feldspars and quartz it is according to an increasing percentage of silica. That is, in the first series the most siliceous mineral crystallizes first, while in the second series the most basic crystallizes first. In the third part of the table, where the order of crystallization is given for all the essential minerals, it is seen that the silica percentage of the minerals falls and rises twice, the last minerals to crystallize being much more siliceous than the first.

The first essential mineral is iron oxide with no silica, and the last is silica combined with no other elements.

In the ferromagnesian silicates the ferrous iron decreases in quantity and the ferric iron increases, while the total amount of iron at first decreases and then increases. The magnesia decreases a little, and sometimes increases in biotite. The lime, which belongs to only two of these minerals, decreases. The alumina increases steadily. The alkalies appear in the last of the series, and only in small amount. except the potash in the biotite, which is considerable.

In the second series of minerals the variations are more regular. The alumina and lime decrease uniformly, and the alkalies increase; soda appearing before the potash.

It is to be remembered that the crystallization of these minerals in the diorite is largely synchronous for all of them; and that they simply started to crystallize in the order given. The crystallization of those near together in the series took place at one and the same time; and only the minerals at the extremes of the series may have formed at distinctly different times. The earliest minerals probably ceased to grow before the orthoclase and quartz commenced to crystallize.

In the case of the diorite at Electric Peak, then, the crystallization of the magma commenced with the separation of iron oxide alone, followed by a silicate of ferrous oxide and magnesia, with little or no lime and alumina. Then followed more complex compounds of iron oxides, magnesia, lime, alumina and alkalies. The more simple feldspar compounds began to crystallize early in the series and continued to the end, after the ferromagnesian molecules had separated from the magma, the crystallization being closed by silica alone, the least complex compound.

SEPULCHRE MOUNTAIN.

GEOLOGICAL DESCRIPTION.

East of Electric Peak, across the deeply cut valley of Reese Creek, lies Sepulchre Mountain, so called from a mass of breccia on one of its high northwest spurs, which resembles a sarcophagus. The mountain rises to a height of 9,600 feet, and stands isolated from the surrounding peaks, from which it is separated by geological faults and also by deep drainage channels. It is composed of volcanic breccias and massive lavas that form a body of rock 3,000 feet thick, resting on Cretaceous and older strata.

The southern and southwestern slopes of the mountain are rounded from the action of the ice which has passed over the mountain from the Gallatin range. They are mostly covered with grass and sage brush, and present comparatively few rock exposures. This is also the character of the hills and ridges southwest of the mountain, which lie east of the fault at the base of Electric Peak, and form part of the geological body of Sepulchre Mountain.

The north and east faces of the mountain are precipitous and rocky, and afford excellent sections of the volcanic mass. The long northwestern spur is also rugged, and exposes the geological structure of this part of the mountain. This difference of surface character is shown by the illustration, Pl. LII, from a photograph of the north and west sides of the mountain.

The breccias exhibit little or no evidence of bedding, and are associated with flows of lava, the whole having a distinctly volcanic character. The western portion of the breccia is traversed by numerous dikes of andesite and dacite, which trend for the most part in a north and northeast direction from the vicinity of Cache Lake. A few trend east. The distribution and location of these later intrusions are shown on the map, Pl. LIII, in a general way. It is probable that there are a number of dikes cutting one another in the southwestern portion, rather than a few broad bodies, as represented on the map; the data were not sufficient to locate the different bodies, and the map has been drawn so as to represent what seems to have been the order and position of the eruptions.

In the northwestern spur of Sepulchre Mountain the dikes are well marked, and stand out prominently from the surrounding breccia. They are from 5 to 25 feet wide, and are not perfectly straight, but maintain a generally uniform direction and can be traced by the eye for some distance. Long after the eruption of these dike rocks, when the region had been faulted and erosion had removed a great part of the rocks, and had cut the valley of Glen Creek, a flow of rhyolite flooded the country and filled this valley, covering the south and west base of Sepulchre Mountain to an altitude of about 8,100 feet. The rhyolite has been almost entirely removed, but remnants of the sheet are found in numerous places. This closed the series of volcanic events, as they are recorded in this vicinity, though in other parts of the region the rhyolite was followed by eruptions of basalt.

THE VOLCANIC ROCKS AT SEPULCHRE MOUNTAIN.

The volcanic rocks composing Sepulchre Mountain consist of andesitic breccias and tuffs with lava-flows of the same andesites, besides dikes of andesite and dacite. By far the greater part of the material is tuff breccia, which is easily separable into an older and a newer, or a lower and an upper breccia.

THE LOWER BRECCIA.

The *lower breccia*, which is about 500 feet thick, is light colored and is characterized by phenocrysts of biotite and hornblende. It carries a great amount of fragments of Archean schists which are not found in the overlying dark colored breccias. The lower breccia passes into tuff in places, containing fragments of carbonized wood; and at the extreme end of the northwest spur it is distinctly bedded with bowlders of foreign rocks scattered through layers of fine grained material. In places the upper portion of this bottom breccia is green and partly altered, as though it had been weathered before the upper breccia was deposited on it. In the northwestern spur of the mountain the upper breccia is distinctly seen to rest on an uneven surface of the lighter colored bottom breccia.

It is probable that the bottom breccia was thrown from some neighboring Archean area, and is considerably older than the overlying, basic breccia. This relation between a bottom breccia of hornblende-mica-andesite carrying Archean fragments, and overlying, basic breccias is found to exist in other places in this region.

An examination of the various specimens of this older breccia shows that it varies in mineral composition as well as in color and microscopical habit. It is mostly light colored, gray, white, and red. In places it is dark colored. Some varieties carry abundant large phenocrysts, others contain a multitude of small ones. Though the great bulk of it is characterized by porphyritical biotite, hornblende and plagioclase, some portions are poor in biotite, and are hornblende-andesite, while other parts approach dacite in composition, having biotite and quartz phenocrysts with those of plagioclase. The groundmass of the differnet fragments making up this breccia varies from glassy and microlitic to microcrystalline.

Associated with the bottom breccia at the northeast base of Sepulchre Mountain is a vesicular basalt with porphyritical augites and decomposed olivines. It is of small extent, is amygdaloidal, with quartz, agate, and calcite. Its exact relation to the breccia was not discovered

SEPULCHRE MOUNTAIN, FROM ITS NORTHWEST SPUR.

but it appears to be an older basalt, more intimately connected with the bottom breccia than with the upper breccia. It does not resemble the younger basalts on the north side of the Yellowstone River opposite Sepulchre Mountain.

THE UPPER BRECCIA.

The *upper breccia*, which lies upon the one just described, is dark colored at its base, where it consists almost wholly of pyroxene-andesite with little or no hornblende. Many of the fragments are finely vesicular and basaltic in appearance, without macroscopic phenocrysts. At the south base of the mountain this breccia is accompanied by vesicular flows of pyroxene-andesite, with large porphyritical pyroxenes and feldspars. Intimately connected with this breccia is that of hornblende-pyroxene-andesite, which forms the uppermost portion of the mountain. They appear to grade into one another by an increase in the amount of hornblende. This later breccia is also accompanied by vesicular flows of the same kind of andesite. It is mostly lighter colored, though some of it is quite dark, with prominent hornblendes, and has an andesitic habit and not a basaltic one. There is no evidence of a geological break between the lower and upper portion of the upper breccia, which may be considered as a continuous geological body, made up of fragments and flows of andesite, which have been ejected from a common source during a prolonged series of eruptions.

The andesitic material composing it varies in mineral composition and outward appearance between certain limits. This variation will be described in detail.

TABLE XII.—*Mineral variation in the uppper breccias of Sepulchre Mountain.*

Mineral groups.	Specimen number.	Phenocrysts other than feldspar.			
		Pyroxene.	Hornblende.	Biotite.	Quartz.
B_1	1	much	......	......	......
	2	much	......	......	......
	3	much	......	......	......
	4	much	......	......	......
	5	much	......	......	......
	6	much	......	......	......
	7	much	......	......	......
	8	much	......	......	......
B_2	9	much	little	......	......
	10	much	little	......	......
	11	much	little	......	......
	12	much	little	little	......
	13	much	little	......	......
B_3	14	much	some	......	......
	15	much	some	......	......
	16	much	some	......	......
	17	much	some	......	......
B_4	18	much	much	......	......
	19	much	much	......	......
	20	much	much	......	......
	21	much	much	......	......
	22	much	much	......	......
	23	much	much	......	......
	24	much	much	......	......
	25	much	much	......	......
	26	much	much	......	......
	27	much	much	......	......
B_5	28	some	much	......	......
	29	some	much	......	......
	30	some	much	......	......
	31	some	much	......	......
	32	some	much	little	......

Thirty-two thin sections have been made from the upper breccia, which upon investigation resolve themselves into a series of glassy andesites, some of which carry hypersthene, augite, and plagioclase phenocrysts, and others hypersthene, augite, hornblende, and plagioclase. They may be arranged, as in Table XII, according to the relative abundance of these minerals.

The first two specimens are very basaltic in appearance, with small phenocrysts. They carry a few decomposed crystals, which were probably olivine, but have the microstructure of the associated andesites.

The varieties without hornblende, B_1—that is, the pyroxene-andesites—have a groundmass of globulitic brown glass filled with microlites of feldspar, pyroxene, and magnetite grains. The shade of brown varies from very dark to light, and the size and abundance of the microlites also varies. The feldspar microlites are plagioclase with rather low extinction angles.

The *pyroxene* always includes hypersthene and augite. They have very much the same general appearance and habit, both occurring in some instances in large crystals, and in others in small ones. In the same rock section they differ as to the character of their crystal outline. Some individuals are bounded by crystal planes, especially in the prism zone, while others are rounded, particularly at the ends of the crystals. Some have rough surfaces, with multitudes of irregularly shaped tongues of glass penetrating the surface of the crystal. This does not appear to be the result of a corrosion of the crystal, but of a rapid crystallization of the mineral at the end of its growth, when the surrounding glassy magma was becoming filled with microlites, and was crystallizing from more numerous centers, for there are instances where larger depressions in the surface of the pyroxene crystals can be seen to have been occasioned by the presence of small crystals of feldspar, which must have hindered the growth of the pyroxene. They have numerous inclusions of glass, with gas bubbles, which are irregularly scattered through the minerals in most cases, but are occasionally arranged zonally; besides which are grains of magnetite and a few small crystals of apatite.

The hypersthene is pleochroic, and is green parallel to $\mathfrak{c}$, yellow parallel to $\mathfrak{a}$, and light red parallel to $\mathfrak{b}$. In most of the thin sections it is light colored, but in one instance there is a large individual with very strong colors and pleochroism, which carries brown inclusions in the shape of thin plates arranged in lines at right angles to the vertical axis of the crystal. These inclusions resemble those characteristic of many hypersthenes in coarse grained rocks. In this instance the hypersthene crystal occurs in a glassy, vesicular rock, and the inclusions do not appear to have resulted from an alteration of the mineral subsequent to the solidification of the rock, but to have been primary inclusions of some foreign substance. The lighter colored hypersthenes do not carry such inclusions. The color frequently varies in concentric zones, the center being light in some cases and dark in others.

In some forms of the rock the hypersthene and augite have narrow reddish brown borders which are in part opaque. This border, though not so strongly marked as the black margin to many hornblendes, appears to be of similar origin and to be due to an action of the magma on the crystals before the final consolidation of the rock. It affects the pyroxene microlites in the groundmass as well as the phenocrysts.

The color of the augite is light green without pleochroism in thin sections; and is easily confounded with the sections of hypersthene which exhibit little pleochroism. Its optical characteristics are the same as those of the augite in the diorites already described; in fact, the pyroxenes of both rocks are alike optically, and have the same distinctions with respect to cleavage, which is more perfect in the augites than in the hypersthenes.

Instances of the complete inclosure of one of the pyroxenes by the other, or of their intergrowth, are rare. In the few cases observed small hypersthenes are surrounded by augite, indicating the earlier crystallization of the hypersthene. But the occasional intergrowths of the two, and the partial inclosures of adjacent individuals in groups, proves that the crystallization of most of the hypersthene and augite phenocrysts was contemporaneous. When decomposition has attacked the rock hypersthene yields before the augite, and is converted into a green fibrous mineral, probably bastite.

The *feldspar* phenocrysts are all plagioclase, which from their optical characters appear to be labradorite. They are small in most forms of the rock, but larger and more abundant in others. They are rectangular in long and short sections, a few are broad and polygonally outlined. The sections are mostly straight edged, some are rounded at the corners, and others are rough like the pyroxene crystals. The rough projections of the feldspars have crystal faces and appear to be due to an irregular checking of their crystallization. They exhibit the characteristic polysynthetic twinning of labradorite and are beautifully zonal. But the zones do not differ much in optical orientation, the extinction being quite uniform throughout each individual.

Glass inclusions are frequent in the feldspars; in some of the larger crystals the central portion is crowded with inclusions of the brown glass containing the same microlites as the surrounding groundmass. These inclusions are usually in rectangular negative crystal cavities. Many of the smaller feldspars are almost free from them. There are occasionally grains of magnetite and pyroxene.

In most cases the feldspar and pyroxene phenocrysts are separated by the groundmass of the rock. But when they occur in juxtaposition it is evident that the feldspar is a younger crystallization which started after the pyroxene had commenced to crystallize, but before it had finished, for the feldspar interferes with the perfect development of the pyroxene.

Magnetite occurs in phenocrysts associated with the pyroxene and also isolated in the groundmass. It is in definite crystals and in irregular grains.

There are five representatives of the pyroxene-andesites which carry a few crystals of hornblende, B_2, and constitute transitional varieties between these rocks and the hornblende-pyroxene-andesites. They exhibit the same characters as the andesites just described.

The *hornblende* is in small irregular crystals, some being rounded and others in angular shapes. It is reddish brown and brownish green, with strong pleochroism. Many of the individuals, especially the rounded ones, have a narrow border of magnetite or one of small crystals of pyroxene, feldspar, and magnetite. There are all gradations, from rounded hornblendes with opaque borders to small angular pieces of hornblende surrounded by comparatively large crystals of pyroxene, feldspar, and some magnetite, which form a group of interlocked crystals in the glassy groundmass. The angular outline of the hornblende and its penetration between the crystals of feldspar and pyroxene would militate against the supposition that the hornblende is a remnant of a previous crystal that had been partially resorbed in the groundmass, were it not for the occurrence in one thin section of a group of different crystals with a hexagonal outline, corresponding to the cross section of the hornblende remnants contained in it which are properly oriented for such a section. The greater part of the group consists of feldspar and pyroxene with some magnetite. It is not to be supposed that these minerals crystallized out of the melted hornblende substance without interchange of material from the surrounding magma. The larger groups in the same rock section exhibit no definite outward form, but are bounded by the outlines of the outer crystals, so that we may conclude that the process of resorption of the hornblende phenocrysts was in some cases accompanied by the immediate formation of grains of magnetite and the absorption of the other chemical constituents by the magma; while in other cases the melted hornblende recrystallized in situ as pyroxene and magnetite. But in the instances just mentioned the partial resorption of the hornblende was followed by a greater tendency toward crystallization in the magma immediately surrounding the melted hornblende, which led to the development of a group of all the minerals then capable of forming. These minerals are the same in size and character as the small crystals scattered through the glassy groundmass.

In rock section No. 12 several small individuals of biotite occur with the same kinds of borders as those surrounding the hornblende. This thin section and one other, No. 32, are the only ones carrying biotite. It is in very small amounts in each case.

The remaining thin sections may be classed as hornblende-pyroxene-andesites, in which the proportions of hornblende and pyroxene vary. In the first four, B_3, the pyroxene is in excess of the hornblende. In the following ten, B_4, they are about equal and in the last five, B_5, the hornblende is in excess. The varieties thus form a series from those without hornblende to others with much hornblende and very little pyroxene.

In these andesites the microscopical character of the pyroxenes is the same as in those first described, except that they are in better shaped crystals, seldom rounded or with dark borders. The hypersthene is mostly light colored in thin section, but in several rock sections some of the individuals are strongly colored at the center, while others are more strongly colored at the margin.

The *hornblende* differs throughout these sections in color and in the extent to which it has been resorbed. In some cases it shows no sign of resorption. The form of the crystals when perfect is derived from the unit prism and clinopinacoid and the usual terminations. In many instances the crystal faces are poorly preserved and only the general characteristic form remains, especially in cross sections.

The color is intensely red in some varieties of the rock, in others it is reddish brown, chestnut brown, greenish brown, and also brownish green, with the corresponding pleochroism. This difference of color bears no relation to the presence or absence of opaque border nor to the amount of resorption exhibited by the hornblende. It does not appear to be due to secondary alteration of the hornblendes, since they all occur in perfectly fresh glassy rocks, and the color is generally uniform for all the hornblende in one rock section, when the rock is not a tuff.

The character of the border when present varies for different individuals of hornblende in one rock section. Around some it is a narrow margin of magnetic grains, while in a few instances it is a heavy opaque border. Other hornblendes in the same section are surrounded by crystals of pyroxene, plagioclase, and magnetite. In many sections, however, all the hornblendes have been affected to the same extent and have a narrow opaque border, while in others there are no borders at all.

It does not seem possible to connect the character or degree of the resorption with any definite degree of crystallization of the groundmass of the rocks. And, as just stated, different phases of resorption and of borders occur in one and the same rock section. It is often noticed that the center as well as the margin of the hornblende crystal has become an aggregate of pyroxenes and feldspars, and that very little of the hornblende substance remains. But it is also observed that many of the hornblendes which show no evidence of resorption have large and irregularly shaped inclusions and "bays" of the groundmass in them. So that it is probable that many of the cases of apparent extensive resorption or corrosion may be crystals which originally contained large bays of groundmass. Inclusions of glass are not very abundant, except in certain individuals.

There are numerous instances in which the hornblende incloses small pyroxenes and plagioclases, as well as magnetites, and others in which hornblendes and plagioclases have crystallized beside each other and have mutually interfered, proving that their growth was contemporaneous in part. As there are two or more generations of plagioclase and pyroxene, it is natural that the hornblende appears to be contemporaneous with the earlier feldspars and pyroxenes, and older than the later generations.

The *feldspars* are all plagioclase, but appear to belong to different species. They are in rather small crystals in most of the rock sections. The larger ones are generally labradorite, and many of the small ones are the same, but in a number of the sections the extinction angles indicate andesine or oligoclase. They are mostly rectangular with perfect crystallographic outline, some are tabular and polygonal, and in this position they exhibit the most striking zonal structure, which is almost universally present. The twinning is that characteristic of andesitic plagioclases. Glass inclusions are of frequent occurrence. In some cases the feldspar contains a great amount of glass which almost equals the bulk of the feldspar substance. Occasionally the feldspar has an irregular form and an indented outline, made by the projection of crystal points, the margin of the individual having a different optical orientation from the central portion, and appearing to be formed of more alkaline plagioclase. These are not very common.

The groundmass of these andesites is the same as that of the pyroxene andesites in some cases, and is composed of globulitic brown glass with microlites of pyroxene, feldspar and magnetite. But in most of the sections it consists of colorless glass crowded with small microlites of the same minerals. It carries microscopic crystals of these minerals which are porphyritical with respect to the groundmass when seen with a microscope, but which in turn form part of the groundmass which carries the macroscopic phenocrysts.

THE DIKE ROCKS.

The dike rocks of Sepulchre Mountain, as already mentioned, consist of a series of andesites and dacites, the earliest of which resemble the pyroxene-andesites and hornblende-andesites of the breccias. They vary in mineral composition as indicated by the porphyritical crystals of all sizes that are scattered through the groundmass, and range from rocks with phenocrysts of hypersthene, augite and plagioclase, to those with phenocrysts of quartz, biotite, hornblende and plagioclase. This variation is shown in the accompanying table (Table XIII), in which the 103 thin sections of these dike rocks are arranged according to the porphyritical minerals contained in them.

While the greater number of pyroxene-andesites and hornblende-pyroxene-andesites carry no biotite, there is a small amount of it in some of the latter varieties. In one instance biotite, hornblende, and pyroxene occur together in considerable amounts.

TABLE XIII.—*Mineralogical variations in the dike rocks of Sepulchre Mountain.*

Mineral group.	Specimen number.	Phenocrysts other than feldspar.				Mineral group.	Specimen number.	Phenocrysts other then feldspar.			
		Pyroxene.	Hornblende.	Biotite.	Quartz.			Pyroxene.	Hornblende.	Biotite.	Quartz.
D_1	33	much	....	....	....	D_7	85	....	much	some	....
	34	much	....	....	....		86	....	much	some	....
	35	much	....	....	....		87	....	much	some	....
	36	much	....	....	....		88	....	much	some	....
	37	much	....	....	....		89	....	much	some	....
D_2	38	much	(?)	....	....	D_8	90	....	much	much	....
	39	much	little	....	....		91	little	much	much	....
	40	much	little	....	....		92	....	much	much	....
	41	much	little	....	....		93	....	much	much	....
	42	much	little	....	....		94	little	much	much	....
D_3	43	much	some	....	....		95	....	much	much	....
	44	much	some	....	....		96	....	much	much	....
	45	much	much	....	....		97	....	much	much	....
	47	much	much	....	....		98	....	much	much	....
	48	much	much	....	....		99	....	much	much	....
	51	much	much	trace	....		100	....	much	much	....
	52	much	much	little	....		101	....	much	much	....
	46	some	much	little	....		102	(?)	much	much	....
	49	some	much	little	....		103	(?)	much	much	....
	50	some	much	little	....	D_9	104	....	some	much	....
D_4	54	little	much	....	....		105	....	some	much	....
	55	little	much	....	....	D_{10}	108	much	much	much	little
	56	little	much	....	....		114	little	much	much	little
	57	little	much	....	....		115	little	much	much	little
	58	little	much	....	....		106	....	much	much	little
	60	little	much	....	....		107	....	much	much	little
	63	little	much	....	....		109	....	much	much	little
	65	little	much	....	....		110	....	little	much	little
	66	little	much	(?)	....		111	....	much	much	little
	61	trace	much	....	....		112	....	much	much	little
	64	trace	much	....	....		113	....	much	much	little
	53	little	much	little	....	D_{11}	116	....	much	much	much
	59	little	much	little	....		117	....	much	much	much
	62	trace	much	little	....		118	....	much	much	much
	67	little	much	little	....		119	....	much	much	much
D_5	68	....	much	....	....		121	....	much	much	much
	69	....	much	....	....		122	....	much	much	much
	70	....	much	....	....		123	....	much	much	much
	71	....	much	....	....		126	....	much	much	much
	72	....	much	....	....		127	....	much	much	much
	73	....	much	....	....		120	....	some	much	much
	74	....	much	....	....		124	....	some	much	much
	75	....	much	....	....		125	....	some	much	much
	76	....	much	....	....		128	....	some	much	much
	77	....	much	....	....		129	....	some	much	much
	78	....	much	....	....		130	....	some	much	much
	79	....	much	....	....	D_{12}	131	....	little	much	much
	80	....	much	....	....		132	....	little	much	much
	81	....	much	....	....		133	....	little	much	much
	82	....	much	....	....		134	....	little	much	much
D_6	83	....	much	little	....		135	....	little	much	much
	84	....	much	little	....						

There is a number of hornblende-andesites with neither pyroxene nor biotite, and others with a small amount of both. In most of the hornblende-mica-andesites there are no porphyritical pyroxenes; they occur in a few varieties only and in small amounts, and are equally rare in the dacites.

The greatest amount of porphyritical quartz is generally accompanied by considerable biotite and less hornblende.

Plagioclase feldspars are present in all the varieties of these rocks, but vary in composition from labradorite in the basic andesites to oligoclase or andesine in the dacites.

As to the microscopical characters of the essential minerals it may be said that they are like those already described for the essential minerals in the andesites which form the breccias.

The *pyroxenes* are the same, and consist of hypersthene and augite in all cases where they are fresh. In many instances a part of the pyroxene is entirely altered and part is fresh, and is augite, the hypersthene having been completely decomposed. They have the same color and pleochroism and crystal form as those in the andesites just described, and need no further comment.

The *hornblende* in some of the pyroxene-andesites is represented simply by paramorphs, which consist of grains of magnetite and pyroxene with the outward form of hornblende crystals; in others it is in small individuals, with a broad or narrow black border, occasionally with no border. In the hornblende-pyroxene-andesites the hornblende has a black border in some instances, but in the majority of cases it is entirely free from any border; the same is true of it in the hornblende-andesites. In the more acid andesites and dacites the hornblende exhibits no signs of black border.

In many instances where the crystal form is well developed both the orthopinacoid and clinopinacoid is present besides the unit prism faces, which is characteristic of the hornblende in the diorites of Electric Peak.

The color of the hornblende varies somewhat from brown and greenish brown to brownish green and green, with the usual pleochroism. It is brown and greenish brown in most of the pyroxene- and hornblende-andesites, but is very generally green and brownish green in the hornblende-mica-andesites and dacites. Its color is like that of the hornblendes in the porphyrites and diorites of Electric Peak.

Many of the hornblendes carry glass inclusions, and some have large bays and irregularly shaped inclusions of groundmass. They also inclose grains of magnetite and apatite, and occasionally are intergrown with pyroxene in such a manner that the two appear to have crystallized at the same time.

In some of the dacites the hornblende is entirely decomposed, while the biotite is still intact.

The *biotite* is chestnut brown, in thin section, with the ordinary absorption. The optic angle is very small and the mineral behaves like a uniaxial one. Its crystal form is simple and the individuals are generally quite thick. It is unaltered in almost all the rock sections, and carries a variable amount of inclusions of magnetite and apatite, with occasional zircon. In one instance it completely incloses a small crystal of plagioclase.

The *feldspars* are all plagioclase, and exhibit the characteristic polysynthetic twinning. In the more basic andesites they are mostly very small individuals, with rectangular sections and high extinction angles, indicating labradorite. They are usually very abundant. In some instances they are fewer in number, and do not exhibit high extinction angles or high double refraction, and appear to be oligoclase.

In the more acid andesites and dacites the plagioclases are larger and have more crystal faces, the sections being more polygonal and broader. The extinction angles are lower, and there seems to be several kinds of plagioclases among the phenocrysts; some are sharply rectangular with numerous twin lamellæ, and extinction angles indicating labradorite, while the majority of the individuals are not rectangular, have fewer lamellæ and lower extinction angles, and exhibit very marked zonal structure. They appear to be oligoclase; they all carry more or less glass inclusions, which are very abundant in some individuals and in some rock sections, and are quite scarce in others. The different specimens of the rocks vary greatly in the amount of inclusions in the phenocrysts. In one of the hornblende-andesites which has a brown, globulitic, glassy groundmass, many of the feldspars inclose patches and small bits of the brown glass, but one of the larger plagioclases also carries a great number of opaque needles and grains, arranged in several systems of parallel lines, which are identical with the inclusions in many of the labradorites in the diorites of Electric Peak. Besides this individual of feldspar there are several others which exhibit the same thing to a slight degree. There is another fine example of it in a glassy hornblende-andesite; the feldspar in this case carries abundant inclusions of glass as well as the clouds of microscopic needles. This is important, as it proves the primary nature of these particular inclusions, and indicates that the phenocrysts containing them crystallized under conditions similar to those attending the crystallization of the labradorites in the diorites of Electric Peak.

The *quartz* phenocrysts occur in the biotite-hornblende rocks, and vary in amount from a few microscopic individuals to very abundant macroscopic ones. Their crystal form is well marked in many cases and corresponds to the double pyramid, but other individuals in the same rock section are rounded, and some have quite an irregular outline. It seldom, if ever, happens that all the individuals of quartz in one rock section exhibit the same degree of perfection of crystal form; rounded grains and idiomorphic crystals are scattered indiscriminately through the rock. The same is true in many instances of the hornblende individuals, as already described.

The quartzes occur singly in isolated crystals, and also in groups of two or more individuals with different orientations, grown together in the same manner as those of feldspar or of the ferromagnesian silicates. Glass inclusions are found in nearly all the quartzes, but in very different amounts, some being crowded with them, while others are almost free from them. They are usually in negative crystal cavities, occasionally in rounded ones. In some cases they are accompanied by the six-rayed cracks so common in the quartzes of rhyolites. The quartzes often inclose bays of groundmass, and occasionally small crystals of hornblende, biotite, and plagioclase. These latter inclosures show that the quartzes crystallized after part, at least, of the hornblende, biotite, and plagioclase had crystallized. The inclosing quartzes are rounded at the corners. In one instance a quartz contains small fluid inclusions besides those of glass.

Magnetite, which is very abundant in the more basic rocks, and is in much smaller amounts in the dacites, needs no special description.

The *apatite* occurs in short, stout, hexagonal prisms; it is colorless, and is rare in the basic andesites, and more abundant in the more acid andesites and dacites. The same is true of the *zircon*, which is seldom observed in the basic andesites.

Small individuals of *allanite* are found in three of the dacite sections. It is dark brown, with strong absorption.

The groundmasses of these rocks, which result from the processes of final solidification of the various magmas, differ in degree of crystallization, in mineral composition, and in structure.

In the pyroxene- and hornblende-pyroxene-andesites the groundmass in many cases is glassy, with multitudes of microlites of pyroxene and plagioclase and grains of magnetite. In many others it is completely crystallized and the outline of the microlites is no longer sharply defined. In one glassy hornblende-pyroxene-andesite there is a segregation of minerals, which is interesting from the fact that the mass is not holocrystalline, but contains in the interstices between the large crystals vesicular glass with skeleton feldspars, and much fewer microlites than the glassy groundmass contains. The segregation, at first glance, resembles those holocrystalline groups of hornblende and plagioclase so common in the andesites and porphyrites. It consists of large hornblende crystals, with a few small biotites and pyroxenes inclosed in them, besides some plagioclase. But the feldspars carry many fine glass inclusions, which are also found in the hornblendes. The interstitial glass is partly colorless, partly globulitic, carrying long, slender skeleton plagioclases, with square cross sections, and a few needles of pyroxene with grains of magnetite attached. This glass is quite vesicular, while the groundmass of the rock presents a wholly different appearance. The latter is compact, and crowded with small microlites of feldspar and pyroxene and magnetite, having a typical felt-like structure. The hornblende and plagioclase of the segregation have the same characters as those of the same minerals in the surrounding rock, but they carry more glass inclusions. The crystal form of the minerals on the outside of the segregation is perfect, and the large crystals project into the surrounding groundmass of the rock. The segregation can not be the broken fragment of some foreign rock mass, but must be a local crystallization which advanced more rapidly than that of the surrounding portion of the rock, but did not result in complete crystallization. Within the interstitial glassy portion are numerous hollow cavities.

In the holocrystalline varieties of these rocks the groundmass has attained different degrees of crystallization, which may be compared with those exhibited by the intrusive rocks at Electric Peak. Separating the rocks into five groups to correspond to the preponderance of pyroxene with little hornblende; of pyroxene and hornblende; of hornblende alone, or with little pyroxene; of hornblende and mica, and of mica, hornblende, and quartz (See Tables XII and XIII), and arranging them according to the size of grain of the groundmass, they fall into the order given in Table XIV. In this table the grades of crystallization correspond to those established for the intrusive rocks of Electric Peak, which are expressed in Table VIII, with the addition of five more divisions which embrace two finer grained degrees of holocrystalline structures and three degrees of glassiness.

TABLE XIV.—*Grades of crystallization of the eruptive rocks of Sepulchre Mountain.*

	B_1, B_2, D_1, D_2.	B_3, B_4, B_5, D_3.	D_4, D_5, D_6.	D_7, D_8, D_9.	D_{10}, D_{11}, D_{12}.
1	9, 10	28			
2	1, 2, 3, 4, 11, 12, 33, 34, 35, 39, 40	14, 18, 29	68		
3	5, 6, 7, 8, 13, 41	15, 16, 19, 20, 21, 22, 23, 24, 25, 30, 43, 44, 45, 46			
4		17, 26, 27, 31, 32	53, 69, 70, 83	85	
5			54, 71, 72	90, 91, 104	
6	36	47, 48, 49	55, 73, 74	86, 92, 93	106, 116, 117
7	37		75, 76, 77, 84	94, 95	107, 118, 119, 120, 131
8			56, 57, 58, 59, 79, 80, 81, 78	87, 96, 97, 98	108, 109, 110, 111, 121, 122, 123, 124, 125, 132, 133
9			60, 61, 62, 63, 64	99, 100, 105	112, 126, 127
10					
11			65, 66, 82		134
12		50		88, 89	
13					113, 135
14	38	51		101	
15					
16			67	102	
17					
18					128
19				103	114, 115, 129, 130
20		52			
21					
22					
23					
24					
25	42				

The microstructure of the acidic varieties is not the same as that of the basic, so that it is difficult to compare the grain of one directly with that of the other; but since the intermediate rocks possess microstructures intermediate between these extremes, it is possible to establish a kind of relationship between them, and it is admissible to place them in the same line across the table, it being understood that the correspondence is an approximation.

A glance at Table XIV shows that a great majority of the varieties are very fine grained forms that have only reached the crystallization of the few smallest grained forms of the Electric Peak rocks. A small number of them are more coarsely microcrystalline and correspond to the grain of the dike rocks at Electric Peak. A large number are finer grained than any of these rocks, or are glassy. The coarsest grained forms have been attained by the most basic varieties, but they do not represent bodies of any considerable extent. Specimen No. 42, grade 25, comes from a small exposure with no definite limits, surrounded by much finer grained rocks. It is properly a diorite-porphyrite, and carries much biotite of final consolidation, which has not been reckoned with the phenocrysts.

The coarsest grained forms of the acid varieties, however, represent larger bodies and are more abundant in the field.

In explanation of the degrees of crystallization indicated in the table, it may be said that the first three are glassy groundmasses, the first one having fewer microlites than the second. In the third the microlites are closely crowded together. The next two represent microlitic structures in which no glass can be detected; they appear to be holocrystalline. In the sixth grade the form of the microlites is more indistinct, but the general structure is the same as before. Beyond this the different degrees indicate increasing grades of a structure which may be described in general as follows: Commencing with the lowest order, the groundmass is composed of a multitude of indistinct microlites of lath-shaped feldspars; between crossed nicols this aggregation extinguishes light in small patches, which bear no fixed relation to the position of the microlites within them. As the dimensions of the lath-shaped feldspars become larger it is observed that the patches of light and darkness arise from the cementing material between these feldspars. This cement possesses the same optical orientation for small spaces which in cross section produce the patches just alluded to. In still coarser grained forms it becomes apparent that the cementing material is quartz which has crystallized in irregularly shaped patches inclosing many smaller feldspars. The size of these feldspars and of the interstices between them is taken as the grain of the rock, and not the size of the patches of quartz. For it is observed that as the rocks become more coarsely crystalline the feldspars, which are plagioclase, increase steadily in size and each quartz patch cements fewer of them, until in still coarser grades the quartz forms allotriomorphic individuals between the plagioclases and does not surround any, so that in these varieties of rock the size of grain is judged by the dimensions of the plagioclases and the interstices of quartz. The patchy structure just described is that already mentioned on page 589 and called micropoicilitic.

In the most siliceous varieties of the rocks the microstructure is different. The smallest grained forms appear to approach a granular structure, in which, however, the feldspars exhibit a more or less rectangular shape and the quartz shows a tendency to appear in minute, poorly defined dihexahedrons. As the grain becomes larger the form of the quartz grains becomes more pronounced. They are rudely idiomorphic, with sections that are in many cases equilateral rhombs, extinguishing the light parallel to their diagonals. In the coarsest grained forms of the dacites these imperfectly idiomorphic quartzes are characteristic of the groundmass and reach a diameter of from $0{\cdot}08^{mm}$ to $0{\cdot}10^{mm}$. Their surface is indented with the ends and corners of small plagioclases, the structure of the groundmass being hypidiomorphic. These quartzes often contain minute colorless inclusions in negative crystal cavities which have every appearance of being glass and correspond to the glass inclusions in the quartz phenocrysts of the same rocks. The partially idiomorphic quartzes in the groundmass are to a slight degree porphyritical with respect to the other constituents, but belong to the final consolidation of the magma.

GENERAL CONSIDERATION OF THE MINERAL AND CHEMICAL COMPOSITION OF THE ERUPTIVE ROCKS OF SEPULCHRE MOUNTAIN.

Mineral composition.—The mineral variations in the group of rocks forming Sepulchre Mountain are much simpler and require much less discussion than those of the intrusive rocks of Electric Peak. They have already been expressed in the Tables XIII and XIV. From these tables it is evident that the so-called transitional forms of the rocks are as numerous and as important as those forms which would be considered type rocks. It is possible to describe those varieties of andesite with augite and hypersthene and no hornblende as typical pyroxene-andesite, those varieties with nearly equal amounts of pyroxene and hornblende as typical hornblende-pyroxene-andesites, those varieties with hornblende alone as typical hornblende-andesites, and so on for typical hornblende-mica-andesites and typical dacites. And for convenience of description this may be admissible. But in the occurrence at Sepulchre Mountain such a method of description would create a false impression and would lead one to expect definite bodies of such type rocks with facies which should present the transitional variations; whereas, there are definite bodies of the so-called type rocks and equally definite bodies of the intermediate varieties which are quite as numerous. There is no particular mineralogical modification of the rocks at this place, which from its greater abundance or its special mode of occurrence renders it a type rock. On the contrary, the whole accumulation of eruptive rocks which are subsequent to the bottom breccia, with its admixture of Archean fragments, must be considered as a series of volcanic rocks that vary in mineral composition, through gradual changes from pyroxene-andesite to dacite.

Starting with those rocks which carry phenocrysts of pyroxene and plagioclase, it is observed that as the hornblende makes its appearance and increases in amount the pyroxene decreases. Biotite accompanies the hornblende in the more acidic varieties and increases in amount with the acidity of the rock. Quartz first appears in small quantities and increases with the acidity of the rock, the hornblende decreasing at the same time. To this rule there are exceptions which are indicated in the table; biotite is found to a slight extent in some of the hornblende-pyroxene-andesites and pyroxene occurs in small amounts in some of the hornblende-mica-andesites. It is, of course, understood that this relation between the essential minerals may be different for groups of andesites in other regions.

Chemical composition.—The chemical composition of the eruptive rocks of Sepulchre Mountain is shown in the accompanying table of chemical analyses:

TABLE XV.—*Chemical analyses of rocks from Sepulchre Mountain.*

Specimen number.	33	80	20	2	21	95	102	129	131
SiO_2	55.83	55.92	56.61	57.17	60.30	64.27	65.50	65.66	67.49
TiO_2	1.05	.94	.79	1.03	.76	.32	.45	1.37	.13
Al_2O_3	17.11	17.70	13.62	17.25	16.31	17.84	14.94	15.61	16.18
Fe_2O_3	4.07	3.16	5.89	2.48	4.35	3.36	1.72	2.10	1.30
FeO	3.75	4.48	2.60	4.31	1.41	1.29	2.27	2.07	1.22
MnO	none	trace	.35	none	.13	none	.20	none	.08
CaO	7.40	5.90	6.61	6.61	5.62	3.42	2.33	3.64	2.68
BaO	....	....	.14	....	.15	....	.13	....	....
MgO	5.05	4.34	5.48	4.83	2.39	2.00	2.97	2.46	1.34
SrO	....	....	trace	....	trace	....	trace?	....	....
Li_2O	none	.09	....	trace	....	.03	....	.36	....
Na_2O	2.94	4.08	3.13	3.44	3.99	3.84	5.46	3.65	4.37
K_2O	1.71	2.28	2.71	2.03	2.36	2.48	2.76	2.03	2.40
P_2O_5	.21	.18	.06	.05	.20	.16	.09	trace	.13
SO_3	trace	trace	?	trace	.10	trace	.06	.13	....
Cl	none	none	....	trace	....	none	....	.12	....
CO_2	....	....	none	....	none	....	none	....	....
H_2O	1.28	1.42	2.27	1.20	2.50	1.32	1.37	1.07	2.69
	100.40	100.45	100.26	100.40	100.57	100.33	100.25	100.27	100.01
Less O for Cl	....	....	....	....	....	....	....	.03	
								100.24	

Nos. 33, 80, 2, 95, and 129 were analyzed by Mr. J. E. Whitfield, Nos. 20, 21, and 102 were analyzed by Dr. T. M. Chatard, and No. 131 was analyzed by Mr. L. G. Eakins.

The first, No. 33, and fourth, No. 2, are analyses of pyroxene-andesites which carry no hornblende; the first is a dike near the summit of the mountain, the other is from a surface flow at its southwest base. Nos. 20 and 21 are of hornblende-pyroxene-andesites, occurring as breccia in the upper part of the mountain. No. 80 is of hornblende-andesite, which is an intruded body in the small hill northeast of Cache Lake at the head of Reese Creek. No. 95 is a hornblende-mica-andesite from the same locality, also an intrusive rock. No. 102 is the same kind of andesite from an intrusive mass at the north base of Sepulchre Mountain, and Nos. 129 and 131 are dacites from the ridge south of Cache Lake.

The range of variation in the percentage of silica is about the same as that of the rocks at Electric Peak. The character of the variations of the other oxides in these rocks is shown by the accompanying diagram, which represents the variations in the molecular proportions of the essential oxides and has been plotted in the manner already described on page 628.

A glance at this diagram shows that it has the same form as that of the group of analyses of the rocks from Electric Peak. The variations in the oxides other than silica are quite irregular for a gradual change in the silica. The alumina varies rapidly in places and retains a high position in the diagram. The alkalies gradually increase with the silica, the soda molecules being twice as numerous as those of potash and their variations being alike with one exception. Magnesia varies most widely and in striking contrast to the alumina; in each instance they vary in opposite directions. The lime is nearly as irregular as the magnesia, both decreasing rapidly from the less siliceous to the more siliceous end of the series. The two oxides of iron are strikingly reciprocal in their variations, the significance of which has been pointed out in discussing the diagram for Electric Peak. In the group of analyses from Sepulchre Mountain the oxidation of the iron bears a noticeable relation to the presence of hornblende, biotite, and magnetite in the rocks.

From a study of these analyses it is evident that the chemical variations in this group of rocks are the same in character and extent as those in the intrusive rocks of Electric Peak. Moreover, it appears that the variations between similar varieties of andesite—such as those between different pyroxene-andesites—are as great as and in some cases

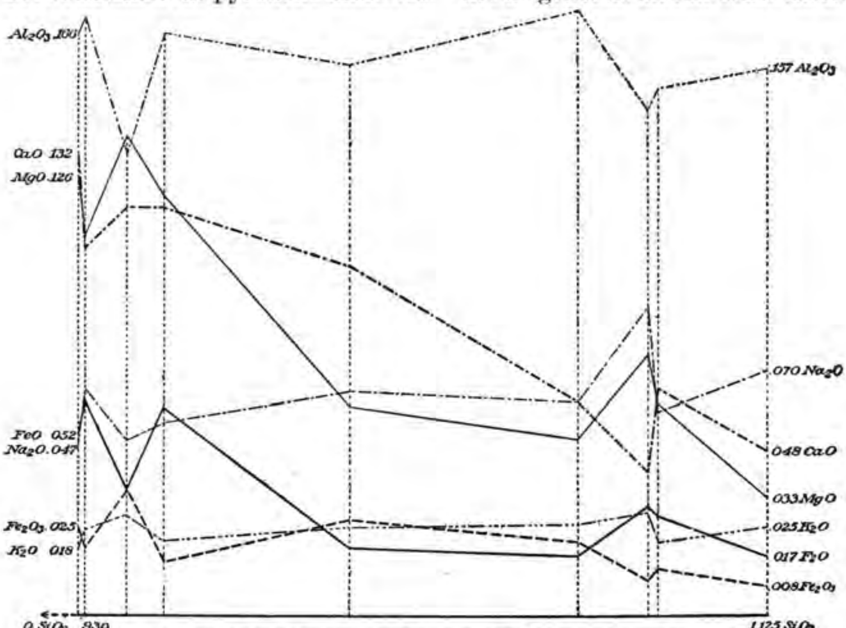


FIG. 81.—Molecular variation of the rocks of Sepulchre Mountain.

greater than the variations between varieties of andesites which are distinguished mineralogically from one another. Thus Nos. 33 and 2 are pyroxene-andesites without hornblende, Nos. 20 and 21 are hornblende-pyroxene-andesites, while No. 80 is a hornblende-andesite. It is not possible to point to any chemical character of these rocks which is distinctive of this mineral variation, with the exception of the oxidation of the iron, which, though slight, is an important one; for it undoubtedly relates to forces which did not alter the fundamental relation between the bases in the magma, but simply modified it by changing the oxidation of one of them. The last four analyses are of hornblende-mica-andesites and dacites. The chemical variations between them are as pronounced as those between the more basic members of the series, without there being the corresponding differences between the kinds of ferromagnesian silicates, so far as it can be detected microscopically.

They all carry hornblende and biotite and no pyroxene, the relative proportions of these minerals varying. The character and amount of the feldspars differ in these rocks, and so do the abundance and mode of occurrence of the quartz. In Nos. 129 and 131 quartz appears as phenocrysts; in the other rock it is confined to the groundmass.

COMPARISON OF THE ROCKS FROM THE TWO LOCALITIES.

Having described the geological structure of Electric Peak and of Sepulchre Mountain and the occurrence and character of the igneous rocks in each locality, it remains to point out the relationship of the two groups of rocks to each other, and the petrological deductions which may be drawn from their investigation.

To arrive at the relationship of the volcanic rocks of Sepulchre Mountain to the intrusive rocks of Electric Peak it is necessary to observe, in review of the facts already presented, that the latter cut through Cretaceous shales and sandstones and have imparted sufficient heat to them to metamorphose them for a great distance, indicating the passage of large quantities of molten magma through the fissures; while the lavas of Sepulchre Mountain rest on Cretaceous strata and also carry large blocks of black shale inclosed within them. They plainly show by their crushed and dragged portions that a profound fault has separated the block of Sepulchre Mountain from that of Electric Peak, dropping the former down considerably more than 4,000 feet. Consequently the volcanic rocks of Sepulchre Mountain once occupied a higher elevation than the present summit of Electric Peak and its bodies of intrusive rock.

In Electric Peak there is a system of fissures that radiates outward toward the south and southwest, as shown by the dikes of porphyrite. At the west base of Sepulchre Mountain there is a system of dikes and intruded bodies that radiates outward toward the north and northeast. These fissures antedate the great faulting just mentioned and represent the east and west halves of a system of fissures trending from north and south around to northeast and southwest which crossed one another at the point where the broadest body of intruded rock is now found. The axis of this system appears to have been inclined toward the east, that is, to have dipped toward the west, and was cut across by the great fault which dropped Sepulchre Mountain.

The igneous rocks that broke through the strata of Electric Peak consist of a series of porphyrites, occurring in sheets between the strata, and another series of diorites and porphyrites that were erupted through the vertical fissures just alluded to. The central fissure or fissures became the conduit through which the molten magmas followed one another at successive intervals of time. In the outlying narrow fissures the magmas solidified as dikes of porphyrite, while within the heated conduit they consolidated into coarse grained diorites of various kinds. The magmas of this series of eruptions became more and more siliceous. Their succession is indicated in the accompanying table.

TABLE XVI.—*Order of eruption of the rocks at Electric Peak and Sepulchre Mountain.*

Succession of eruptions at Electric Peak.	Succession of eruptions at Sepulchre Mountain.
A. Intrusion of sheets of **porphyrite** from the southwest.	A. Extravasation of **andesitic breccia** from some Archean area.
B. Intrusion of **dike- and stock-rocks** in the following order:	B. Eruption of **andesitic breccias and dikes** in the following order:
Pyroxene-porphyrites, grading into **pyroxene- and hornblende-diorites** with biotite of final crystallization, with dikes of pyroxene- and hornblende-porphyrites, grading into	**Pyroxene-andesites**, breccia, and flows passing into
	pyroxene-hornblende-andesites, breccia, and flows, with dikes of similar andesites, grading into
hornblende-biotite-diorites with biotite of early crystallization, with dikes of hornblende-biotite-porphyrites;	**hornblende-biotite-andesites** in dikes, grading into
quartz-biotite-diorite-porphyrite with some hornblende, with dikes of quartz-biotite-porphyrite.	**dacites** with phenocrysts of quartz, biotite, and some hornblende.

The igneous rocks that formed the breccias and lava flows of Sepulchre Mountain with their dikes and larger intruded bodies constitute a series of andesites, basalts and dacites, which reach a degree of crystallization that places part of them among the porphyrites. They commenced with an andesitic breccia that is filled with Archean fragments, which must have been thrown from some neighboring center of eruption located in an Archean area. Such a center exists a few miles to the north. This was followed by a series of magmas that were at first somewhat basic and became more and more siliceous. The series is represented in the right hand column of Table XVI. From this it is seen that the succession of eruption in each locality was the same, after the first period, A, in which the magmas evidently came from different sources. Each series of the second period began with basic magmas and ended with acidic ones. Their division in the table into four groups is not intended to convey the idea that they belong to four distinct periods of eruption. The whole series in each case is more correctly a single, irregularly interrupted succession of outbursts of magma that gradually changed its composition and character. Upon comparing the rocks which have resulted from the corresponding phases of these series of eruptions, the similarity of the porphyritic forms is immediately recognized. The nature and distribution of the phenocrysts in the different varieties of andesite and dacite, which determine their macroscopical habit, have their exact counterpart in the different varieties of porphyrites. The microscopical characters of the phenocrysts in the corresponding varieties of porphyrites and of the intruded andesites and dacites are identical. The character of the various groundmasses, however, is different in the two groups, being more highly crystalline in the porphyrites—many of the andesites being glassy. Many of the finer grained diorites have a habit, derived from the distribution of the ferromagnesian silicates and larger feldspars, which resembles that of some of the andesites and dacites which correspond to them chemically.

Finally, the study of the chemical composition of the intrusive rocks of Electric Peak and of the volcanic rocks of Sepulchre Mountain proves that these two groups of rocks have identical chemical compositions, for the varieties that have been analyzed are but a few of the many mineralogical and structural modifications assumed by these magmas on cooling. The analyses serve as indications of the range of the chemical variability of these magmas.

From the geological structure of the region, then; from the correspondence between the order of eruption of the two series of rocks; from the resemblance of a large part of the rocks of both series, macroscopically and microscopically, and from the chemical identity of all the rocks of both groups, it is conclusively demonstrated that:

I. The volcanic rocks of Sepulchre Mountain and the intrusive rocks of Electric Peak were originally continuous geological bodies.

II. The former were forced through the conduit at Electric Peak during a series of more or less interrupted eruption.

III. The great amount of heat imparted to the surrounding rocks was due to the frequent passage of molten lava through this conduit.

We have, then, in this region the remnant of a volcano, which has been fractured across its conduit, has been faulted and considerably eroded; and which presents for investigation on the one hand, the lower portion of its accumulated debris of lavas, with a part of the upper end of the conduit filled with the final intrusions; and on the other hand, a section of the conduit within the sedimentary strata upon which the volcano was built.

CORRELATION OF THE ROCKS ON A CHEMICAL BASIS.

Correlating the two groups of rocks according to their chemical composition and arranging them as in Table XVII, we see that the hornblende-mica-andesites, Nos. 95 and 102, are the equivalents of the quartz-mica-diorites, Nos. 215, 213, 205, 227, and 223, and of the quartz-pyroxene-mica-diorite, No. 211. The dacites, Nos. 129, 131, are the equivalents of the quartz-mica-diorite-porphyrites, Nos. 233 and 230. The hornblende-pyroxene-andesites and the pyroxene-andesites, Nos. 33, 80, 20, 2, and 21, are the equivalents of the coarse grained pyroxene-mica-diorite, No. 197, with variable percentage of quartz, and of the fine grained diorites, Nos. 176 and 177, and of a fine grained facies, No. 171.

The dacites and hornblende-mica-andesites included within this correlation are intruded bodies within the breccia of Sepulchre Mountain, and have the same mineral composition as the corresponding porphyrites and diorites of Electric Peak. They differ from them in structure and degree of crystallization, the details of which have already been described in earlier parts of this paper.

The glassy andesite with pyroxene and hornblende phenocrysts, however, present the utmost contrast to the chemically equivalent, coarsely crystalline diorites. In the former the hypersthene, augite, hornblende and plagioclase are sharply defined, idiomorphic crystals in a groundmass of glass, which is crowded with microlites of plagioclase and pyroxene, besides grains of magnetite. The hornblende is brown, occasionally red, and the other phenocrysts have all the microscopical characters which distinguish their occurrence in glassy rocks. In the diorite the hornblende is green, in some cases brown; and the hypersthene, augite and hornblende are accompanied by biotite, and are all intergrown in the most intricate manner, with evidence that they commenced to crystallize in the order just given. The labradorite is often clouded with minute opaque particles, which are characteristic of its occurrence in many diorites; it is surrounded by a shell of more alkaline plagioclase, which with occasional individuals of orthoclase and considerable quartz, closed the crystallization of the magma. Magnetite, apatite and zircon are the accessory minerals. The quartz contains fluid inclusions, which complete the correspondence of this diorite with typical diorites of other regions.

From the structure of this region, which has been so finely exposed by faulting and erosion, it is evident that of the different magmas erupted a part found their way into vertical fissures and took the form of dikes; part reached the surface and became lava flows and breccias, while other portions remained in the conduit. Therefore the various portions of the magmas solidified under a variety of physical conditions, imposed by the different geological environment of each, the most strongly contrasted of which were the rapid cooling of the surface flows under very slight pressure, and the extremely slow cooling of the magmas remaining within the conduits under somewhat greater pressure.

TABLE XVII.—*Correlation of the two groups of rocks upon a chemical basis.*

SiO_2%.	No.	Volcanic rocks of Sepulchre Mountain.			Intrusive rocks of Electric Peak.	
		Name.	Essential minerals.		Name.	Essential minerals.
			Phenocrysts.	Groundmass.		
69.24	230	...	...	...	quartz-mica-diorite-porphyrite.	quartz, biotite, plagioclase, and alkali feldspar, hornblende.
67.54	223	...	...	...	quartz-mica-diorite	biotite, hornblende, plagioclase, (orthoclase), quartz.
67.49	131	dacite	quartz, biotite, hornblende, plagioclase.	holocrystalline, quartz, feldspar.		
66.05	227	...	...	...	quartz-mica-diorite	biotite, hornblende, plagioclase, (orthoclase), quartz.
65.97	233	...	...	...	quartz-mica-diorite-porphyrite.	biotite, hornblende, plagioclase, (orthoclase), quartz.
65.66	129	dacite	quartz, biotite, hornblende, plagioclase.	holocrystalline, quartz, feldspar.		
65.60	205	...	...	...	quartz-mica-diorite	biotite, hornblende, (pyroxene), plagioclase, (orthoclase), quartz.
65.50	102	hornblende-mica-andesite.	hornblende, biotite, plagioclase.	holocrystalline, quartz, feldspar.		
65.11	213	...	...	...	quartz-mica-diorite	biotite, hornblende, augite, hypersthene, plagioclase (orthoclase), quartz.
64.85	215	...	...	...	quartz-mica-diorite	hornblende, biotite, plagioclase, (orthoclase), quartz.
64.27	95	hornblende-mica-andesite.	hornblende, biotite, plagioclase, magnetite.	holocrystalline, quartz, feldspar.		
64.07	211	...	...	...	quartz-pyroxene-mica-diorite.	biotite, hornblende, augite, hypersthene, magnetite, plagioclase, (orthoclase), quartz.
61.22	176	...	...	...	pyroxene-mica-diorite.	biotite, hornblende, augite, hypersthene, magnetite, plagioclase, (quartz).
60.30	21	hornblende-pyroxene-andesite.	hornblende, augite, hypersthene, plagioclase, magnetite.	glassy, microlitic.		
58.05	177	...	...	...	pyroxene-mica-diorite.	biotite, hornblende, augite, hypersthene, magnetite, plagioclase, (quartz).
57.38	171	...	...	...	pyroxene-porphyrite	augite, hypersthene, biotite, magnetite. plagioclase, quartz.
57.17	2	pyroxene-andesite	augite, hypersthene, plagioclase.	brown glass, microlitic.		
56.61	20	hornblende-pyroxene-andesite.	hornblende, augite, hypersthene, plagioclase.	glassy, microlitic.		
56.28	197	...	...	...	pyroxene-mica-diorite.	biotite, hornblende, augite, hypersthene, magnetite, plagioclase, quartz.
55.92	80	hornblende-andesite	hornblende, plagioclase	microcrystalline.		
55.83	33	pyroxene-andesite	augite, hypersthene, plagioclase.	glassy, microlitic.		

TABLE XVIII.—*Correlation of the grades of crystallization of the rocks from Sepulchre Mountain and Electric Peak.*

Grades of crystallization.	Sepulchre Mountain.																	Electric Peak.														
	Breccias.					Dike rocks.												Dike rocks.											Stock rocks.			
	B_1.	B_2.	B_3.	B_4.	B_5.	D_1.	D_2.	D_3.	D_4.	D_5.	D_6.	D_7.	D_8.	D_9.	D_{10}.	D_{11}.	D_{12}.	d_1.	d_2.	d_3.	d_4.	d_5.	d_6.	d_7.	d_8.	d_9.	d_{10}.	d_{11}.	s_1.	s_2.	s_3.	s_4.
1		9, 10			28																											
2	1, 2, 3, 4	11, 12	14	18	29	33, 34, 35	39, 40			68																						
3	5, 6, 7, 8	13	15, 16	19, 20, 21, 22, 23, 24, 25, 26, 27.	30		41	43, 44, 45, 46.																								
4			17		31, 32				53	69, 70	83	85																				
5									54	71, 72			90, 91	104																		
6						36		47, 48, 49	55	73, 74		86	92, 93		106	116, 117												163				
7						37				75, 76, 77	84		94, 95		107	118, 119, 120.	131						144					164, 165				
8									56, 57, 58, 59.	78, 79, 80, 81.		87	96, 97, 98		108, 109, 110, 111.	121, 122, 123, 124, 125.	132, 133.					142						166, 167				
9									60, 61, 62, 63, 64.				99, 100	105	112	126. 127							145. 146				162	168, 169				
10																							147	150								
11									65, 66	82							134						148, 149			159, 160.						
12								50				88, 89										143			153, 154	161						
13															113		135								155				170			
14						38		51					101											151, 152	156, 157				171			
15																													172			
16									67				102							139					158				173			
17																													174	203		
18																128														204, 205		
19													103		114, 115	129, 130		136			140, 141									206	216, 217	
20								52										137												207, 208		228, 229
21																														209		230, 231
22																													175			232, 233
23																													176			234, 235
24																													177, 178		218	236
25							42												138												219	237
26																													179, 180			
27																													181	210		
28																													182			
29																													183			
30																													184, 185			
31																													186, 187			
32																													188			
33																													189, 190, 191.			
34																													192	211		
35																													193	212	220	238
36																														213	221	
37																													194		222, 223, 224.	
38																													195	214		
39																													196	215		
40																													197		225, 226, 227.	
41																													198			
42																													199			
43																													200			
44																													201			
45																													202			

The effect of this diversity of conditions upon the degree of crytallization of the various portions of these rocks is well shown in the accomnynying Table XVIII, which has been derived from Tables VIII and XIV.

In this table are presented all of the specimens from Sepulchre Mountain and Electric Peak. They are arranged in four principal divisions: First, the breccias and lava flows; second, dikes and larger bodies intruded in these breccias; third, dikes in the Cretaceous strata of Electric Peak; fourth, the main stock and its immediate apophyses. These groups are still further subdivided into columns which correspond to mineralogical differences in the rocks, and bear the same letters as the mineralogical subdivisions in Tables III, VIII, XII, and XIII. Consequently each of the four principal groups has the most basic members at the extreme left and the most acidic ones at the extreme right. The mineralogical range is, therefore, repeated four times. The table illustrates a number of facts. It exhibits the relative degree of crystallization of the breccias, lava flows, dikes, and stock rocks, and shows that a great number of intermediate steps can be recognized between the most glassy andesite and the coarsest diorite. It shows that the dike rocks furnish the connecting link between these two extremes, and that the dike rocks of Electric Peak have the same range of grain as the majority of those of Sepulchre Mountain. But many of those at Sepulchre Mountain are still finer grained and some are glassy, being vesicular also. Between these rocks there is the closest possible resemblance macroscopically, and the two groups might have been described conjointly so far as their petrographical characters were concerned. The variation of grain within each of the four principal divisions is very significant when taken in connection with the geological occurrence of the different rocks. The limited range of variation in the first group is in accord with the fact that all of these rocks are surface ejectamenta. The range in the third group from more crystalline basic rocks to less crystalline acid rocks, as already pointed out on page 621, shows the greater tendency of the basic rocks to crystallize. And since the dikes here represented are nearly the same size, this variation of grain corresponds to differences in the chemical composition of the rocks. On the contrary the variations in the second group indicate a slightly greater crystallization of the acid rocks. This, however, is due to the fact that the basic rocks in this group, with a few exceptions, occur in small dikes, while the acid rocks for the most part form broad intruded bodies a number of hundred feet wide. In these cases the size of the mass has had more influence on the degree of crystallization than the chemical composition of the magma has had. In the fourth group the basic rocks exhibit a wider range of grain than the acidic, being much coarser and also considerably finer grained than the latter. This arises from the fact that the basic rocks form a much larger mass and exhibit great variation of grain, having fine grained facies that have been fully discussed in an earlier part of this paper.

These Tertiary diorites and others that cut the volcanic lavas in several localities in this region correspond to the *andesdiorites* and *andesgranites* of Stelzner, who described stocks of granular rocks penetrating the andesitic tuffs in the Argentine Republic. The study of these Tertiary granular rocks led him to the conclusion that the degree of crystallization of eruptive rocks is in no way dependent on their age, but depends on the physical conditions under which the mineralogical differentiation and the cooling of the magma took place.[1]

From the study and comparison of the chemical analyses of the two groups of rocks under investigation it is demonstrated that the magmas that reached the surface of the earth in this place had exactly the same chemical composition as those which remained inclosed within the sedimentary strata. It proves with equal clearness that the different conditions attending the final consolidation of the ejected and of the intruded magmas affected *not only their crystalline structure, but their essential mineral composition*. The most marked illustration of this is in the occurrence of biotite in the two series. In the volcanic rocks of this locality biotite is an essential constituent of the more siliceous varieties, and is only rarely found as an accessory constituent of the varieties with less than 61 per cent of silica. In the intrusive rocks it is an essential constituent of all the coarse grained varieties, even the most basic. In the finer grained porphyritic forms it is a constituent of the groundmass to a variable extent. The second most noticeable difference is the presence of considerable quartz in the coarse grained forms of the basic magma and its absence from the volcanic forms of the same magmas.

From these observations, then, we see that in this region there are chemically identical rocks which have distinctly different mineral compositions, but which were once parts of a continuous body of molten magma. We are led, therefore, to the conclusion that—

The molecules in a chemically homogeneous fluid magma combine in various ways, and form quite different associations of silicate minerals, producing mineralogically different rocks.[2]

The bearing of these facts upon the question of the classification of igneous rocks is that, since different portions of a large body of a chemically uniform magma may assume a variety of geological forms within

[1] Alfred Stelzner: Beiträge zur Geologie und Paleontologie der Argentinischen Republik. Cassel and Berlin, 1885, p. 207.

"Sie (die Andengesteine) wird uns, wie ich meinerseits glaube, immer mehr und mehr erkennen lassen, dass die grössere oder geringere Krystallinität eruptiver Gesteine keineswegs, wie man so lange und so hartnäckig behauptet hat, von dem Alter der letzteren abhängig ist, sondern lediglich von den physikalischen Umständen, unter denen die mineralische Differenzirung und Erkaltung der gluthflüssigen Magmen vor sich ging."

[2] This conclusion is the same as that stated by Justus Roth:

"Es können mineralogisch ganz verschiedene Gesteine in dieselbe Gruppe gehören, denn *feurigflüssige Massen von gleicher oder sehr nahe gleicher chemischer Zusammensetzung können in verschiedene Mineralien auseinanderfallen*. Die Ursachen, welche diese Erscheinung bedingen, lassen sich höchstens muthmassen und mögen in Unterschieden des Druckes, der Temperatur, des umgebenden Mediums der Unterlage u. s. w. gesucht werden." Die Gesteins-Analysen in tabellarischer Übersicht und mit kritischen Erläuterungen. Berlin, 1861. p. XXI.

the earth's crust or upon its surface and may crystallize into rocks with different mineral composition, it is more proper to consider intrusive and effusive rocks that have like chemical composition as *corresponding* or *equivalent* rocks than those forms of the two series that have similar mineral composition. Thus we would not say that certain volcanic rocks which are the *equivalents* of certain intrusive ones differ from them chemically by such and such variations among the oxides, for the term *equivalent* would then simply refer to their mineralogical character, and we might be comparing portions of totally different magmas that had no geological connection with one another. Used in the other sense, we should say that certain volcanic rocks differ from their *corresponding* or *equivalent* intrusive rocks by the presence or absence of certain minerals, and in this way we would be grouping together the extrusive and intrusive portions of the same body of magma. The classification would then rest on a common geological and chemical basis.

In this region of Electric Peak and Sepulchre Mountain the greatest mineralogical differences accompany the greatest differences in structure or degree of crystallization; hence we may assume that the causes leading to each are coexistent. The source of these causes must be sought in the differences of geological environment, and these affect the rate at which the heat escapes from the magmas and the pressure they experience during crystallization.

It is to be remarked that the most essential mineralogical difference between the intruded rocks and their chemically equivalent extrusive forms is the much greater development of biotite and quartz in the intruded rocks; these minerals being abundant even in the basic intrusions and absent from their basic volcanic equivalents. That their simultaneous development is naturally to be expected in many cases is evident from a consideration of the character of their chemical molecules and that of other minerals common to these rocks. For if we assume that biotite is made up of two molecules, K and M, corresponding respectively to $K_6Al_6Si_6O_{24}$ and $R_{12}Si_6O_{24}$, and compare these with the molecules of orthoclase, $K_2Al_2Si_6O_{16}$, of olivine, R_2SiO_4, and of hypersthene $RSiO_3$, we see that molecules which under some conditions might have taken the form of olivine or hypersthene and potash-feldspar, which latter may have entered into combination with lime-soda feldspar molecules to form somewhat alkaline feldspars, may under other conditions combine as biotite with the separation of free silica or quartz; in which case also the feldspars of the rock would be less alkaline.

Another mineralogical difference between the two groups of rocks just mentioned is the greater development of hornblende in the intruded rocks in place of augite, which is chemically its equivalent, though it has not been determined whether in this case the hornblende of the diorite has precisely the same composition as the augite of the andesite. The probability is that there are slight differences between them.

EFFECT OF MINERALIZING AGENTS.

The crystallization of quartz, biotite, and hornblende in fused magmas, according to our present knowledge, requires the assistance of a mineralizing agent; for it has been demonstrated by synthetical research that these minerals will not crystallize into the forms they assume in igneous rocks when their chemical constituents are fused and simply allowed to cool under ordinary atmospheric conditions. But they have been produced artificially with the aid of the mineralizing action of water and other vapors. Now there is ample evidence both in the ejected lavas and in the coarsely crystallized rocks in the conduit that water vapor was uniformly and generally distributed through the whole series of molten magmas, and there is no evidence that there existed in the magmas which stopped within the conduit any more or different vapors than those which existed in the magmas that reached the surface. Hence we conclude that:

The efficacy of these absorbed vapors as mineralizing agents was increased by the conditions attending the solidification of the magmas within the conduit.

Moreover, if it is necessary, as advocated by the French geologists, MM. Michel Lévy,[1] de Lapparent[2] and others, to refer the crystallization of certain minerals, as quartz, to the mineralizing influence of absorbed vapors, it is evident that the required mineralizing agent is universally present in sufficient quantities, since there are no instances where a magma of the requisite chemical composition has failed to crystallize completely with the development of quartz when subjected to the proper physical conditions.

However, it is probable that differences in the amount or in the kind of mineralizing agents produce differences in the degree or nature of the crystallization of similar magmas which have solidified with the same geological environment.

It has been suggested by Dr. H. J. Johnston-Lavis[3] that the nature of the rocks surrounding a conduit through which molten magmas pass materially affects the amount and character of the vapors introduced into these magmas, which will vary as the surrounding rocks are more or less porous and are saturated with different kinds of waters. The effect of these vapors on the structure and composition of igneous rocks is also discussed by the same writer.

The effect of differences in the amount of the mineralizer in a single magma is well illustrated in the structure of the obsidian at Obsidian Cliff, Yellowstone National Park,[4] where the alternating layers of

[1] "Structures et Classification des Roches Éruptives." Paris, 1889, pp. 5 and 12.

[2] Revue des Questions Scientifiques. Paris, 1888, p. 36.

[3] "The Relationship of the Structure of Rocks to the Conditions of their Formation." Sci. Proc. of the Royal Dublin Soc., vol. 5 (n. s.), part 3, July, 1886, pp. 113 to 155.

[4] Obsidian Cliff, Yellowstone National Park, by J. P. Iddings. Seventh Annual Report of the Director of the U. S. Geological Survey, Washington, D. C., 1888, p. 287.

holocrystalline and glassy rock appear to be unquestionably due to the irregular distribution through the magma of vapors, which in the upper portion of the flow have produced alternating layers of pumice and compact glass. The mineralizing agent was present, however, in the alternate glassy layers as well as in the crystallized or in the pumiceous ones, for in the highest portion of the flow the whole mass is pumiceous but in different degrees, and the presence of absorbed vapors may be detected chemically and physically in the compact layers. Its amount, however, was not sufficient to produce complete crystallization under the attendant physical conditions. Its effectiveness in this case was controlled by the geological occurrence of the magma.

It is to be observed, in addition, that whatever the mineralizing vapors in acidic magmas may be, there is the same evidence of their existence in intermediate and in basic magmas, whether we investigate them chemically or physically, or study the phenomena of their geological occurrence. There are even indications of their greater abundance in the basic lavas, many of whose glasses contain a high percentage of water, and the highly vesicular character of whose lava-flows is universal. Nor are the geological evidences less conclusive that demonstrate the existence of abundant explosive agents in the basaltic and andesitic magmas that have hurled their shattered masses over broad areas of country, and have piled vast accumulations of basaltic breccia throughout our western territory.

Nevertheless, with all these evidences of the universal presence of mineralizing agents in basic magmas, we do not recognize their influence upon the microstructure or crystallization of basic lavas. We may assume, then, that in the majority of these cases they have no influence.

But when the basic magmas become coarsely crystalline, and separate into minerals, the cystallization of some of which we have already referred to the action of mineralizing vapors, we may logically assume that in these cases the absorbed vapors have influenced the crystallization of the magmas.

If this reasoning is correct, then the action of mineralizers upon basic magmas is controlled by the physical conditions under which they solidify.

Finally, if mineralizing agents are universally present in igneous magmas, and if their action, so far as we can observe it, is controlled by the physical conditions imposed by the geological history of each eruption, we should not regard the presence or absence of certain minerals, relegated to the influence of mineralizing agents, as evidence of the presence or absence of these agents in the molten magma; but we should see in it the evidence of special conditions controlling the solidification of the magma, and should seek the fundamental causes of the mineralogical and structural variations of a rock in the geological history of its particular eruption.

APPLICATION TO THE CLASSIFICATION OF IGNEOUS ROCKS.

The facts brought out by the study of this occurrence of igneous rocks seem to the writer to have a direct application to the problem of the general classification and description of igneous rocks. For while this occurrence cannot be regarded as a representative of all others, still it typifies to a very great extent the relations that exist between intruded magmas and their extrusive forms.

We have observed that in this locality a series of molten magmas was erupted through a common conduit during a succession of fracturings of the sedimentary strata. These magmas not only differed among themselves chemically, but varied somewhat in different portions of one and the same body, producing chemical facies of the main body of a particular rock mass.

When we consider the variations in the chemical composition and structure, and mineral constitution of a continuous geological body, such as may occur along an irregularly shaped crevice or system of fissures from their narrow and remote terminations toward their wider junctions with the main conduit, as well as the interpenetration and welding of older and newer portions of the magmas filling the conduit, with their consequent transitions in some places, and sharply marked intersections or contacts in others, we see that the resulting mass of igneous rocks presents a geological body whose complexity exceeds that of the most intricate web of vegetable organism.

Chemically considered there is a wide range of composition embracing the middle of the whole series of igneous rocks of the surrounding region. In percentage of silica they range from 53 per cent to 69 per cent; and if certain contemporaneous intruded rocks in the immediate neighborhood be included, the range of variation in the intrusive rocks is about the same as that of the volcanic rocks, from 48 per cent to 74 per cent.

Structurally, there are all forms from coarsely granular to porphyritic glassy, including all possible intermediate structures.

Mineralogically, there are all the combinations existing in this region, from that of quartz, alkali-feldspar, and mica, to that of basic lime-soda-feldspar and pyroxene, with a little olivine.

Hence the rocks include granite, granite-porphyry, quartz-porphyry, and rhyolite; diorite, quartz-mica-diorite, diorite-porphyrite, pyroxene-porphyrite, hornblende-mica-andesite, hornblende-andesite, pyroxene-andesite, dacite, and basalt. The glassy form of the granite-porphyry or of the quartz-diorite-porphyrite is not found in the immediate vicinity of Sepulchre Mountain, but occurs in the region south as a modification of the rhyolite at the Upper Geyser Basin. The still more siliceous rhyolite of Sepulchre Mountain is represented by a facies of the microgranite at Echo Peak, a point 12 miles south of Electric Peak.

Notwithstanding the range of structural variations within the mineralogical groups just mentioned, it is not possible to trace in exposure any one group through this series of structural variations. It becomes evident that while a perfectly continuous body may, and undoubtedly does in some instances, connect the glassy form of a consolidated magma with a coarsely granular form through intermediate stages of crystalline structure, yet the connected occurrence of all these forms is not a necessity, and in fact does not always exist. For if we consider the course of eruption of a magma that varies in its chemical composition, or the successive outbursts of a series of magmas that differ chemically from one another, we see that if a basic magma which has reached the surface of the earth and has produced glassy rocks—andesites—and has filled the disrupted strata with intruded sheets and dikes of porphyrite, and stands in the conduit under conditions which would eventually produce coarse grained diorite—if a basic magma in this stage of solidification be followed through the same conduit by a more siliceous magma, then the viscous body within the conduit would be forced out on the surface and its place occupied by the later magma, which would thus sever the connection between the intruded sheets or dikes and the surface lavas, and would deprive both of a coarse grained equivalent. Moreover, it is well known that in volcanic regions it usually happens that the lava that flows from a cone severs its connection with the molten magma in the crater, which often descends again within the conduit.

In the case of a great body of magma which varied in composition during a prolonged eruption, so that the first portion of it differed considerably from the last portion, the surface flows and earliest intrusions, if continuously connected with the deep-seated portion, would grade into it not only through a variety of structural modifications, but through a series of chemical and mineralogical variations, so that their actual geological connection would be with a coarse grained rock of a different type.

Furthermore, the magmas, which can be recognized at this locality as having constituted independent eruptions, not only differ in their chemical composition from one another, but vary to such an extent within their own mass that the chemical facies of one body correspond to the main portion of another. Hence the members of the series overlap one another in composition. Consequently a classification or consideration of the various forms of rocks of the same chemical composition involves in this case the artificial grouping of parts and facies of different geological bodies.

In the study and discussion of the igneous rocks of this region it has been found that the natural and most intimate grouping of the rocks brings together varieties of the surface or extrusive rocks which differ chemically, mineralogically, and to a certain extent structurally. In another group it brings together varieties of coarse grained rocks which vary chemically, mineralogically, and to a certain extent structurally. And in another group it presents a collection of intruded sheets and dikes, with similar chemical and mineralogical variations, and another range of structural variations. The distinction between these groups is the range of the structural variations in each, which is coupled with their mode of occurrence. But here also is an overlapping of the groups, there being no sharp line between the first and second, or between the second and third. This, however, is not so much of an objection to the treatment of the subject as that which would follow a grouping upon a chemical basis, for the latter would still leave unreconciled the mineralogical variations that are dependent on the mode of occurrence. It is this complicated relationship which has rendered a clear and comprehensive description of the occurrences so difficult.

Since this complication of relationships between all varieties of igneous rocks exists universally, as it has been shown to exist at Electric Peak and Sepulchre Mountain; and since the classification of igneous rocks along any single line of relationship can not be a simple and at the same time a natural one, it seems to the writer that the most satisfactory treatment of the subject brings together into groups for purposes of description rocks of similar or allied structures, but of various mineral and chemical compositions.

This grouping appears the more rational when it is considered that the chemical variability of rock magmas which leads to the formation of local modifications of rocks or to their chemical facies is, as the writer believes and hopes to be able to demonstrate at another time, the underlying principle which gives rise to the chemical differences among the rocks themselves. In other words, the chemical differences of igneous rocks are the result of a chemical differentiation of a general magma. And in a very special manner all of the igneous rocks of any locality are so intimately related to one another chemically that there is far more reason for considering them as a complex chemical unit than as a number of independent, well defined magmas.

It is to be remarked, moreover, that if, as demonstrated in this paper, the conditions attending or controlling the crystallization of igneous magmas, whether affecting simply the rate of cooling, or acting through the medium of a mineralizing agent within the magma itself—if these conditions determine the species and character of the minerals developed, as well as the crystalline structure of the rock, then the grouping together of rocks of allied structures unites those rocks in which the mineralogical characteristics bear a certain relation to the chemical composition, which relation is different from that which exists in rocks that have crystallized under different conditions. There is, therefore, in such a grouping more than the similarity of structure or the geological association of the rocks in the field.

While the grouping of igneous rocks on a basis of crystalline structure, which would bring together coarse grained forms, medium grained forms, and extremely fine grained and glassy ones, is in a very large measure equivalent to classifying them on a geological basis, still the precise connection between the crystalline structure and geological occurrence of all igneous rocks is not so uniform that it can be expressed in simple terms.[1] It is not, in fact, the particular mode of occurrence of a rock, geologically considered, that determines its structure, but the physical conditions attending its eruption and solidification. And since these physical conditions may be occasioned by somewhat different geological circumstances, the resulting similar structures may be found with different geological environment. That is, a large mass of magma deep within the earth's crust may attain a crystalline character through the cooling of so large an inclosed mass, which may be more closely related, if not identical, to the crystallization of a much smaller mass that has solidified within highly heated rock walls, than it is to the structure of an equally large mass that has been chilled by being forced a longer distance through colder rocks, or that has solidified on the surface of the earth. As another example, narrow bodies of magma which have solidified at very much the same distance from the surface of the earth differ widely in their crystalline structure, according to the temperature of the rocks surrounding them at the time of their consolidation.

Recognizing, then, the intricacies of these geological and physical relations, it seems to the writer advisable to base the classification of igneous rocks on that character which may be determined with certainty from the rocks themselves, namely, the crystalline structure, and which, at the same time, is to so high a degree an exponent both of the chemical composition of the magmas and of the physical and geological conditions attending their solidification.

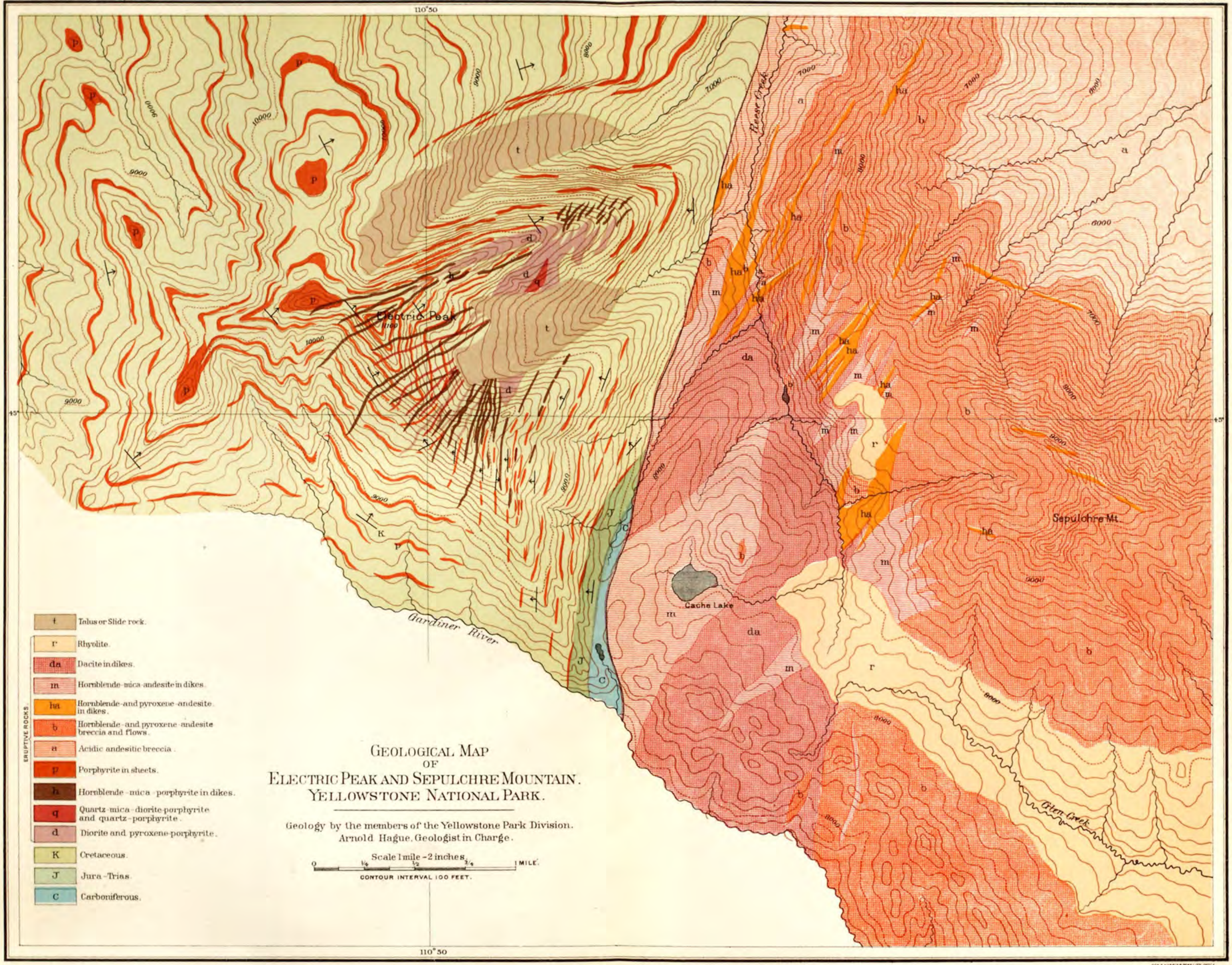
[1] Compare in this connection the conclusions of M. Michel Lévy: "Ainsi, en résumé, les conditions de gisement nous paraissent en relations trop complexes avec les facteurs de la cristallisation pour pouvoir être substituées, comme entrée de classification, à la notion plus précise et toujours présente de la structure des roches."—Structures et Classification des Roches Éruptives. Paris, 1889, p. 10.

APPENDIX.

Owing to the fact that the specimens from Electric Peak and Sepulchre Mountain, which have been described in this paper, were collected at various times during a number of years in which these localities were visited, and consequently occur in widely separated parts of the original collection of rocks from the Yellowstone National Park, they bear numbers which range from 2 to 3,910. The use of these numbers tends to confuse the reader, and a new series of consecutive numbers has been substituted for them in this paper. Since the new series has no existence in actual fact, it is deemed advisable to publish a list of the original numbers with their new equivalents, in order that the work bestowed on this study may be followed up or reviewed by anyone wishing to investigate the subject for his own purposes. The catalogue referred to is given in Table XIX.

TABLE XIX.—*Original collection numbers of the specimens described in this paper.*

New.	Field.	New.	Field.	New.	Field.	New.	Field.	New.	Field.
Nos.	*Nos.*	*Nos.*	*Nos.*	*Nos.*	*Nos.*	*Nos.*	*Nos.*	*Nos.*	*Nos.*
1	3870	49	3858	97	226	145	2732	193	2680*e*
2	221	50	3855	98	3896	146	2720	194	2672
3	3891	51	3889	99	695	147	3205	195	3194
4	323	52	3906	100	3013	148	2725	196	2661
5	3871	53	3883	101	2739	149	2726	197	2669
6	321	54	3860	102	394	150	2711	198	2675
7	332	55	1385*b*	103	3014	151	2714	199	2702
8	3687	56	1385*a*	104	3701	152	2716	200	2686
9	3857	57	3866	105	3899	153	2659	201	3006
10	322	58	3694	106	3854	154	2713	202	3012
11	324	59	3892	107	3881	155	3206	203	2728
12	3	60	3861	108	3015	156	647	204	2704
13	3879	61	3862	109	2737	157	2666	205	2695
14	3872	62	3018	110	3686	158	3208	206	2703
15	395	63	3856	111	3897	159	2746	207	2685
16	3874	64	325	112	1386	160	2747	208	2715
17	392	65	2738	113	2741	161	2705	209	3011
18	3189*a*	66	2743	114	3019	162	2261	210	2682
19	213	67	3685	115	3842	163	2697	211	2681
20	214	68	3695	116	2744	164	2699	212	2727
21	217	69	696	117	3903	165	2698	213	2724
22	3691	70	3690	118	2745	166	2710*b*	214	2729
23	3697	71	3886	119	3904	167	2709	215	3008
24	3869	72	3689	120	3905	168	2710*a*	216	3224*a*
25	3890	73	3898	121	2742	169	2718	217	3224*b*
26	3679	74	3688	122	3678	170	3192	218	3224*c*
27	3698	75	3864	123	3910	171	2679	219	2722
28	218	76	3882	124	3682	172	3193*a*	220	2723
29	3693	77	3884	125	3683	173	3193*b*	221	2730
30	3846	78	3844	126	701	174	3193*c*	222	3222
31	2	79	3843	127	3850	175	3193*d*	223	2676
32	3696	80	694	128	3684	176	2673	224	3199′
33	219	81	209	129	3017	177	2692	225	3198
34	220	82	3020	130	3021	178	2735	226	3195
35	3876	83	3692	131	3682	179	3198′	227	2668
36	3875	84	3852	132	3022	180	2693	228	2672
37	215	85	3700	133	3851	181	2680*a*	229	2662
38	210	86	3849	134	3848	182	2680*b*	230	2670
39	212	87	3865	135	3016	183	3193*e*	231	2671
40	3895	88	3908	136	2734	184	3191	232	2749
41	3887	89	3699	137	2733	185	2680*c*	233	3001
42	2740	90	3902	138	3209	186	2684	234	3003
43	3888	91	3900	139	3009	187	2694	235	3004
44	3894	92	3847	140	2708	188	2680*d*	236	3002
45	3880	93	3189*b*	141	2717	189	2674	237	3007
46	3893	94	3878	142	2665	190	3199	238	2667
47	3885	95	2736	143	2260	191	3193*f*		
48	3877	96	211	144	3221	192	3190		


GEOLOGICAL MAP
OF
ELECTRIC PEAK AND SEPULCHRE MOUNTAIN.
YELLOWSTONE NATIONAL PARK.
Geology by the members of the Yellowstone Park Division.
Arnold Hague, Geologist in Charge.
Scale 1 mile - 2 inches
0 1/4 1/2 3/4 1 MILE.
CONTOUR INTERVAL 100 FEET.
t Talus or Slide rock.
ERUPTIVE ROCKS.
r Rhyolite.
da Dacite in dikes.
m Hornblende-mica-andesite in dikes.
ha Hornblende-and pyroxene-andesite in dikes.
b Hornblende-and pyroxene-andesite breccia and flows.
a Acidic andesitic breccia.
p Porphyrite in sheets.
h Hornblende-mica-porphyrite in dikes.
q Quartz-mica-diorite-porphyrite and quartz-porphyrite.
d Diorite and pyroxene-porphyrite.
K Cretaceous.
J Jura-Trias.
C Carboniferous.
110°50
Electric Peak
Sepulchre Mt.
Cache Lake
Gardiner River
Bear Creek
Glen Creek

INDEX.